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분산성 램파의 전파에서 입력 파형의 복원을 위한 신호처리
Signal Processing Techniques for Recovering Input Waveforms in Dispersive Lamb Wave Propagation

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1. Introduction

Lamb waves are extensively used in plate-like structure inspection because of their guided nature. However, their dispersive properties often limit their use in flaw detection and other applications. Dispersion weakens and defocuses interrogating Lamb waves and makes it difficult to accurately interpret signals reflected from defects or boundaries. Time reversal (TR) processing can be applied to compensate for the effect of dispersive Lamb waves. Thus, the TR operation will enable the amplification of dispersive Lamb wave signals by signal compression in time. Time reversal process with Lamb waves in the present work consists of three steps. Acoustic signal is emitted into a plate by a transmitting transducer. Signal becomes dispersive when propagating along the plate. A second transducer receives the transmitted signal. The signal is reversed in time and reemitted by the initial transmitter. If the time invariance is satisfied, then the recorded signal becomes the same as the original input signal.

The effect of dispersion on the time reversal analysis of Lamb waves was first studied by Ing et al.[1], and then by Wang et al.[2] by introducing the time reversal operator into the Lamb wave equation based on the Mindlin plate theory. Park et al.[3] demonstrated that the use of a narrowband toneburst excitation fully restores the original input signal through a single mode Lamb wave time reversal process. Xu and Giurgiutiu[4] and more recently Park et al.[5] and Jeong[6,7] proposed a theoretical model for studying the Lamb wave time reversal behavior in single and multiple modes, and verified it experimentally.

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In this study, experiments are performed in order to examine the refocusing and recovering the initial input waveform in the long range propagation of dispersive Lamb waves in a plate. Three different time reversal processes (regular TR, 1 bit TR, and reciprocal TR or inverse filtering) are tested and the experimental results are presented.

2. Experiment

Experimental setup is shown in Fig. 1. The sample is an Al plate of 1.2 mm thick, 30 mm wide and 2 m long. The cutoff frequency of A_0 mode Lamb wave here is about 1.3 MHz, so that it was decided to use 1 MHz transducers with variable angle wedges to generate and receive A_0 mode dominantly. Both transducers are of rectangular shape (Panametrics V401) and the matching wedges are made of teflon. The input signal for the transmitter was produced by a function/arbitrary waveform generator (Agilent 33250A), and then amplified by a linear amplifier (E&I 2100L). The generator and oscilloscope were controlled by a PC using GPIB bus.

Signals with Gaussian envelope and 1 MHz carrier frequency were used as an input source (Fig. 2(a)). The output signal received after 2 m propagation is shown in Fig. 2(b). The output signal is composed of very weak S_0 mode, main A_0 mode, followed by weak reverberated signals inside the wedge. The received signals were time reversed and reemitted at the initial transmitter. The signal waveform received after second propagation is shown in Fig. 2(c). Detailed waveform of reconstructed main part is shown in Fig. 2(d), and found that it does not fully recover the original input signal.

Next, a 1 bit TR was tested and the result is shown in Fig. 3(a). It compresses and recovers the main signal slightly better than the regular TR. It increases the amplitude of reconstructed main part about 17 times compared with the regular TR result. However, the sideband signals are also increased significantly.

Fig. 1 Experimental set up for A_0 mode Lamb wave generation and reception with variable angle wedge transducers.

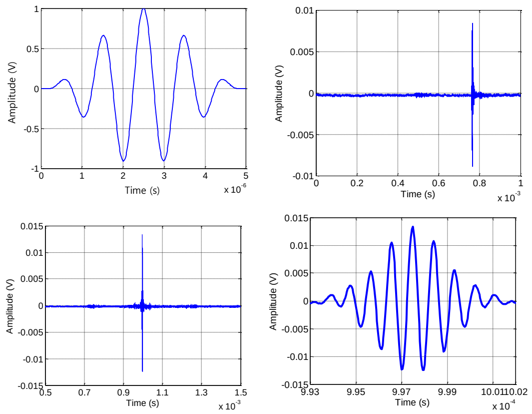

Fig. 2 (a) Input signal, (b) Received signal, (c) Reconstructed signal after regular TR, and (d) Expansion of reconstructed signal.

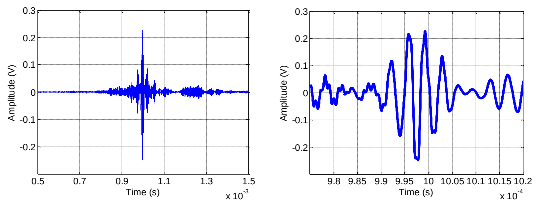

Fig. 3 (a) Reconstructed signal after 1 bit TR, and (b) Expansion of reconstructed signal.

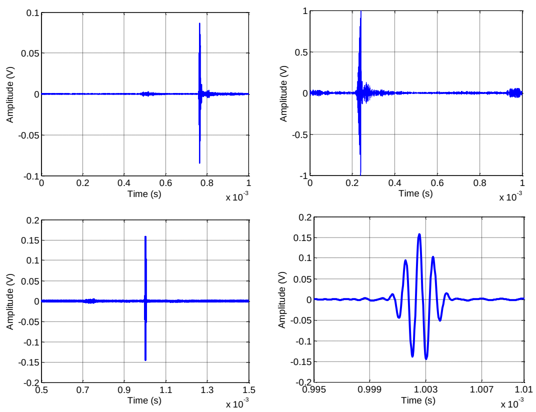

Fig. 4 (a) Received signal, (b) Reemission signal through inverse filtering (IF), (c) Reconstructed signal after IF transmission, and (d) Expansion of reconstructed signal.

The IF approach is based on the inversion of the transfer function $H(\omega)$. The IF results are presented in Fig. 4. As shown in Fig. 4(d), it completely recovers the original input signal and amplifies the recovered signal more than 10 times. Compared to the TR experiments, the IF technique greatly increases the contrast, i.e., the ratio of the recovered signal at time t=1.0 ms and the sideband signal at all other times.

3. Summary

An experimental study has been made with the use of time reversal concepts to recover the input waveform in a long range propagation of dispersive Lamb waves. Three techniques have been tested: Regular TR, 1 bit TR and Inverse filter (IF). The IF approach was found to completely recover the original input signal. Moreover, the IF technique significantly increases the contrast, i.e., the ratio of the recovered signal and the sideband signal.

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