Data-Processing for Ultrasonic Phased Array of Austenitic Stainless Steel Based on Wavelet Transform

Xiaoling Liao, Qiang Wang, and Tianhong Yan

Abstract In order to suppress the large number scattering signal echoes caused by the coarse grain structure which is tend to cover up the defect signal, resulting in the defect misjudgment in the detection of austenitic stainless steel material by ultrasonic phased array, the wavelet transform was applied to deal with the experimental data. By introducing the theory of wavelet transform and based on the study of ultrasonic testing characteristics of austenitic stainless steel welds, ultrasonic phased array testing were performed in an austenitic stainless steel welds test block, a real-time S-scan detection image was chosen for quantitative analysis from an UT acquisition system. The experimental results show that the wavelet transform can enhance the signal-to-noise ratio of the austenitic stainless steel ultrasonic phased array inspection effectively and help identify the location of defects. The researches demonstrate that this method achieves the defect measurement for the 90 mm thick of austenitic stainless steels.

Keywords Ultrasonic phased array • Ultrasonic testing • Austenitic stainless steel welds • Wavelet transform

1 Introduction

Austenitic stainless steel is a face-centered cubic crystal structure of the iron-based alloys, it has been widely applied in harsh environments, especially in the field of aerospace and nuclear industry for its non-magnetic, high toughness and excellent plasticity performance.

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Ultrasonic phased array system for non-destructive testing (NDT) has been used increasingly in recent years. Compared with conventional single element transducers, the ultrasonic phased array can perform multiple inspections without the need of reconfiguration.

Due to the imperfect welding technology, grain noise usually appears in NDT ultrasonic phased array testing, which caused by unresolvable reflectors and the defects tend to locate in austenitic stainless steel welds and lead security issues. This noise can be suppressed by certain de-noising algorithms, such as band pass filter, low pass filter and wavelet de-noising algorithm.

In order to satisfy the security requirements in these fields, non-destructive tested for these material is necessary. In addition, more and more researches were done to take effective measurements to suppress the noise in the ultrasonic. Several acoustic and ultrasonic testing techniques are trying to be used to work for the inspection such as acoustic emission, guided waves and phased array [1]. Among these techniques, phased array is good at checking for degradation in thick wall coarse-grain materials like austenitic stainless steel [2–4].

Because of some key advantages over Fourier analysis, wavelet analysis has been widely utilized in signal estimation, classification and compression. Wavelet transform cut up data into different frequency component, and reconstruct the useful components by thresholding policy. Also with its multi-resolution characteristics, it is widely used in ultrasonic signal de-noising processing to improve the signal-to-noise ratio [5].

In this paper, conventional ultrasonic testing problems are analyzed combined with the principle of phased array [6, 7], and wavelet transform is made through the ultrasonic phased array testing experiment on defects in the depths of 40 mm in the austenitic stainless steel block. The choice of the mother wavelet is also discussed in this paper [8]. Choosing the appropriate wavelet based on the correlation coefficient and denoising has been applied.

2 Experimental Studies

2.1 Experimental Instruments and Method

Pulse-echo method was chosen and Omniscan MX2 detector by Olympus was employed in this experiment. Detection parameters are shown in Table 1. The probe has 64 array elements but only 16 of them simultaneous excitation, its frequency is 5 MHz and oil was used as the coupling agent in this experiment. Besides, the S-scan angle is 40–70° and the defect in the depth of 40 mm is the main defect we detect.

In order to simulate the defects, we made a test block. The material of the test block is 304 and it is 90 mm thick. Five side–drilled holes with a diameter of 2 mm were machined in the block (Fig. 1). Three of them are in the austenitic stainless

Table 1 Detection parameters

Probe model	Wedge model	Scan style
5L64-A12	SA12-N55S	S Scan 40–70°

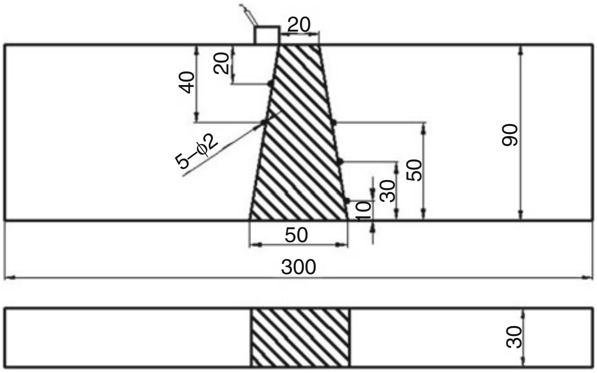

Fig. 1 The structure and size parameters of the test block

steel and their depths are 10, 30 and 50 mm. Two of them are in the austenitic stainless steel welds and their depths are 20 and 40 mm. The probe radiate by refraction through a Plexiglas wedge and produces transverse waves.

