COMPARISON OF SIGNAL PROCESSING TECHNIQUES FOR UT-NDE ON NUCLEAR POWER PLANTS

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Abstract

This paper deals with the comparison of signal processing techniques of ultrasonic data. The goal of signal processing is the ultrasonic speckle suppression and the visibility enhancement of flaw-reflected ultrasonic echo. The performance of conventional SSP(split spectrum processing) method and the wavelet denoising method are compared and discussed for tested ultrasonic data.

Tested ultrasonic data obtained from the weld area of centrifugal-casted stainless steel material and safe-ending material with holes and notch of variable depths are presented. In experimental results, the outputs of wavelet-based denoising method show the clear and sharp peaks at the positions of flaw-reflected echos comparing with those of SSP method.

1. INTRODUCTION

NDE(Non destructive evaluation) process can be critically important in the safety evaluation of nuclear power plant. One common method of performing a NDE is to apply an ultrasonic pulses to material in question. Pulse-echo reflection techniques are used for ultra sonic flaw detection in most commercial instruments.

Ultrasonic signals for NDE suffer from a special kind of noise called granular or speckle. Speckle is originally a term used for granular pattern that appears in B-scan images and can be considered a multiplicative noise and term "speckle"is also used back ground noise generated by scatterng factors such as grain boundaries in A-scanned time signals. In A-scaned time signals, speckle, ultrasonic noise from grain boundaries and other micro-structural inhomogeneities causes a fundamental limit on detection of small cracks, flaws and other defects.

Various signal processing techniques have been utilized in the past for enhancement of detected echos from speckle noise environment such as filtering techniques, deconvolution techniques, time-frequency analysis techniques.

In these techniques, recently a powerful approach for noise reduction has been proposed by Donoho and Johnstone[1]. It employs thresholding in the wavelet domain and has been shown to be asymptotically near optimal for a wide class of signals corrupted by additive white Gaussian noise. It has been successfully applied to 1-D and 2-D data such as geophysical data, and to coherent imaging process data. Moreover, the same method can be use in a wide variety of related problems such as linear inverse problems, data compression and statistical estimation.

To suppress ultrasonic speckle, we also apply wavelet threshold approach to A-scanned ultrasonic signals but we do not use threshold approach by orthogonal wavelet transform which is proposed by Donoho and Johnstone but use by translation-invariant wavelet transform.

2. SIGNAL PROCESSING TECHNIQUES FOR UT-NDE

2.1 Wavelet-Denoising and SSP method

A flaw enhancement technique call SSP(split spectrum processing) has previously been shown to improve flaw visibility by suppressing speckle with respect to flaw echo[2]. SSP method obtains the amplitude spectrum of the echo signal by a short time Fourier transform(STFT) routine divides the spectrum into desired number of bands by means of digital windowing, and finally inverse transforms each band to obtain the frequency diverse signal set. Windowing is accomplished by Gaussian-shaped windows that have selectable constant bandwidth and fixed frequency spacing. The center frequencies of resulting signals range within the half-power bandwidth of the transducer. These signals are then normalized with respect to amplitude, giving zero mean outputs with maximum magnitude of unity. Several techniques have been processing the decorrelated signals by STFT, including conventional averaging algorithm and novel minimization algorithm. But pass band filters in bank of filters used in the SSP method have constant absolute bandwidth, which in many cases is not the optimal representation for ultrasonic signals obtained using wideband transducer in pulse-echo mode. It has been suggested that SSP method with filters of constant frequency to bandwidth ratio, i.e., constant relative bandwidth, can be more efficient for analyzing broad band ultrasonic signals[3].

The wavelet transform is the alternative technique to emerge for processing signals with non-stationary spectral components. Application of these techniques extended to many fields such as geophysics, mathematics, biomedical engineering and communication. Multi-resolution signal decomposition using wavelet transform has been extensively studied in the development of perfect reconstruction quadrature mirror filter bank(PRQMF). The wavelet transform is defined in terms of orthonormal basis functions obtained by scaling and translation of a mother wavelet.

Wavelet-denoising technique has 3 steps as following.

Step 1. Underlying signal is transformed to wavelet domain.

Step 2. Threshold scheme is applied to wavelet coefficients of underlying signal.

Step 3. Denoised signal is obtained from coefficients applied to thresholding by inverse wavelet transform.

