Improvement of On-line Ultrasonic Detection for Internal Flaws in Steel Strip using Adaptive Signal Processing

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Abstract. A novel adaptive signal processing method for application to on-line ultrasonic detection of internal flaws in steel strips was developed.

To improve the detectability of on-line detection systems, it is necessary to reduce obstructive echoes. However, it is difficult to distinguish obstructive echoes from flaw echoes by analysing the frequency or timing of those echoes. Focusing on the fact that the shape and timing of obstructive echoes are approximately the same in repetitions of the same channel in a probe array, we developed an adaptive signal processing method for reducing obstructive echoes in which generated reference signals are subtracted from the original ultrasonic signals.

The developed signal processing method is as follows: (1) Preserve the ultrasonic waveform signals of each channel. (2) Generate reference signals from past signals. Before this process, we decided a go-back number N considering the continuity of flaws and line speed, and in this process, we use signals from N-times before the current signal. In addition, a synchronous addition method is used in generating the reference signals in order to reduce random noise. (3) Subtract the latest waveform signal from the reference waveform signal of the same channel.

Because obstructive echoes are approximately the same in repetitions of the same channel in a probe array, obstructive echoes are reduced by the developed method. In addition, this method is effective even if there is a difference between the shape and timing of the obstructive echoes of one channel in the probe array and those of another channel. The method is also applicable in cases where the shape and timing of the obstructive echoes change when the steel strip changes.

Obstructive echoes were reduced by approximately 4 dB or more by applying the developed method to signals of an on-line inspection system.

1. Introduction

Internal flaws in steel sheets tend to become the origin of cracks and surface breaks when the steel sheets are subjected to plastic deformation. Therefore, it is necessary to detect internal flaws on the steel production line. Lamb wave testing is widely applied as an on-line detecting method [1] [2]. However, the detectability of the Lamb wave technique is not adequate for detecting minute flaws (≤50 μm).

For detection of minute flaws in steel sheets, an on-line testing technique using an ultrasonic probe array had been developed [3]. In this method, a line-focused ultrasonic beam (frequency: 25 MHz) is transmitted from each probe of the transmitting probe array and
received by the receiving probe array. High detectability in comparison with the conventional Lamb wave test had been achieved by this method.

In recent years, the critical size for harmful inclusions has decreased due to the trend toward thinner-gauge sheet products to meet environmental and economic needs. Therefore, in this study, we attempted to improve the probe array testing technique, and as a result, we confirmed improvement of the signal to noise ratio.

2. **Investigation of on-line ultrasonic signal**

Figure 1 shows a schematic diagram of the detecting system. In this system, the transmitted ultrasonic wave enters vertically, and the transmitted wave is received by the receiving probe. In addition to the transmitted wave, flaw reflected waves are also received when a flaw exists on the ultrasonic path.

![Schematic diagram of detecting system.](image)

Fig. 1 Schematic diagram of detecting system. 
*T1, T2: transmitted waves, F1, F2: flaw reflected waves.*

To improve the system, firstly, we investigated on-line ultrasonic signals. The specification of the probe used in this work is the same as in the method reported previously. [3] (The transmitting probe and receiving probe have the same specification; the frequency is 25 MHz.)

Figure 2 shows the ultrasonic signals received by the receiving probe of an actual probe array. In the signals in Fig. 2, no flaw echo signals were detected because no internal flaws existed in the ultrasonic paths. However, as shown in Fig. 2, some obstructive echoes were observed. These results indicated that the propagation times of the obstructive echoes were almost the same, and their waveforms were also nearly identical.

Further investigation also revealed that the obstructive echoes were slightly different between receiving probes, and the echoes changed somewhat when the thickness of the steel sheet changed.
Figure 3 shows the supposed cause of the obstructive echoes. A conceivable reason for the obstructive echoes is as follows: Firstly, some ultrasonic wave, which is transmitted from a focused probe, enters a steel sheet. Its incidence angle is slightly different from 0 degrees. Therefore, at the boundary of the water and the steel, mode conversion from a transverse wave to a shear wave occurs. Then, the shear wave propagates to the other side of the boundary, and at the boundary, mode conversion from the shear wave to a transverse wave occurs. The propagation time of this path is longer than the time of the transmitted wave ($T1$ in Fig. 1) because the sound velocity of a shear wave in steel is slower than that of a transverse wave in steel.

Fig. 2 On-line ultrasonic signals detected by a receiving probe.

Fig. 3 Supposed cause of obstructive echoes.
3. Method for improvement

To improve the signal to noise ratio of the detecting system, we developed a digital signal processing method. Figure 4 shows the basic concept of the developed method. In this method, some reference signal is subtracted from the original signal. Because obstructive echoes occur in both the original signal and the reference signal, the obstructive echo is eliminated by the subtraction.

Figure 5 shows the practical signal processing for reducing obstructive echoes. In this processing, the reference signal is generated by using the original signals of some pulses in the past. The signals using to generate the reference signal and the signal subtracted in the processing are received by the same probe because the waveforms of obstructive echoes depend on which probe receives the signals. The number of steps back in the past to the signal which is used to generate the reference signal (i.e., the go-back number \( N \) in Figure 5) is decided by considering both the continuity of flaws and the change of obstructive echo waveforms. The reason for averaging to generate the reference signal is to reduce random noise.
4. Experimental Results

Next, the developed signal processing method was applied to the on-line signals of the actual probe array system. Figure 6 shows a result of signal processing in comparison with their original signals. The thickness of the tested steel sheet was 2 mm. Subtraction processing reduced the obstructive echoes in all the signals shown in Figure 6, and the noise level (including obstructive echoes) was reduced by approximately 4 dB. Further experiments also confirmed that the average level of the flaw echoes was approximately the same in comparison with their original signals. Therefore, as a result, improvement of the signal to noise ratio was also achieved.
Fig. 6 Experimental results of developed signal processing method.

5. Conclusion

To improve detectability in on-line testing of steel sheets, a signal processing method for the ultrasonic detection system using the line-focused probe array was developed. Obstructive echoes were reduced by subtracting adaptively generated reference signals from the original signals. It was confirmed that the signal to noise ratio was improved by approximately 4 dB.

References