# De-noising of ToFD Signals from Austenitic Stainless Steel Welds using Stationary Wavelet Transform

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## ABSTRACT

Inspection of structural materials is an important aspect in many industrial applications. Ultrasonic Non-Destructive Testing (NDT) is one of the most widely used techniques in this aspect. Conventional pulse echo and through transmission methods in Ultrasonic Testing (UT) are not reliable in detection of defects with random orientation due to its reflection principle. Time of Flight Diffraction (ToFD) method has gained more popularity in this area in the recent past. It uses diffraction energy and has more advantages in detection, sizing and positioning of the defects irrespective of type, orientation and characteristics. This technique is hampered by several of the unwanted signals arising due to ultrasonic interaction with the material grains. This noise affects the visibility of a defect signal especially when the defect size is small. Many signal processing techniques such as split spectrum processing, wavelet transform and correlation etc are available for de-noising of signals. Among this Discrete Wavelet Transform (DWT) is widely used due to its added advantage of time-frequency information simultaneously. Stationary Wavelet Transform (SWT) is a form of DWT with the main difference that it is translation invariant unlike DWT. In this paper SWT has been used for de-noising of the real time ultrasonic ToFD signals from austenitic stainless steel welds and its performance is compared with that of the DWT.

## General Terms

NDT, Ultrasonic Testing, ToFD, Signal Processing, Wavelets.

## Keywords

Stationary Wavelet Transform, Discrete Wavelet Transform, De-noising, Signal-to-Noise ratio.

## 1. INTRODUCTION

Ultrasonic NDT is the most popular techniques in analyzing the quality of the structural materials. It is often limited by the scattered signals from the coarse-grain structure of the material, instrumental noise and other ambient signals. Though instrumental noise is more dominating, it can be reduced to great extent by averaging of the signals and decreasing the channel gain of the equipment. Other noises include probe noise which doesn't have significant contribution to the actual noise. As a result it can be neglected. Removal of structural noise has been more challenging task in several materials especially austenitic stainless steel due to its coarse grain structure. It has been most widely used structural material and its quality is of at most importance in sensitive applications such as nuclear reactor vessels. So a proper method for sizing, positioning and characterization of the defect is necessary. Ambient noise can dominate the defect echo in many cases where the defects are comparatively smaller in size. Many signal processing techniques [1-3] have been used for improving the defect to noise ratio. Split spectrum processing is often used for enhanced defect detection [4-6]. Conventional Fourier Transform (FT) where the signal is assumed to be stationary fails in providing temporal information. Short Time Fourier Transform provides temporal resolution to some extent as it is mainly constrained by its fixed window size [7].

DWT is widely used in de-noising and characterization of the defects in ultrasonic signals another advantage being its time-frequency information simultaneously. Mother wavelets which act as the basis for the Wavelet Transform (WT) have good resemblance to that of ultrasonic signals and hence are well suitable for processing. This paper uses a form of DWT namely SWT for de-noising and its performance is compared to that of the DWT.

## 2. TIME OF FLIGHT DIFFRACTION

ToFD method uses diffraction principle [8-10] and has greater advantages over the conventional pulse echo in defect detection, positioning and sizing [11-14]. This is because it is independent of the orientation of the flaw. When an ultrasonic signal encounters a defect the waves get diffracted from the tips of the defect [15]. These tips act as distinct sources for diffracted signals of low amplitudes that are captured by the receiver. This enables good sizing of the defects. Longitudinal waves are launched from the transmitter because of their higher velocity compared to the mode converted shear waves thus enabling proper positioning of the defect. Figure 1 shows the schematic set up of ToFD.

## 3. DISCRETE WAVELET TRANSFORM

Wavelets are simple oscillatory functions of finite duration. They can be used as building blocks for several of the non-stationary signals in a way similar to sinusoids which can be used to represent a signal using Fourier representation. Unlike FT, wavelet transform uses functions which are localized in both time and frequency domain.

