APPLICATION OF SIGNAL PROCESSING TECHNIQUES TO ULTRASONIC TOFD TESTING OF AUSTENITIC WELDS

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Abstract

The desired properties of austenitic steels lead to their numerous applications in many industries. Welded austenitic materials have columnar grains, anisotropic elastic properties, and a heterogeneous structure. These properties are controlled by both the procedure and parameters of welding. The complex structure of austenitic welds can distort and scatter the ultrasonic beams. In ultrasonic testing of austenitic welds, this situation can lead to low signal-to-noise ratio and make the interpretation of results quite difficult. In this paper, the relatively new ultrasonic technique of time-of-flight diffraction (ToFD) is used for inspection of austenitic welds. Special signal processing techniques are implemented in order to improve the low signal-to-noise ratio of ultrasonic signals and make the interpretation of results easier.

1. Introduction

The desired properties of austenitic steels such as high resistance to corrosion, resistance to creep at high temperatures, and good weldability lead to their numerous applications in many industries. Oil, gas, petrochemical and unclear industries employ austenitic stainless steels in their equipments. Welded austenitic materials have columnar grains, anisotropic elastic properties, and a heterogeneous structure [1] whereas base metal (wrought 316L) has random grains with small grain size. Figure 1 illustrates the difference between grain structures of base metal and austenitic weld metal. These properties are controlled by both the procedure and parameters of welding processes. Ultrasonic testing of austenitic welds is difficult because the structure of austenitic welds can distort and scatter the ultrasonic beams. This situation can lead to low signal-to-noise ratio (SNR) and make the interpretation of results quite difficult.

There are two methods that can be used for improving the SNR of ultrasonic signals in ultrasonic testing of austenitic welds. The first is selection of optimized inspection parameters such as wave mode, frequency, angle, etc., and the second is enhancement of measured signals by signal processing techniques. In this investigation, A flawed mockup of austenitic weld is prepared using shielded metal arc welding (SMAW). An artificial defect (notch) produced by electro-discharge machining is implanted in the weld. The relatively new ultrasonic technique of time-of-flight diffraction (ToFD) [2] is used for inspection of the specimen. Signal processing techniques including Wiener filtering and autoregressive spectral extrapolation (ARSE) [3] are used for processing of the A- and B-scan images obtained from the ToFD measurements.

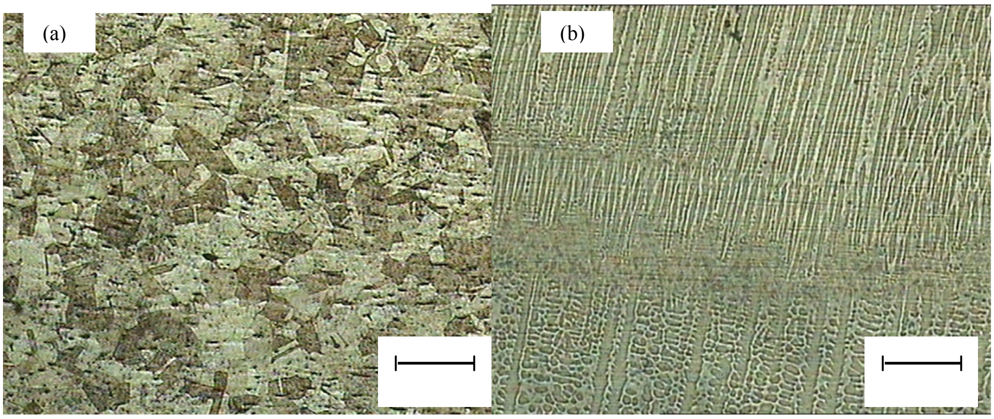

Fig. 1. Comparison of grain structure, (a) Base metal, (b) weld metal

2. Time of Flight Diffraction Technique

Time-of-flight diffraction (ToFD) technique is a relatively new ultrasonic testing method which could be used for inspection welded components. In this technique, two longitudinal angle beam probes are used in pitch-catch mode. The frequencies used are generally higher than conventional ultrasonic probes and the results are presented as either A- or B-scan images. Some of the advantages of ToFD over conventional ultrasonic testing are:

- The entire body of the weld can be scanned in a single pass with high reliability and very quickly.
- Size and depth of discontinuities can be measured very accurately.
- Since the ToFD is based on detection of diffracted signals, the orientation of a discontinuity does not affect it.
- Longitudinal angle beam used in ToFD technique makes it possible to examine thick austenitic stainless steel welds.

