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WAVELET TRANSFORM BASED METHOD FOR EDDY CURRENT TESTING OF CLADDING TUBES

B. Sasi, B. P. C. Rao, S. Thirunavukkarasu, T. Jayakumar and P. Kalyanasundaram

Metallurgy and Materials Group
Indira Gandhi Centre for Atomic Research
Kalpakkam - 603 102

Abstract

A wavelet transform based signal processing method has been developed for detection of defects in fuel cladding tubes made of stainless steel. In this method, wavelet transform features such as multi-resolution analysis, denoising and reconstruction are implemented to enhance the signal-to-noise ratio (SNR) of eddy current (EC) signals. This method has been validated on different types of artificial defects in fuel cladding tubes.

Keywords: Eddy currents, wavelet transform, defect detection, signal processing, signal-to-noise ratio

1.0 INTRODUCTION

For quality control of cladding tubes (20% cold worked AISI type 316 stainless steel with 5.1 mm OD and 0.37 mm wall thickness) eddy current (EC) testing is employed for detection and characterization of defects. During the testing of one batch of cladding tubes, continuous disturbing signals of large amplitude were noticed throughout the length of the tube, making it difficult to detect defects due to poor SNR. Laser projected interferometry revealed the presence of thickness variations, also called periodic bands on the outer surface of the tubes [1]. Studies have been carried out using conventional, multi-frequency and phased array EC methods with limited success for detection and evaluation [2]. Recently, neural network based on-line method has been developed for detection and accurate depth evaluation [3]. Yet another method is proposed in this paper. This method is based on time-frequency analysis, called wavelet transform, which enables suppression of periodic bands and detection of small defects. This method incorporates the attracting features of wavelet transforms such as a) self adjusting window which is useful for detecting the signal embedded in noise, b) de-noising, and c) reconstruction. In this paper, details of this method, experimental studies and results are discussed.

2.0 WAVELET TRANSFORM

Wavelet transform enables analysis of a signal at different frequencies with different resolutions. This is achieved by employing windowing technique with variable sized window for every single spectral component enabling decomposition of signal into a coarse and detail approximation [4]. To achieve this, wavelet prototype called mother wavelet and its dilated and time-shifted windows, called daughter wavelets are used. From the mother wavelet function, a set of daughter wavelets $\psi_{a,b}(t)$ are obtained by incorporating dilation and translation variables *a* and *b*, respectively.

$$\psi^*_{a,b}(t) = a^{-1/2}\,\psi((t-b)/a) \qquad (1)$$

while the dilation variable *a*, ($a=2^j$) controls the daughter wavelet's frequency and the translation variable *b*, ($b=k2^j$) controls the spatial shifting. The wavelet decomposition of a signal is obtained by successive high-pass g(t) and low-pass h(t) filtering of a signal in time domain [5].

$$h_{(j,k)}(t)=2^{-j/2}\,g(2^{-j}t-k) \qquad (2)$$

$$g_{(j,k)}(t)=2^{-j/2}\,h(2^{-j}t-k) \qquad (3)$$

These steps are incorporated using DWT procedure. In this, signal x(t) is first passed through a half band high-pass filter and a low-pass filter. Typical one level of decomposition can mathematically be expressed as

$$Y_{high}(k) = \Sigma_n\, x(t)*g(2k-t) \qquad (4)$$

$$Y_{low}(k) = \Sigma_n\, x(t)*h(2k-t) \qquad (5)$$

The outputs of high-pass and low-pass filters are subjected to further decomposition until two samples are left. The outputs of these filters at each level give information about the frequency components present at that level of decomposition. Selective elimination of coefficients, in other words frequencies, at specific level is possible without disturbing the same as well as other frequencies at other levels. By going in the reverse direction signal reconstruction is performed to obtain a signal of specific spectral components. This step of selective suppression of disturbing or noisy characteristics at various decomposition levels is often referred to as de-noising.

3.0 WAVELET TRANSFORM METHOD

The objective of this method is to utilize the above mentioned decomposition, de-noising and reconstruction features of WT to suppress disturbing signals from periodic bands in cladding tubes so that small defects, otherwise masked by the disturbing signals, are detected. The method involves decomposition of real and imaginary components of EC signals using DWT, application of level based thresholding and reconstruction of the real and imaginary components of EC signals.

In order to implement these steps, a software has been developed using MATLAB. For the purpose of validation of various steps, EC signals from 4 holes and 6 notches (Table 1) machined in cladding tubes have been used. The encircling differential EC probe operating at 450 kHz has been used. The real and imaginary components of EC signals have been digitized using a 12 bit ADC at a sampling rate of 1 kHz.

Table 1. Artificial defects considered in the study.