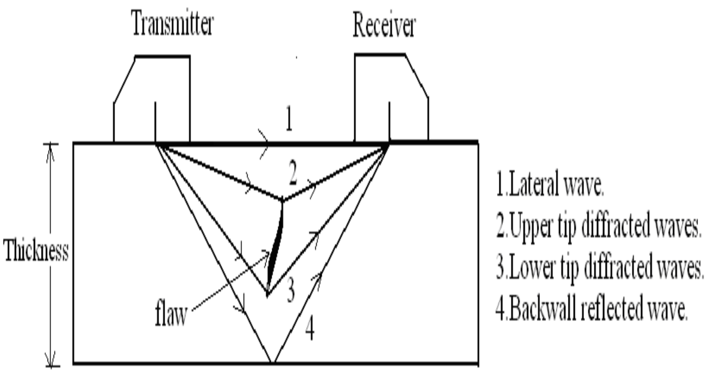

**Fig 1: TOFD Schematic set-up**

WT provides both time and frequency information simultaneously which is not the case with Fourier Transform which gives only frequency domain information. Both Continuous and Discrete Wavelet transform have varying applications in medical image fusion, image and signal de-noising etc. Main difference between them is that the readability and ease of analysis in case of CWT is good compared to DWT but it is computationally intensive. DWT is enough for good reconstruction of the signal with less data-space. In DWT the signal is split into approximations and details using low-pass and high pass filters respectively which act as quadrature mirror filters. After decomposition the approximations and details are down sampled in order to reduce the redundant samples arising after the reduced bandwidth. Figure 2 shows the decomposition of signal into its approximations and details using high pass (HP) and low pass (LP) filters for 2-levels of decomposition. The details which contain the high frequency noise are thresholded and the signal is reconstructed back to give de-noised signal [16-21].

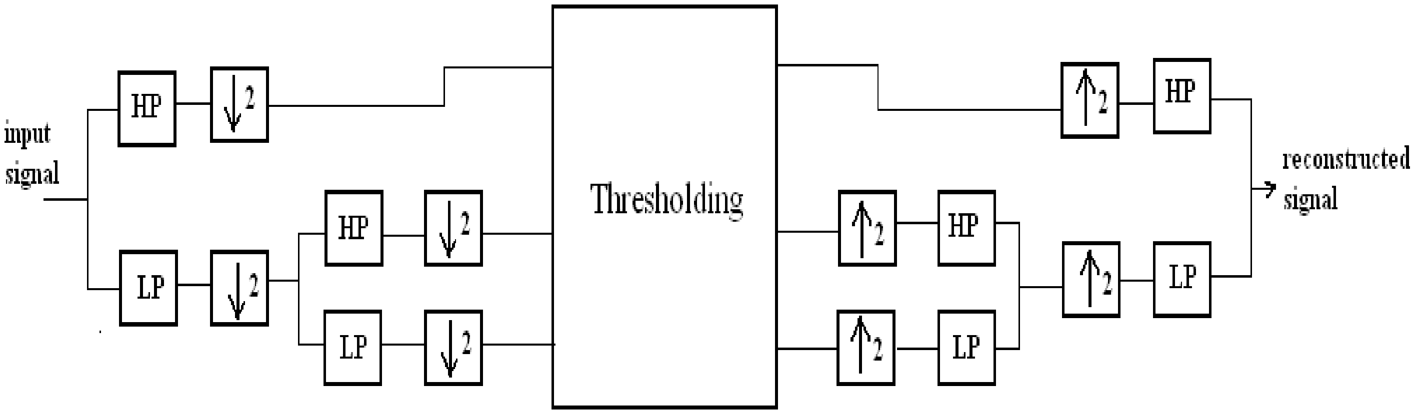

**Fig 2: Threshold based de-noising using Wavelet Transform**

## 4. STATIONARY WAVELET TRANSFORM

Stationary Wavelet Transform (SWT) can be considered as a form of wavelet transform. Conventional DWT suffers due to the lack of important property of translation-invariance. Unlike DWT, SWT has translation-invariance property i.e. a shift in time domain is equal to a similar shift in SWT of the signal. SWT simply fill the gaps present in the conventional DWT. It is achieved by removing the down-samplers in DWT process and up sampling the filter coefficients by a factor of $2^{(j-1)}$ in the $j^{th}$ level of decomposition. SWT is used for de-noising [22-23] similar to that of DWT. Fig. 3 shows the decomposition of the signal in case of SWT. Fig. 4 shows the step of up sampling at each level of decomposition.