3. Signal Processing

Measured ultrasonic nondestructive testing signals include the effects of the measurement system and propagation paths taken by transmitted and received waves. In an ultrasonic testing system, the measurement system impulse response, $(\,)$, can be modeled as the convolution of the impulse responses of the test specimen, *x(t)*, and measurement system, *h(t)*, plus additive noise, *n(t)*,

$$(\,) = h(\,) * (\,) + (\,) \qquad (1)$$

where * denotes the linear convolution operator. To extract the desired impulse response of the test specimen, *x(t)*, from Eq. (1), one has to use a deconvolution process. In general, simple deconvolution processes could only be used for relatively smooth and noiseless signals. For the signal given by Eq. (1), a deconvolution technique called Wiener filtering could be a good choice [4]. A Wiener filter is formulated based on the minimization of a least square error. In the frequency domain, a Wiener filter is written as [3],

$$(\,) = \frac{(\,)^{*}(\,)}{|(\,)|^{2} + {}^{2}} \qquad (2)$$

$$^{2} = 0.01|\;(\;)|^{2} \qquad (3)$$

where $^{-}(\;)$ is the complex conjugate of, and, and $(\;)$ are the Fourier transforms of, $(\;)$, and $(\;)$ respectively.
The signal obtained by applying the Wiener filter to the signal can be further improved by another process called autoregressive spectral extrapolation (ARSE). To apply the ARSE, a certain window of the digitized spectrum which has a relatively higher SNR compared to the rest of the signal is selected. The ARSE model is then applied to this frequency window, assumed to lie between the points with indices and , and the ARSE coefficients are found. The lower and upper parts of the digitized spectrum are extrapolated using the following equations [3],

$$\hat{x}_p = -\sum_{i=1}^{k} a_i^{-} x_{p+i} \quad p=1,2,\ldots,m-1 \qquad (4)$$

$$\hat{x}_q = -\sum_{i=1}^{k} a_i^{-} x_{q+i} \quad q=n+1,\ldots,N \qquad (5)$$

where $\hat{x}_p$ and $\hat{x}_q$ are extrapolated values and and $^{-}$ are the ARSE coefficients and their conjugates, respectively.

In what follows, we will be using a combination of Wiener filtering and ARSE to process the ToFD signals obtained from testing of austenitic welds.

4. Experimental study

An Austenitic weld sample with a lack of fusion (LoF) defect was built using Manual Metal Arc (MMA) welding. It was made of a 25 mm thick AISI 316L stainless steel. An artificial defect shown in the form of a vertical machined slot was implanted in the weld. The slot was 3 mm deep, 0.5 mm wide, and 26 mm long representing an inter-pass lack of fusion defect, see Fig. 2. The weld was then inspected by ultrasonic ToFD technique using two 65º, 6 MHz longitudinal angle beam probes. The probes center spacing (PCS) was 65 mm.

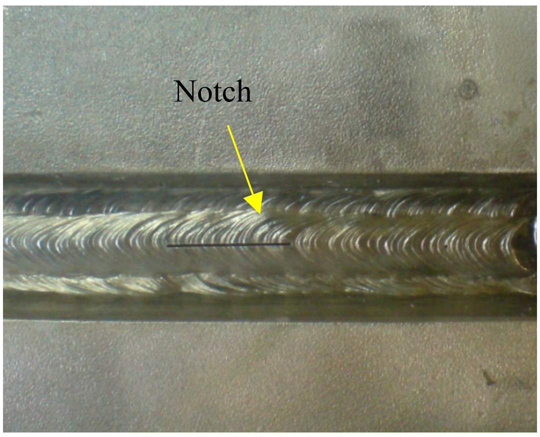

Fig. 2. Artificial flaw machined in the weld

5. Results

Both A- and B-scan images can be produced from ToFD signals. A- and B-scan images obtained from the defected part of the weld specimen are shown in Figs. 3 and 4, respectively. Figure 3(a) shows the raw signal obtained from the defect. This signal is then processed by a combination of Wiener filtering and ARSE. To apply the Wiener filtering, a reference signal (wavelet) is required. The lateral wave shown in Fig. 3(b), which is the first echo observed in a ToFD test, was taken as the wavelet. The frequency spectrum of the wavelet is also shown in Fig. 3(d). The raw signal was then processed by Wiener filtering followed by ARSE. This processed signal is shown in Fig. 3(c). It is observed that while in the raw signal, the defect cannot be easily identified, the processed signal has revealed the defect quite clearly.

