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ACOUSTIC METHODS

Discrete Wavelet Transform based Denoising of TOFD Signals of Austenitic Stainless Steel Weld at Elevated Temperature

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Abstract—Time of flight Diffraction technique is an advanced ultrasonic NDE methods, adopted in weld integrity testing. During the Time of flight Diffraction (TOFD) inspection of the stainless steel welds at high temperature, grain scattering noise is developed. In Time of flight Diffraction testing, the quality of the signal plays a dominant role in characterizing the defects. Hence, signal denoising is an essential prerequisite for the successful application of Time of flight Diffraction testing. In this work, one austenitic stainless steel weldment was artificially induced with slag defect. At high temperatures, the Time of flight Diffraction testing has been conducted on the weld piece and the resultant signals are applied over the proposed algorithms. Various combinations of wavelets, decomposition levels with different thresholding levels are applied to select an optimum denoising method. The evaluation of wavelet based denoising is achieved by calculating the Signal to Noise Ratio (SNR). Results show that the noises can be suppressed well and Signal to Noise Ratio is improved.

Keywords: symlet, coiflet, soft thresholding, hard thresholding, SNR and TOFD

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1. INTRODUCTION

Ultrasonic testing is a mandatory requirement during in service inspection of the welds in the main and safety vessels of a prototype fast breeder reactor [1]. TOFD testing is one of the effective ultrasonic testing method. There are various factors that affect the ultrasonic test results at high temperatures. The temperature changes cause ultrasonic velocity changes, which in turn causes a change of beam angle thereby improper location of the defects [2]. The velocity of sound changes with temperature, which not only has an influence on the time of flight of diffracted and reflected signals, but also on the angles of refraction. This leads to the increment in ultrasonic noise [3]. The efficiency in defect detection is mainly affected by the noise and to improve the efficiency, many signal processing techniques are used. In the past, many signal processing methods have been proposed [4, 5] for efficient noise reduction in ultrasonic signals. Wavelet Analysis is one of the most promising signal conditioning techniques. Various authors operate with different de-noising methods and DWT is being used across a variety of fields showing its universality. Legendre et al. [6] proposed a wavelet-based method to perform the analysis of NDE ultrasonic signals. They proposed a windowing process in the time-frequency domain. J.L. San Emeterio [7] et al. proposed db1, db6, db12 based denoising procedure for ultrasonic signals. This paper presents denoising methods for TOFD signals of defected austenitic stainless steel weldments at elevated temperatures, using wavelet transforms. According to the characteristics of a signal, a proper wavelet should be chosen as the mother wavelet. In order to find an effective denoising method, symlet4 and coiflet4 with various employed. These are evaluated in terms of signal to noise ratio. Austenitic stainless steels have a austenitic, Face Centered Cubic (FCC) crystal structure. They offer high corrosion resistance, extreme weldability and withstanding capability at elevated temperatures. Austenitic stainless steel material is used for manufacturing the safety vessels of prototype fast breeder reactor (PFBR). This paper is structured as follows. Introduction of TOFD technique is discussed in Section 2. In Section 3, the basic theoretical descriptions of wavelets are discussed. In Section 4, the experiments of signal denoising by wavelets are performed for TOFD signals using MATLAB. In Section 5, the results and the scope of wavelet transform based denoising is discussed.