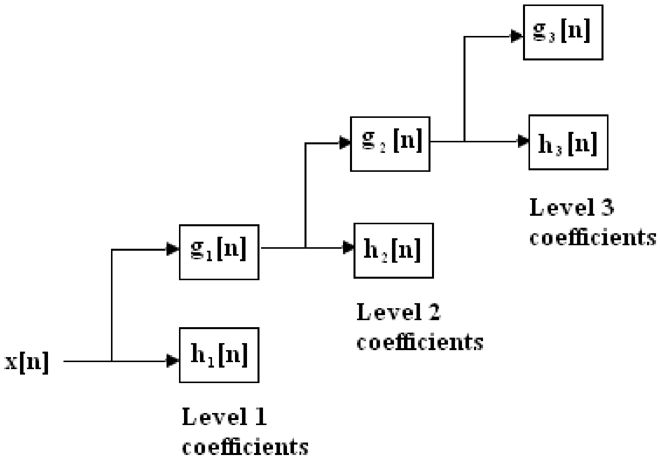

**Fig 3: Decomposition in SWT**

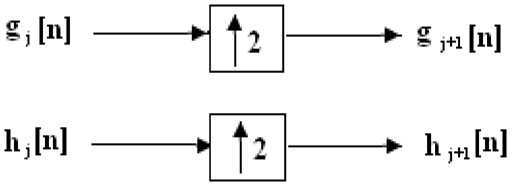

**Fig 4: Up-sampling at each level of decomposition**

## 5. EXPERIMENTAL SET-UP

A 25mm thick, 200x200mm weld pad of austenitic stainless steel grade 304LN has been fabricated by Shielded Metal Arc Welding method. A slag inclusion of length 40mm was intentionally introduced in the weld. This weld pad has been scanned by ToFD technique. A 4 MHz, 45° longitudinal angular probe was used to launch waves into the material. The experiment was conducted at room temperature and the equipment used was MICROPLUS from AEA Technology, UK. The channel gain was set to 80dB. ToFD signals were acquired using a digital storage oscilloscope (YOKOGAWA – DL9140, 5GS/s, 1GHz). Fig. 4 shows the complete set-up.

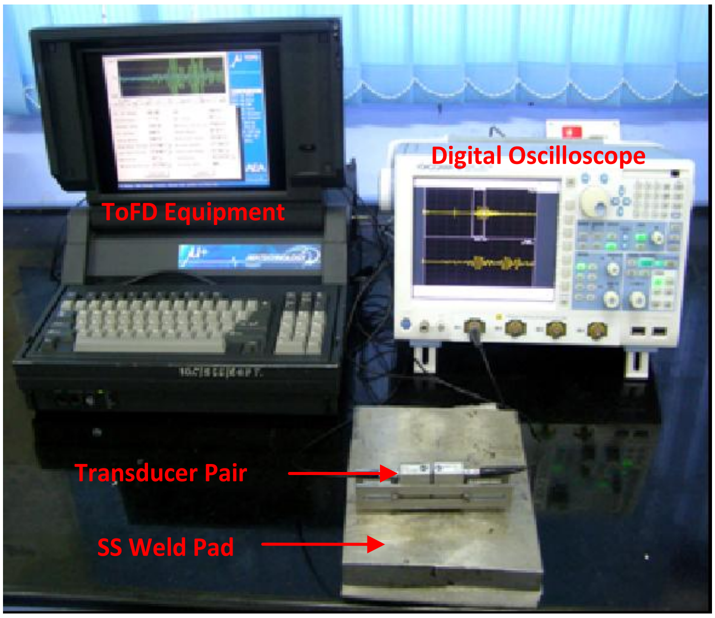

**Fig 5: ToFD signal acquisition experimental set-up**

## 6. DE-NOISING TOFD SIGNALS

Ultrasonic ToFD signals were obtained using the equipment and the specified parameters. A large number of signals were obtained keeping the probe in the same position. These signals were averaged and this process led to the removal of time-varying instrumental noise to some extent. As the most dominating instrumental noise was removed to certain level, removal of backscattered or grain noise remains the next main objective.

The improved defect signal is then processed using wavelet transform. Daubechies family of wavelets was selected for de-noising because of its moderate number of filter coefficients required when compared to Symlet. The signals were subjected to 4 levels of decomposition using DWT as well as SWT separately.

The performance of de-noising is measured using SNR value. Several methods of measuring the SNR have been proposed in the past. In this paper $SNR_{rms}$ [24] is calculated using the formula given by,

$$SNR_{rms} = \frac{D_{pp}}{\sigma_n}$$

where $D_{pp}$ is the peak to peak value of the defect and $\sigma_n$ is the standard deviation of the noise.

## 7. SWT AND DWT PERFORMANCE ANALYSIS

Large number of real-time ToFD signals was collected and de-noising process was performed on each of these signals. The SNR values of different signals were averaged and final average improvement in SNR is obtained. Fig. 6 shows one such signal with defect which is dominated by noise. Fig. 7 shows the spectrum of the signal and noise. As seen from the spectrum the defect signal spectrum coincides with that of the noise spectrum which indicates the failure of conventional filtering process for de-noising. Instrumental noise has greater contribution with higher amplitudes at the lower frequencies. Structural or backscattered noise and other material noise have lower amplitudes at lower frequencies and higher amplitudes at higher frequencies. Fig. 8 shows the magnified view of the original defect signal. Fig. 9 and 10 shows the de-noised signal with DWT and SWT respectively. Though one cannot visually appreciate the performance of SWT over DWT, the difference can be clearly observed with respect to SNR values. The SNR improvement for five such defect signals is tabulated in Table.1 and graph in Figure  Results show that improvement in SNR by SWT is greater when compared to DWT.