Donoho and Johnstone mainly consider two threshold schemes to denoise unwanted signal in wavelet domain. The first scheme is hard threshold(keep value if it is above some threshold , set it is zero else) and the second scheme is soft threshold(additionally shrink values by that are not set zero) Both schemes are within a logarithmic factor of the ideal risk. Hard thresholding typically yields the smaller mean square error(MSE). Soft thresholding achieves near minimax MSE subject to the constraint that recovery signal is at least as smooth as original signal. In practical issues, hard thresholding exhibits spurious oscillations, soft thresholding avoids spurious oscillations. Since to classical denoising method, there is a tradeoff between noise reduction and over smoothing of signal details[4]. The major drawback of wavelet-denoising is translation-varying problem. Hence changing the initial translation of noisy signal may yield significant difference of denoising performance. The time-invariant property is particular important in statistical signal processing applications such ultrasonic flaw detection, pattern recognition of flaw shape.

An alternative method to overcome the shortcoming of Donohos' wavelet denoising technique changes wavelet transform type, i.e., it applies wavelet denoising technique to translation invariant wavelet transform instead of orthogonal wavelet transform[4].

In recently translation wavelet transform is developed by researcher. Translation invariant wavelet decomposition permits all translations for their wavelet coefficients and scaling coefficients to keep translation invariant property. The implementation algorithm of translation invariant wavelet transform is widely introduced by publications.

2.2Specimen preparation and experimental setup

For experiments, two pieces of narrow gap welds connecting the steam generator to main reactor coolant piping were prepared as specimen. It is composed the centrifugal-casted stainless steel(CCSS) and safe-ending(SE) material which is connected by narrow gap welding. The specimen has external diameter of about 393 mm, and wall thickness of 80 mm. Fig. 1 provides further details on the specimen.

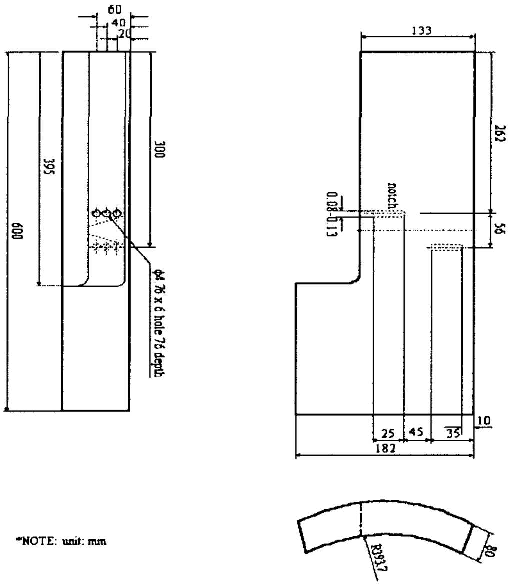


Fig.1. Geometric schematics of specimen

Series of side drilled holes are induced both in the various depth of base material and in the weld. To simulate far side surface cracks, rectangular EDM notches of various heights were machined at realistic positions in the heat affected zone(HAZ) and base material.

The ultrasonic signal is acquisited by 1MHz center frequency, 45° angle beam dual transducer. The ultrasonic waveforms are sampled in sampling frequency 500MHz by digital oscilloscope that is triggered to the pulser and receiver. Then the sampled ultrasonic waveforms are transmitted to personal computer connected to the digital oscilloscope by GPIB cable and the noise suppression program is executed by the MATLAB program in notebook computer.

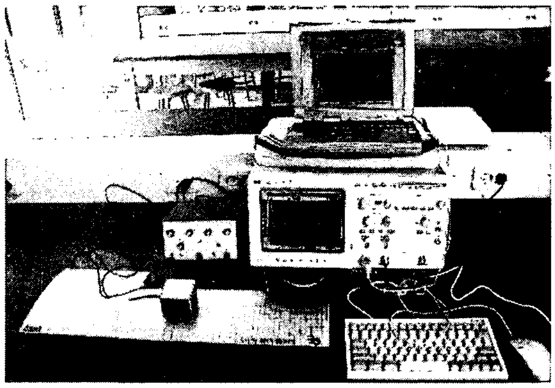


Fig.2. Photograph of experimental equipment

2.3Experimentalresults

In order to measure performance of translation invariant wavelet-based denoising (TIWD) technique, we generate an artificial flaw echo signal from ultrasonic signal reflected from hole in SE part of specimen as seeing fig. 3.

