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Measurement of Work Material Edge Position in Press Working Using Surface Waves

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1. Introduction

Press processing is a technology in which a material is sandwiched between a die and a press machine, and a strong force is applied to form the material. It is used in the manufacture of various industrial products. If it is possible to accurately measure the position of the end face of the workpiece that is sandwiched between the die and the press machine during press processing, it is possible to handle difficult-to-process materials, improve processing accuracy, and improve productivity [1]. Direct distance measurement using a laser is a method of measuring the position of the end face of the workpiece with high accuracy. However, considering the system cost and ease of installation of the measurement system, it is expected that the measurement using ultrasonic waves will be effective. In this study, the method of measuring the reflected wave of the surface wave propagating on the die surface at the edge of the workpiece is investigated, and the accuracy of the edge position measurement is evaluated.

To obtain high resolution of reflector positions and high signal-to-noise ratio (SNR), the use of pulse compression techniques (PCT) is effective [2]. However, the resolution of PCT is determined by the sharpness of the autocorrelation function of the transmitted signal, that is, the bandwidth of the transmitted pulse, and is limited by the effective bandwidth of the transducer used for measurement. To further improve the resolution performance, the application of super-resolution FM chirp correlation (SCM) [3][4] is appropriate. In this research, the above measurement is realized by finite element method (FEM) simulation, and its effectiveness is evaluated.

2. Outline of SCM

Based on the ultrasound transducer bandwidth settings assumed in this study, the SCM method used in this paper is as follows. Within a 6 MHz bandwidth from 4 MHz to 10 MHz, an FM chirp signal with a 2 MHz bandwidth and a time width of 10 μs is transmitted 15 times with different center frequencies, and the echoes for each are received. The echo signal is pulse-compressed and then converted to an IQ signal by a quadrature detector. Subsequently, the variance-covariance matrix **R** of the obtained IQ signal is estimated as the arithmetic mean of fifteen echoes with different center frequencies. Using this **R** and the Toeplitz matrix $\mathbf{R}_0$ constructed from the baseband representation r of the compressed waveform of the transmitted chirp signal, we compute the SCM profile signal:

$$S(t_i) = \frac{r_i^{\mathrm{H}}\mathbf{R}_0^{-1}r_i}{\sum_{k=D+1}^{M}\left|r_i^{\mathrm{H}}e_k\right|^2}, i = 1,2,\dots,M, \qquad (1)$$

where *M* is the sampling points of the receive echo and {ei} is the eigenvector of **R**. The first *D* eigenvectors span the signal subspace. On the other hand, the remaining *M*−*D* eigenvectors span the noise subspace. ri is r shifted to time ti. The SCM profile evaluates the reciprocal of the magnitude of the components in the noise subspace, and if there is a signal at ti, the value of the SCM profile increases. By using the covariance matrix $\mathbf{R}_0$ calculated while changing the frequency, it is possible to separate and detect signals at different times.

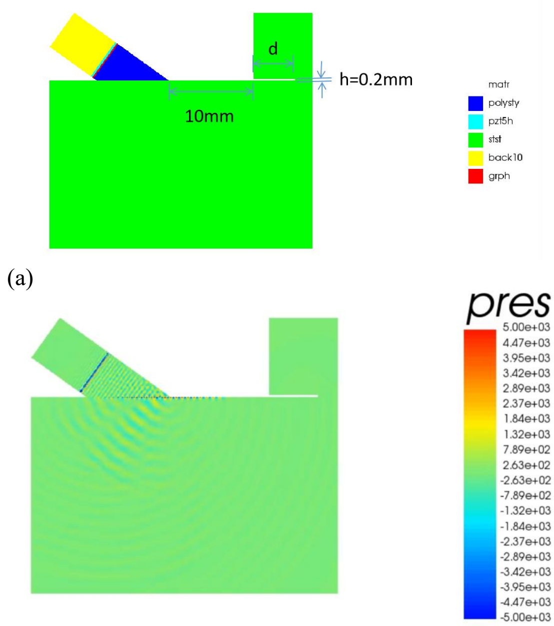

Fig. 1 Simulation model: (a) Single PZT for oblique incidence of proposed system; (b) Screenshot of surface wave propagation by Onscale.