DEFECT TYPE	DEFECT SIZE, mm
Hole (dia)	0.8, 0.6, 0.5, 0.3
Longitudinal notch (length x width x depth)	a) 5 x 0.5 x 0.1 b) 5 x 0.5 x 0.2 c) 4 x 0.1 x 0.08 d) 4 x 0.1 x 0.07 e) 4.85 x 0.1 x 0.1 f) 4.85 x 0.1 x 0.05

Several issues to be addressed to incorporate this method are: selection of mother wavelet, level of decomposition, selection of thresholds at each decomposition level. The signal reconstruction is perfect only if the daughter wavelets are of half band. In this regard, Ingrid Daubechies wavelets are ideal as they are half band filters. In this type of wavelet, wavelets of different orders exist, however for the present study Daubechies wavelet of order 5 ,'dB5' has been chosen as it resembles the shape of the differential EC signal.

For selection of decomposition level, SNR has been evaluated for various decomposition levels for a 0.5 mm dia. hole in a banded tube. SNR has been evaluated by taking the mean signal amplitudes of band and hole. As can be seen in Fig. 1, the SNR is found maximum at the 5^{th} level. Hence, decomposition level of 5, has been chosen and the detailed and approximation coefficients have been upsampled. In order to suppress the signals from bands, level based thresholding has been applied instead of global thresholding. For this purpose, mean amplitude of noise at each level has been taken as the threshold values. Thus, there are 5 threshold values in this method. The thresholded detailed signals have been used for reconstruction of real and imaginary components of EC signals.

4.0 RESULTS AND DISCUSSION

Typical results for a 0.3 mm dia. hole in a banded tube before and after level based thresholding are shown in Fig. 2. The capability of the proposed method to suppress the periodic band signals on one hand and to detect the defect signals, on the other hand, is clearly demonstrated. It must be noted here that detection of 0.3 mm dia hole was not possible by the conventional EC and deconvolution methods[6].

Results of application of the proposed method to banded tube consisting of 4 holes are shown in Fig. 3. It is noted that the proposed has resulted in enhancement of SNR by about 20 dB. This method has also been applied to signals of longitudinal notches (length 4 mm ~ equal to the band extent) that are made over the band and also between the bands. As can be easily observed from Fig. 4, the signal due to the notches is clearly brought out in both the cases, with equal amplitude.

The interesting feature of this method is that the defect signal features such as phase and shape are retained. This allows application of traditional pattern recognition methods such as Fourier descriptors for enhanced detection and characterisation of defects using artificial neural networks and fuzzy logic methods.

CONCLUSION

A method for improving defect detection using wavelet transform has been proposed for eddy current testing of fuel cladding tubes with periodic wall thickness variations. The proposed method uses decomposition, de-noising and reconstruction features of wavelet transforms to enable efficient noise suppression and signal detection. The experimental results confirm detection of 0.3 mm hole, SNR enhancement by 20 dB and retention of shape and phase of the EC signals for implementing traditional artificial intelligence methods.

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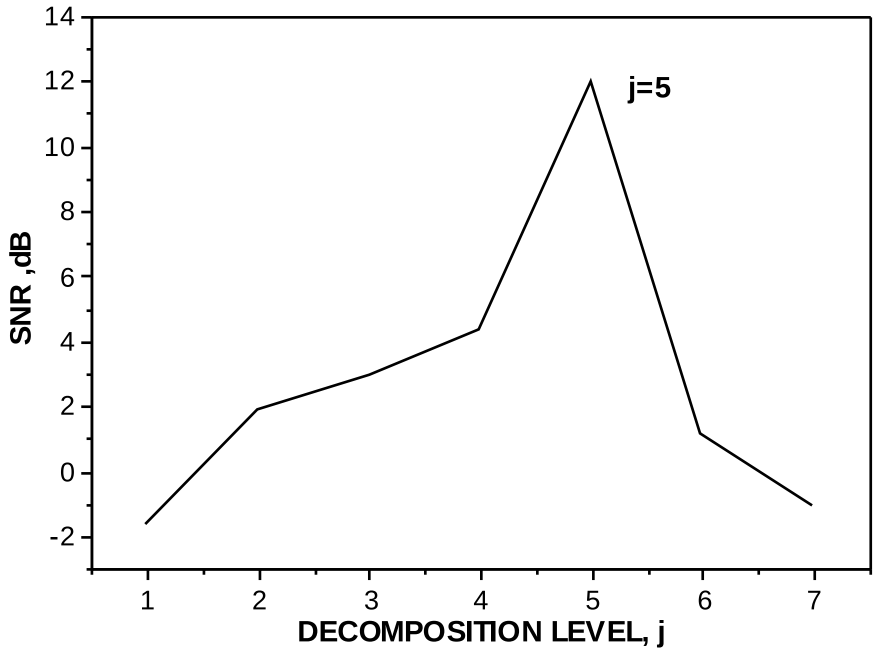

Fig. 1. SNR vs. decomposition level of DWT for 0.5 mm dia hole in a banded cladding tube.