2.2 *Wavelet Transform*

In many applications in signal and image processing the observed data are influenced by noise. An important question in this text is how to estimate the underlying "clear" signal from the noisy observations.

Wavelet transform (WT) based methods is useful for analyzing signals. In overcoming the problems associated with Fourier transform methods, they analyze the signals in time – frequency domain. So the information regarding both the time-domain and frequency-domain are available. Choosing a wavelet member from a wavelet family is at best a trial-and error method.

The Wavelet transform Ws(a, b) of a signal x(t) is given by [9].

$$Ws(a,b) = \int_{-\infty}^{\infty} x(t)\psi\left(\frac{t-b}{a}\right)dt \quad (1)$$

Where $\psi(.)$ is the mother wavelet and a, b are the dilatation and translation coefficients respectively.

Based on the principle of suppressing the noise signal, Wavelet transform procedures can be summarized as (i) wavelet transform of the noisy register; (ii) pruning and/or thresholding of the coefficients in the trans-formed domain; (iii) reconstruction of the de-noised signal by inverse transform [10].

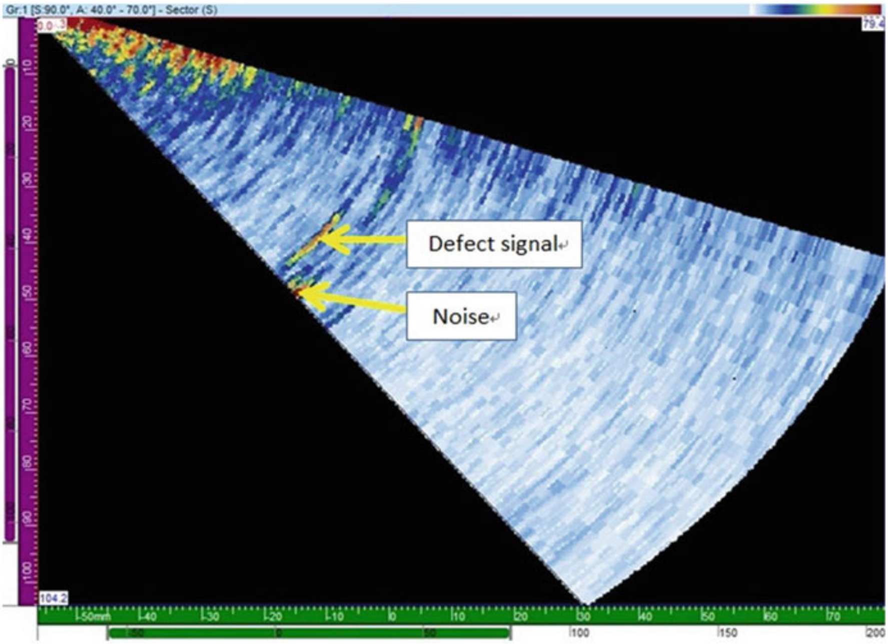

Fig. 2 The test result of the defect in 40 mm depth

According to recently researches, in the detection of ultrasonic echo waves on both time and frequency domains, different kinds of mother wavelet in the Symlet family displays different features. So the mother wavelet of Sym8 was selected in this paper.

2.3 Experimental Data Analysis

To conduct a quantitative analysis, the data of the ultrasonic S-scan image in angle 45° was extracted. In addition, the signal amplitude is expressed by percentage of the total image height in this paper.

As shown in the S-scan images obtained from UT acquisition system (Fig. 2), due to the effects of noise and attenuation caused by coarse grain structure, the signal-to-noise ratio of defect signal has become quite low, defect in 45 mm was caused by instrument(Marked in Fig. 2).