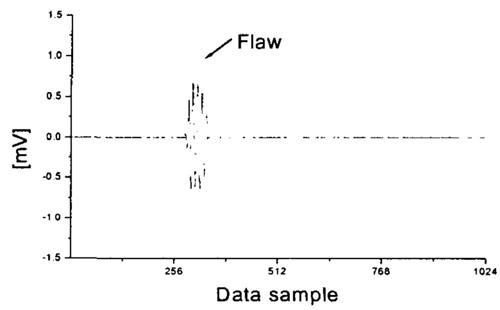
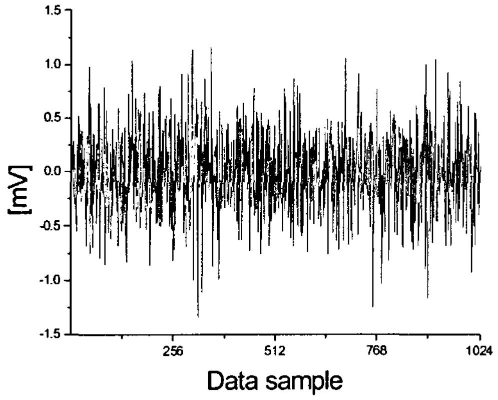


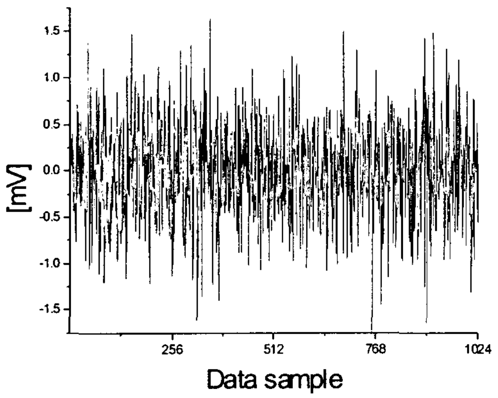
Fig.3. Artificial generated flaw echo signal

The white Gaussian noise is added to artificial flaw echo signal at at levels of 12dB and 15dB as seeing fig. 4. The noise-contaminated flaw echo signals are processed by two methods, TIWD technique, SSP technique respectively.

To compare with visibility enhancement of methods, output signals of methods are expressed by their absolute values and rescaled by maximum peak value= 1.



(a)

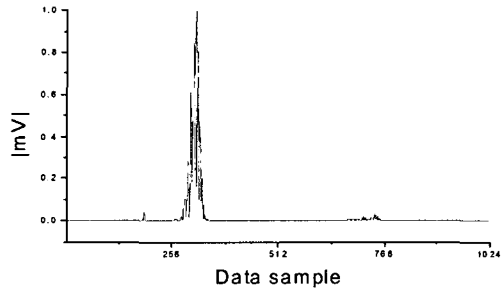


(b)

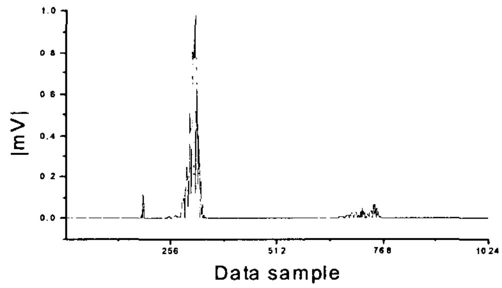
Fig. 4. Plots of flaw echo signals added in white noise at level (a) -12dB, (b) -15dB

The TIWD technique is applied soft threshold rule proposed by Donohos' and wavelet is used D16 proposed by Dauchebiechs. Underlying ultrasonic signal is decomposed 8 levels by translation invariant wavelet transform and denoising process by thresholding is applied at each level. The SSP technique is used optimum window technique that guarantees optimum frequency resolution at 1MHz, the center frequency of transducer. It imply that the output of SSP technique is the best for expression of ultrasonic signal at around of 1MHz.

As showing fig. 5, the results of the TIWD technique detect the peak value at the position of flaw of two simulated flaw echo signal but the resulting plots of SSP technique show the failure of flaw-detection at -12dB and -15dB noiselevel. It imply that the SSP technique can not detect flaw in serious noise environment.



(a)



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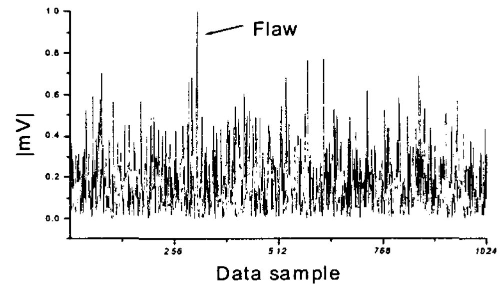
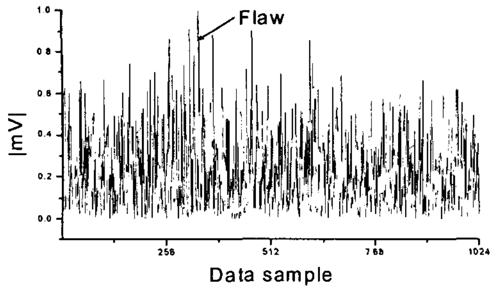