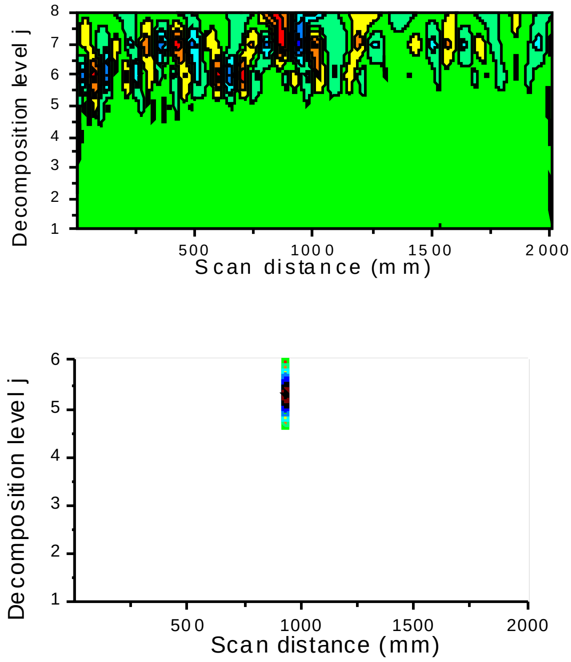

Fig. 2. Contour plots of a) raw signal from 0.3 mm dia hole and b) de-noised with level based thresholding.

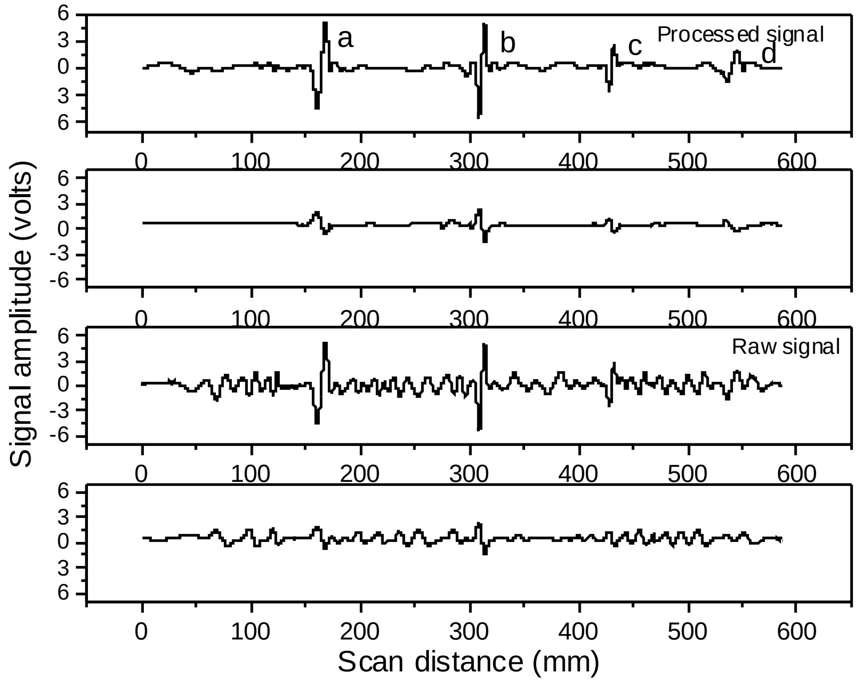

Fig. 3. EC signal from banded cladding tube with a) 0.8, b) 0.6, c) 0.5, d) 0.3 mm dia holes before and after wavelet processing.

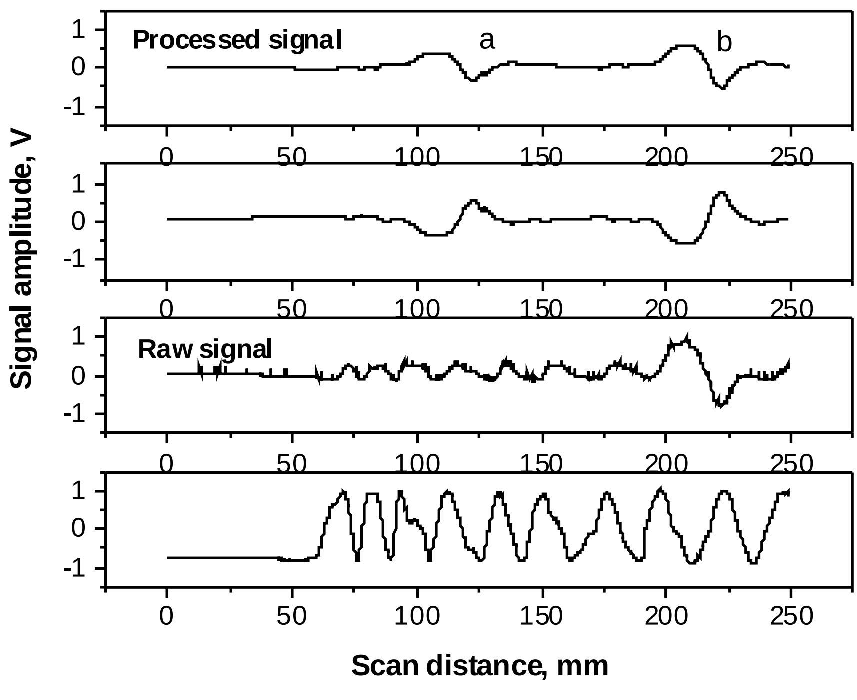

Fig.4. EC signals from cladding tube with longitudinal notches of 4 x 0.1 x 0.08 mm a) over a band and b) between bands