The raw and processed B-scan images are shown in Figs. 4(a) and 4(b), respectively. Once again, we observe that the processing of the B-scan images has improved the SNR quite noticeably. Measurements conducted on processed signals showed that the measured defect size by ToFD technique has an uncertainty of approximately 8%.

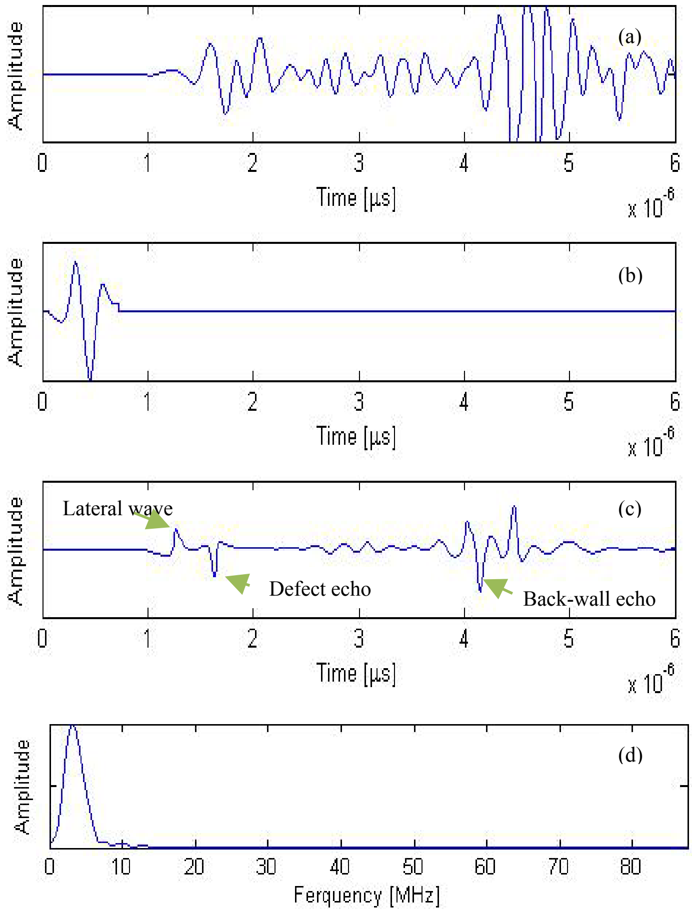

Fig. 3. A-scan signals obtained from the defected part of the specimen, (a) raw data, (b) reference wavelet, (c) processed signal, (d) frequency spectrum of the wavelet.

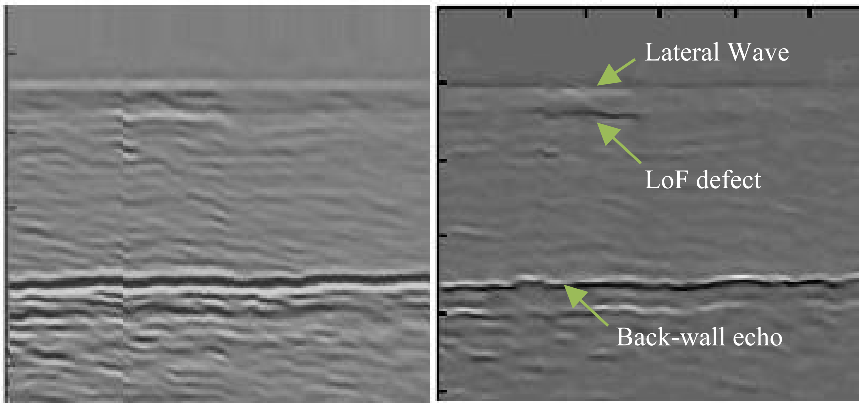

Fig. 4. B-scan image, (a) raw data, (b) processed data.

6. Conclusions

In this paper, improvement of ultrasonic ToFD signals obtained from austenitic welds by application of special signal processing techniques was investigated. A combination of Wiener filtering and autoregressive spectral extrapolation were used to improve the time resolution and signal-to-noise ration of both A- and B-scan images acquired from ToFD measurements on austenitic welds. Preliminary studies shows that this approach is quite promising and can measure the weld discontinuities with high accuracy.

References

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