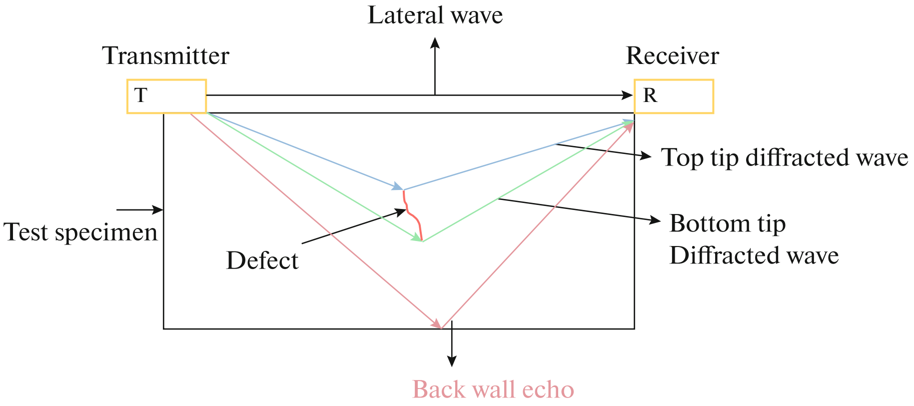

Fig. 1. TOFD System

2. MATERIALS AND METHODS

Conventional Ultrasonic technique uses the pulse transit time to locate and the echo amplitude to size the flaw. For accurate flaw sizing, the amplitude of the back reflected wave may not always be sufficient, since the amplitude of the reflected pulse may be influenced by many parameters other than the size of the reflector. Such parameters include the surface roughness, transparency and orientation of the defect. In order to ensure a more reliable defect sizing ultrasonic NDE technique, the TOFD method was developed. Now, Codes of practice such as ASME and other international codes permit TOFD s one of the methods for assessment of welds, more than 12.5 mm. The most significant distinction between TOFD and the other Ultrasonics testing (UT) methods is that it monitors only forward-scattered diffracted energies from the tips of defects rather than reflected ultrasonic energies. A pair of wide beam angle probes is used in transmitter-receiver mode. Mr. Udo Schlengermann was one of the creators of the TOFD pre-standard ENV583 and was also involved in the development of the British standard BS7709 [8]. The two ultrasonic angle probes are used in the TOFD experiment. One is transmitter and another one is receiver. They are placed on the same surface of the test object shown in Fig. 1. The distance of the probes is calculated according to the wall thickness. The lateral wave runs along the surface, the back wall echo reflects the bottom surface of the test object and reach to the receiver. The other two signals, upper flaw tip diffracted signal and lower flaw tip diffracted signal appear due to in homogeneity [9]. Type 304 (18-8) is an austenitic steel possessing a minimum of 18% chromium and 8% nickel, combined with a maximum of 0.08% carbon.

3. WAVELET TRANSFORM

In wavelet analysis, signals are represented by a set of basic functions. A single prototype function called the mother wavelet is used for deriving the basis function, by translating and dilating the mother wavelet. The wavelet transform can be viewed as a decomposition of signal in the time scale plane. The basic and compact wavelet, which is proposed by Daubechies is an orthonormal wavelets, which is called as Daubechies wavelet. It is designed with extremely phase and highest number of vanishing moments for a given support width. Associated scaling filters are minimum-phase filter. Daubechies wavelets are generally used for solving fractal problems, signal discontinuities, etc. The symlet and coiflet are nearly symmetrical wavelet, which are also proposed by Daubechies as modifications to the db family. Daubechies proposed modifications of her wavelets that increase their symmetry can be increased while retaining great simplicity. The symlet and coiflet have properties similar to daubechies [10, 11]. In this proposed work, symlet and coiflet, symmetrical wavelet have been chosen to TOFD signal.

Wavelet transforms as an excellent time-frequency analysis methods. It can analyze signal in the time and frequency domain simultaneously and it is effective to identify the break signals and the noise of the no n-stationary signals. Based on the signal analysis theory, if wavelet has basis symmetry, it has the ability to construct the regularized wavelet with compactly support and linear phase, so that the signal will not be generated when the wavelet is distorted by the decomposition and reconstruction [12]. It is an important problem to choose basic wavelet. Because of advantage of fourth order wavelet for solving local performance of one dimensional signal, it was chosen as basic wavelet of transform. In DWT analysis decomposition level has been selected based on both sampling frequency and maximum energy of each decomposition level. The maximum energy of TOFD signal is observed at level 5 and 6 [13].

Fig. 2. TOFD Experimental Setup.

3.1. Signal Denoising Using Wavelet

The denoising can be achieved in the following steps:

(1) The noisy ultrasonic signal is decomposed by wavelet into N levels. Here, the symlets with different level of decompositions like 5 and 6 are used to decompose the signal.

(2) The detailed coefficients are thresholded with different functions. Hard and Soft thresholdings are some of the thresholding methods.

(3) Reconstruction of the signal from the detailed and approximation coefficients using IDWT.