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3. Simulation Results and Discussion

This research was conducted as a two-dimensional numerical experiment using the ultrasonic propagation FEM simulator OnScale. The ultrasonic incident angle is set at 54.36 degrees according to Sneer's law to enhance the surface wave pressure. The width of the PZT is 5 mm, and the thickness is suitable for transmitting and receiving in a bandwidth of 4 to 10 MHz. The top, bottom, left, and right boundaries of the computational domain are set as Perfect Matching Layer (PML).

Since the surface wave is weak and has a large distance attenuation, it is buried in the surrounding unnecessary reflected signals. Therefore, the desired reflected signal is emphasized by subtracting the received waveform for the reference position as the reference signal. As shown in the model introduction in **Fig. 1**(a),this time, 15 mm was used as the reference position. PCT and SCM were performed on the obtained differential waveform. A snapshot of the surface wave simulation is shown in **Fig. 1**(b).

Linear frequency smoothing was used to estimate **R**. This is a method of shifting a fixed bandwidth Δω at regular intervals, as shown in **Fig. 2**. The PCT aims to shorten the pulse after compression by using the entire 6 MHz width, while SCM uses fifteen 2 MHz bands from 4 to 10 MHz to estimate **R**.

Using the surface wave velocity of 2864.1 m/s measured in advance to transform the time coordinate into the distance coordinate, we obtained the waveform in **Fig. 3**, and found that the resolution of SCM is higher than that of PCT.

4. Conclusion and Future Work

In this study, both PCT and SCM methods were used to analyze surface-wave ultrasound signals and to confirm whether sufficient resolution was obtained to accurately measure the reflected distance. The two methods were applied to signals artificially generated by the OnScale simulator using a simple model. In order to clearly measure the desired reflected signal, it was necessary to cancel out the influence of multiple reflections by detecting the difference from the waveform with respect to the reference position, but finally the SCM showed sufficient performance. Although the reference position was fixed this time, further performance improvement can be expected by changing it adaptively. In addition, it is necessary to support dynamic measurement by replacing multiple transmission/reception of the SCM with one transmission and subband division by signal processing. After proceeding with these, we plan to evaluate the actual performance through experiments.

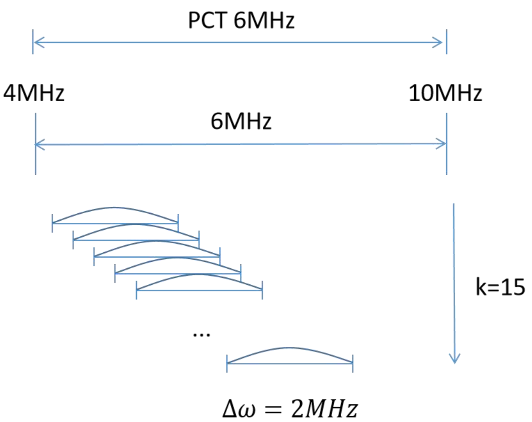

Fig. 2 Linear frequency smoothing for estimating **R.**

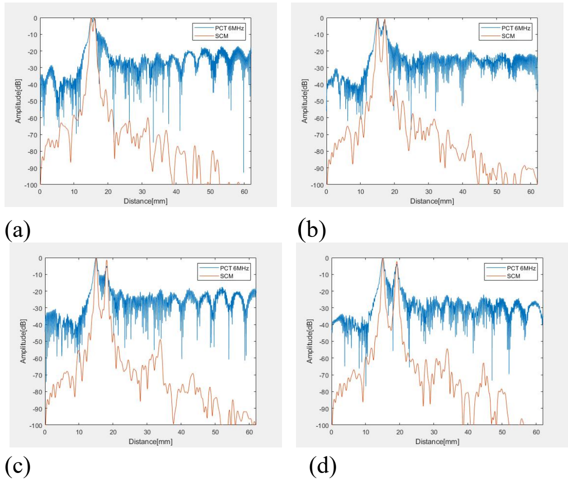

Fig. 3 Experimental results of SCM and PCT for (a) 16mm-15mm, (b) 17mm-15mm, (c) 18mm-15mm, (d) 19mm-15mm.

5.References

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