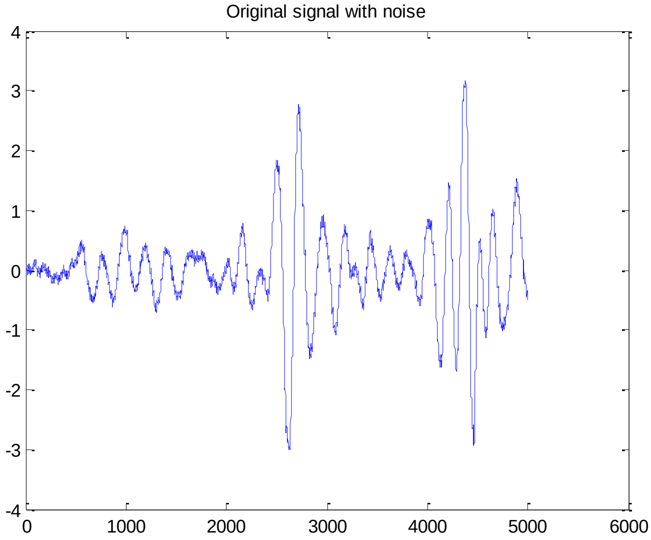

**Fig 6: ToFD defect signal**

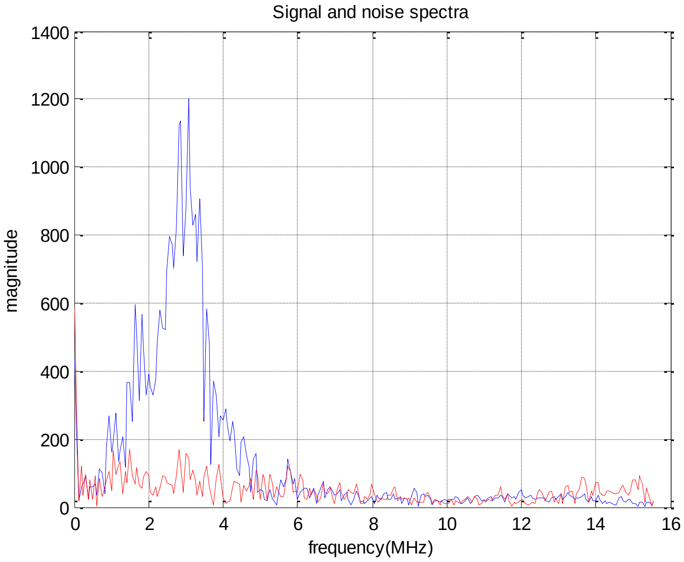

**Fig 7: Defect signal spectrum and noise spectrum**

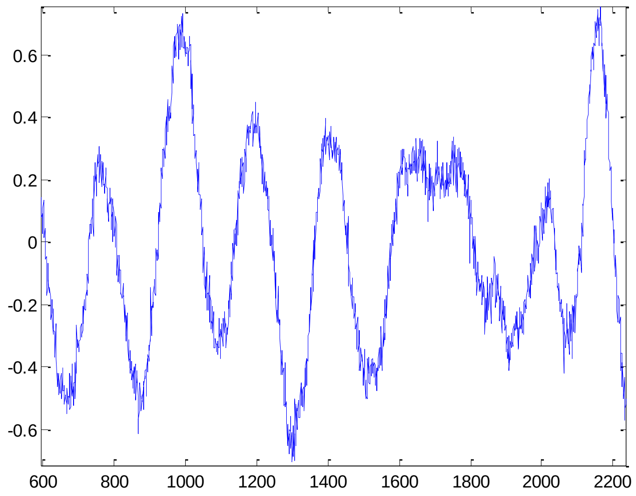

**Fig 8: Magnified view of the defect signal**

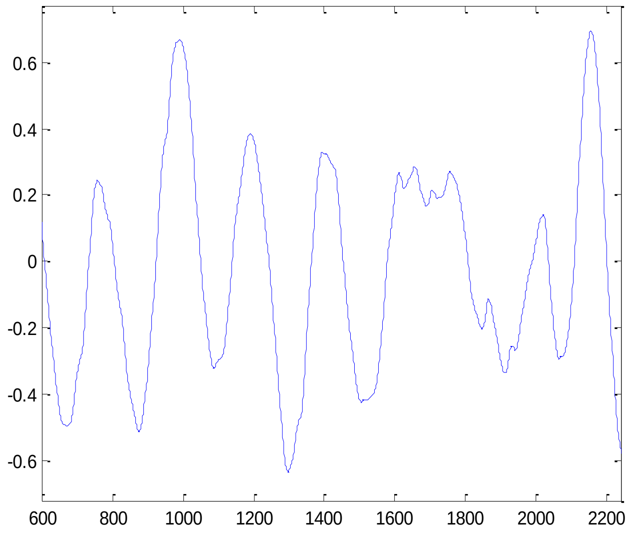

**Fig 9: Magnified view of the signal de-noised with DWT**

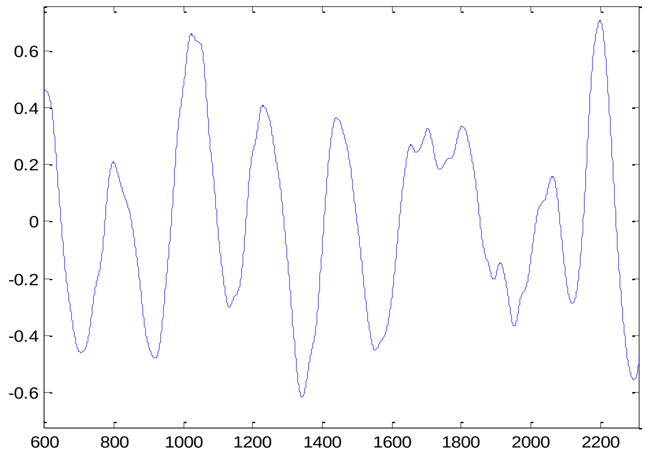

**Fig 10: Magnified view of the signal de-noised with SWT**

**Table 1. SNR Improvement using DWT and SWT**

| Signal/Improvement SNR(db) | Signal Improved by DWT | Signal Improved by SWT |
|---|---|---|
| Signal 1 | 32.5973 | 37.4006 |
| Signal 2 | 31.3683 | 34.0088 |
| Signal 3 | 29.4332 | 38.1846 |
| Signal 4 | 28.4776 | 40.1582 |
| Signal 5 | 30.2568 | 33.9319 |
| Average Improvement | 30.4266 | 36.7368 |

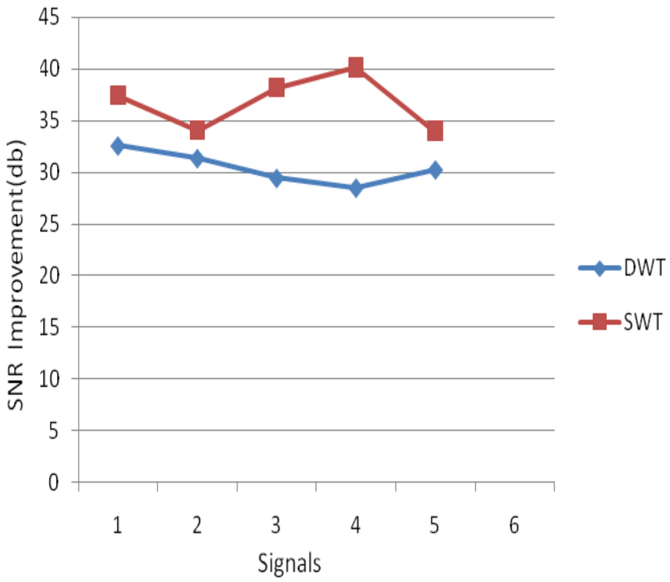

**Fig 11: Comparison of DWT and SWT in de-noising TOFD signals**

## 8. CONCLUSION

Ultrasonic ToFD technique yields highly non-stationary signals with large amount of noise arising out of backscattered waves form the material grains. Noise from the equipment adds to the material noise. An expert system needs plain and noise-free signals in order to extract necessary and reliable features for proper characterization of the defect and the material as a whole. This is critical in case of Austenitic stainless steel welds due to its coarse grain structure. In this paper real-time ultrasonic ToFD signals were obtained from Austenitic stainless steel weld pads. Stationary Wavelet Transform is used for de-noising and its performance has been compared with that of DWT. It can be concluded from the results that SWT has a greater de-noising capability over DWT. This step thus ensures noise-free signal which is ready for characterization and classification of different types of defects.

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