3.1.1. Hard thresholding. The core of wavelet threshold de-noising is estimation of wavelet coefficient. A hard thresholding estimation is implemented with [12, 13]:

$$d_m(x) = \begin{matrix} x & \text{if } |x| > T \\ 0 & \text{if } |x| \le T, \end{matrix} \tag{1}$$

where T is the thresholding. These methods set to zero the coefficients with absolute values below the threshold. Each method has different statistical performance. Hard thresholding keeps the coefficients, creating discontinuities at $x = \pm T$.

3.1.2. Soft thresholding. Soft thresholding decreases the amplitude of all noisy coefficient by T. the soft-thresholding estimator is defined by

$$d_m(x) = \begin{matrix} x - T & \text{if } |x| \ge T \\ x + T & \text{if } |x| \le -T, \\ 0 & \text{if } |x| \le T, \end{matrix} \tag{2}$$

4. EXPERIMENTAL RESULTS AND ANALYSIS

One austenitic stainless steel weld with the dimension of $200 \times 200 \times 25$ mm^3 is fabricated using a double "V" Butt joint. Slag defect was introduced in one weldment. The weld pad was made by shielded metal arc welding (SMAW) process. The weld pad is heated up and at elevated temperatures, The ToFD experiment is performed on these welds and TOFD A Scan signals are acquired. It is observed that amplitude of the signal degrades rapidly varying non linearly with increasing temperature A methodical approach has been adopted to ensure reliability of the experimental data by verifying it with radiography technique. The experimental procedure include the calibration, job identification, visual inspection, scanning and defect identification. A hot plate with provisions to vary the current using a variac setup was used for heating the weld pads. The temperature distribution on the steel plate surface especially in the weld region could be maintained by the variac. ToFD Experiment is conducted on the heated weldment. Experiments are performed using μTOFD of AEA Technology, UK to detect the defect. The photograph of the actual setup is shown in Fig. 2.

The temperature distribution on the weld was verified using Infrared non- contact thermometer. The Infrared Thermography is shown in Fig. 3. Distance between temperature measurement camera and weldment—30 cm

A scan signals are obtained. The resultant signals are nearly symmetrical. Hence, symmetrical wavelets, like symlet4 and coiflet4 are chosen for denoising. These TOFD A scan signals have been decomposed using symlets and coiflets. The decomposition levels are also taken as 5 and 6. Wavelets coefficients have been set, which primarily based on the mother wavelet. For each combination of the mother wavelet, the soft and hard threshold estimators at each resolution level have been used. Figures 4 and 5 show the

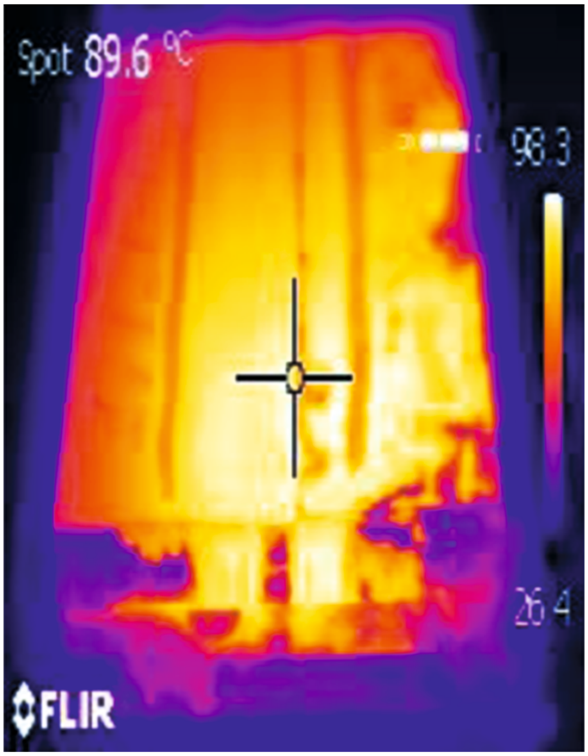

Fig. 3. Thermography of weld pad at 90° at 60°, 90° and 100°.

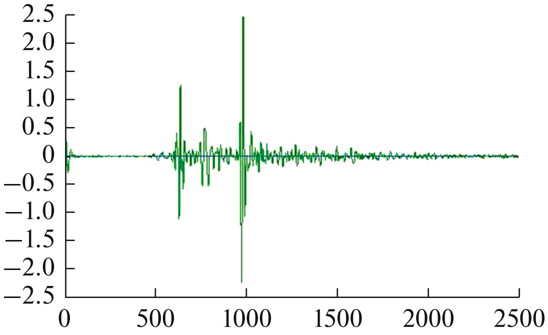

Fig. 4. Original TOFD signal of Slag defect at 60°.