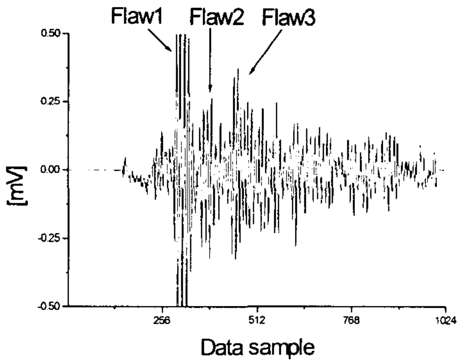
(c)



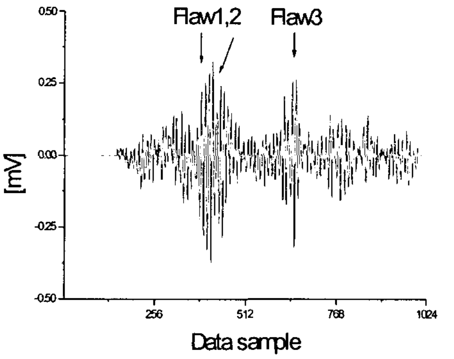
(d)

Fig. 5. Plots of output signals of TIWD and SSP technique for fig. 4.

The two techniques are also applied to the specimen and the visibility enhancement of outputs is compared. The ultrasonic data are obtained from both side of specimen and pre-processed to remove the reflected echos from angle shoe by setting 0.



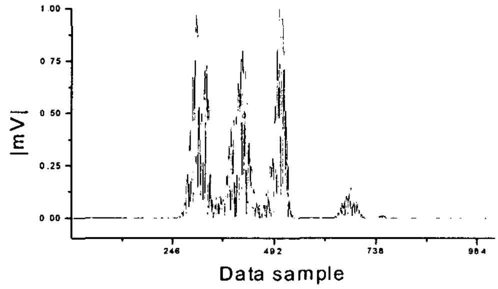
(a)



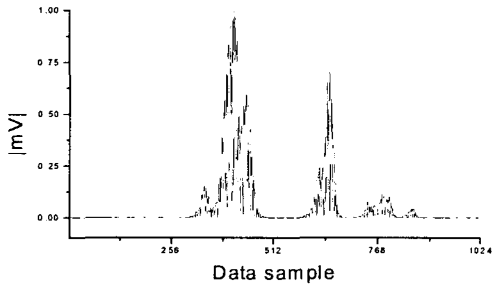
(b)

Fig. 6. Plots of ultrasonic signals obtained from (a)CCSS and (b)SE part of specimen

The ultrasonic data in fig. 6(a) obtains from CCSS side at weld area and also fig. 6(b)from SE side at weld area. Through observation of ultrasonic data, the amplitude of data and waveform from CCSS side are less smaller and more broader than that of SE side, respectively. To verify position of the flaw from ultrasonic data, skilled inspectors experiment and check the ultrasonic signal and all experimental conditions are the same as simulation case study.



(a)



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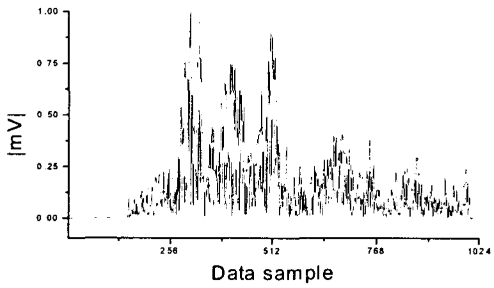

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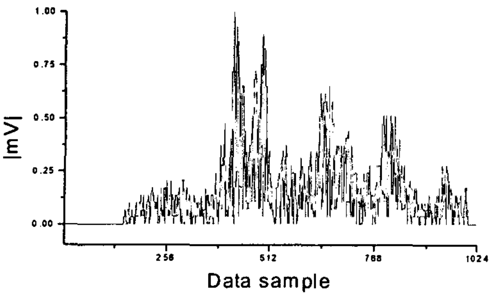

(d)

Fig. 7. Plots of output signals of TIWD and SSP technique

Experimental results show that the TIWD technique detects flaws in all ultrasonic data as fig. 7(a),(b). But results SSP technique fails in the detection of flaws and flaw echos vague in speckle noise because of incomplete removal of speckle noise.

3. Conclusions

In this paper a method for speckle suppression using translation invariant wavelet transform is presented. The translation invariant wavelet transform was introduced and the TIWD method was applied to ultrasonic signals, which were generated from noise-contaminated artificial signals and obtained from weld area of high scattered CCSS and SE materials in specimen. The experimental results are compared with SSP technique. The both study of simulation case and test specimen case shows that TIWD technique can improve visibility of flaw echo in ultrasonic signal.

Acknowledgement

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