In Fig. 3, it presents the analysis results of ultrasonic plot data after wavelet transform. The mother wavelet in this paper was sym8, and the 3rd-order wavelet, the 5th-order wavelet and 8th-order wavelet was used to process the plot. Comparing the Fig. 3a–d, it’s clear that the wavelet transform can suppress the grain

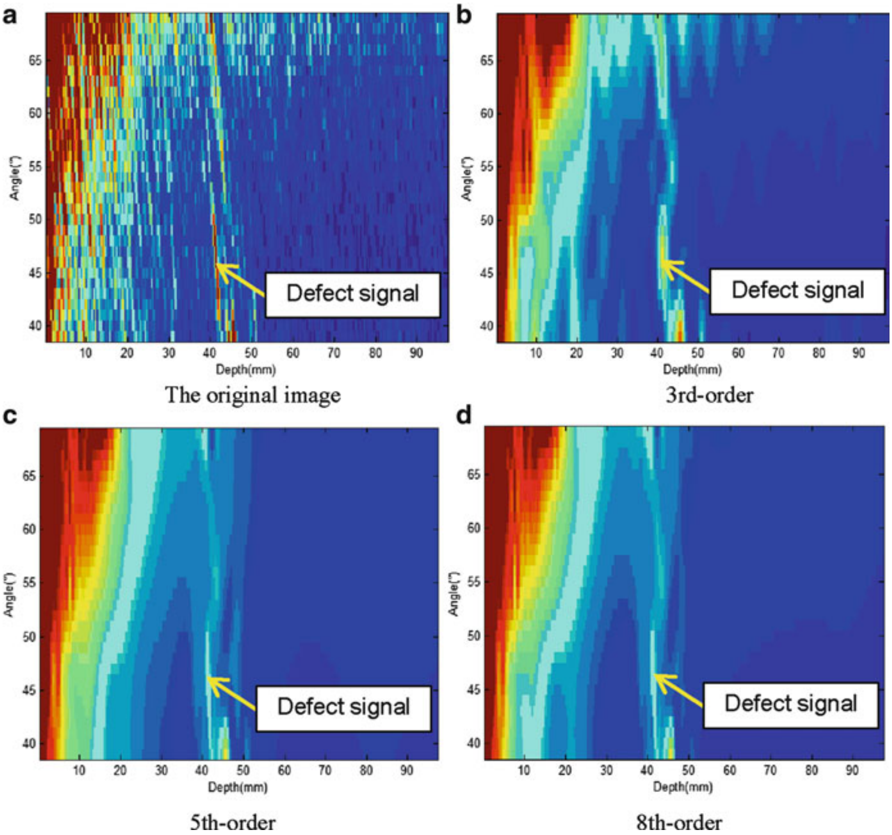

Fig. 3 The effect of transform with mother wavelet sym8 for (**a**) the original plot and (**b**) 3rd-order wavelet transform and (**c**) 5th-order wavelet transform and (**d**) 8th-order wavelet transform

noise well. Particularly, the 3rd-order wavelet transform displays the satisfied performance in suppressing grain noise.

Almost all the depth of noise has been attenuated effectively, and the noise signal curve is very smooth. But the defect in 45 mm caused by instrument is still retain. However, to some extent, it also reduce the useful signal.

3 Conclusion

In this paper we discuss the noise models and the different approaches of processing the noise in the domain of various wavelet transforms. In particular, we focus on how the wavelet transforms with different order affect the processing results. Furthermore, we state three different orders wavelet processing images to discuss the impact.

Wavelet transform approach is presented for analyzing noisy signals. The adopted method shows that the wavelet transform can be effectively applied to austenitic stainless steel measurement.

1. The wavelet de-noising analysis can suppress the grain noise of ultrasonic phased array systems with 64 linear piezoelectric elements for NDT effectively. It can suppress the noise amplitude, smooth the signal curve, and retain the backwall echo signal, though it also can reduce the helpful signal.
2. Ultrasonic phased array technology can effectively detect the defects of austenitic stainless steel. But to the welds' detection, the SNR is low, so in order to increase the defect detection rate, mathematical methods is needed to improve the SNR of deep defects.
3. To coarse grained material and anisotropic structure like austenitic and austenitic welds, the path of the ultrasonic wave would change but the change is irregular.

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