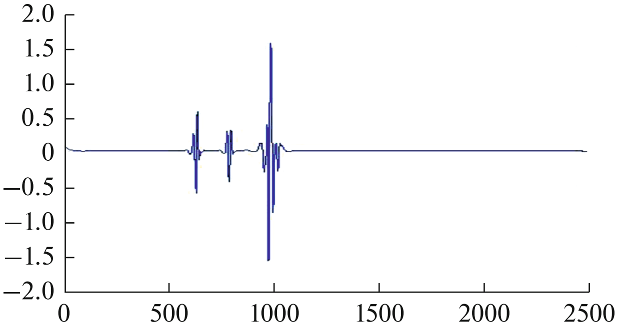

Fig. 5. Denoised signal.

Table 1. SNR (dB) of slag defect signal at 60°

Temperature	60°		
		Thresholding	
Wavelet	Decomposition Level	Soft	Hard
Sym4	5	5.54	6.43
Sym4	6	5.21	6.25
Coif4	5	4.83	6.80
Coif4	6	4.76	6.69

Table 2. SNR (dB) of slag defect signal at 90°

Temperature	90°C		
		Thresholding	
Wavelet	Decomposition Level	Soft	Hard
Sym4	5	2.14	3.55
Sym4	6	1.71	3.49
Coif4	5	2.39	3.87
Coif4	6	2.28	3.23

Table 3. SNR (dB) of slag defect signal at 100°

Temperature	100°		
		Thresholding	
Wavelet	Decomposition Level	Soft	Hard
Sym4	5	1.15	5.18
Sym4	6	1.10	5.13
Coif4	5	4.34	6.11
Coif4	6	4.23	5.95

original TOFD signals and denoised TOFD signals of slag defect at 60°C respectively. The analysis of various combinations of wavelet and thresholding indicates, that the optimal mother wavelet for all the defected TOFD signals are coiflet4, decomposed 5 levels with hard thresholding. This is evaluated with SNR values of various combinations of wavelets, decomposition levels and different thrersholding types Tables 1–3 gives the SNR values of denoised TOFD signals at 60, 90 and 100°C respectively. Soft thresholding is not so efficient in denoising of this TOFD signal; where as hard thresholding proves its ability. SNR is calculated by the expression. The temperature distribution on the steel plate surface especially in the weld region could be maintained within ±4°C during the scanning by adjusting the variac. The uniformity of temperature distribution and also the temperatures in the vicinity of weld and on the weld was verified using Infrared non-contact thermometer (Model: AR872A). It can be observed that the temperature distribution is quite uniform in and around the weld region.

The algorithm performs a periodogram using a Kaiser window with large sidelobe attenuation. To find the fundamental frequency, the algorithm explores the periodogram for the largest nonzero spectral component and to calculate the central moment of all adjacent bins that decrease monotonically away from the maximum. If a harmonic lies within the monotonically decreasing region in the neighborhood of another, its power is considered to belong to the larger harmonic. The function estimates a noise level using the median power in the regions containing only noise, excluding the DC component. The noise at each point is the estimated level or the ordinate of the point, whichever is smaller. The noise is then subtracted from the values of the signal and the harmonics. Kaiser window has been used as a bench mark of the values that a frequency components lying within. I.e., the frequency components are enough to accommodate in the side lobe width of the Kaiser window.

5. CONCLUSIONS

Different combinations of wavelets, decomposition levels, thresholdings are employed to develop an optimum denoising algorithm and the performances are evaluated using the SNR calculations. Basically, symlets and coiflets are symmetrical and hence, it proves its ability to denoise the ultrasonic signal, which is also symmetrical in nature. It is also observed that hard thresholding is better than soft thresholding. Since, the ultrasonic signal is a non stationary signal, hard thresholding is suitable. Results show that Coiflet4 at 5th decomposition level with hard thresholding removes noise well with a high SNR. It is observed from the waveforms of original and denoised waveforms and it is suitable for the Slag defected austenitic stainless steel weld.

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