46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-6930

LINEAR/NONLINEARITY ULTRASONIC MEASUREMENT SYSTEM FOR EVALUATION OF MATERIAL ELASTIC PROPERTIES

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ABSTRACT

An ultrasonic measurement system that can measure longitudinal and transverse wave velocities, elastic modulus, Poisson's ratio, and acoustic nonlinearity parameter, and that can estimate strain-stress relationship has been developed. The system sequentially performs a series of measurements including linear and nonlinear ultrasonic measurements automatically. The linear measurement includes an auto-correlation signal processing function to accurately measure the time-of-flight of echoes. The nonlinear measurement includes a function of automatically adjusting the input voltage, the fast Fourier transform processing, and a linear fitting function to obtain acoustic nonlinearity parameter. A strain-stress relationship in the elastic region, reconstructed from the measured linear and nonlinear properties, is also provided.

Keywords: wave velocity, Poisson's ratio, acoustic nonlinearity parameter, elastic constants, strain-stress relationship

1. INTRODUCTION

The linear and nonlinear ultrasonic techniques are effective non-destructive methods possible to measure elastic properties of materials [1]. Especially, the nonlinear ultrasonic technique can diagnose early material degradation [2-4]. Until now, many researchers have studied the linear and nonlinear ultrasonic techniques separately. Furthermore, an integrated measurement system including both linear and nonlinear ultrasonic measurements has not been developed.

In this study, a linear/nonlinearity ultrasonic measurement system for evaluation of material elastic properties has been developed. The developed system can measure longitudinal and transverse wave velocities, elastic modulus, Poisson's ratio, and acoustic nonlinearity parameter, and that can estimate strain-stress relationship.

2. LINEAR/NONLINEARITY ULTRASONIC MEASUREMENT SYSTEM

The main hardware of the developed linear/nonlinearity ultrasonic measurement system includes a transistor-transistor logic (TTL) signal generator, a function generator, a gated amplifier, and a scope board, as shown in Fig. 1. The TTL signal generator is used for the synchronization of all system equipment. The function generator drives a monochromatic sinusoidal tone-burst signal up to 1 V. The gated amplifier amplifies the output signal from the function generator at a fixed amplification rate. The voltage of the final output signal is controlled from the function generator. The scope board collects the received ultrasonic signals, including the pulse-echo signals and the through-transmission signals. The Labview software program controls the TTL signal generator, the function generator, and the scope board.

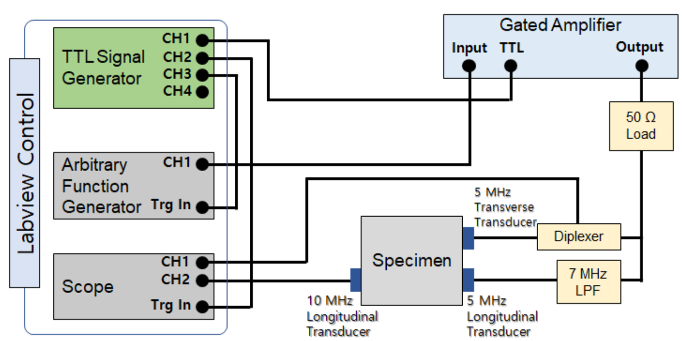

FIGURE 1: SCHEMATIC OF THE DEVELOPED ULTRASONIC MEASUREMENT SYSTEM

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3. MEASUREMENT PROCESS FOR EVALUATION OF MATERIAL ELASTIC PROPERTIES

The system sequentially performs a series of measurements including linear and nonlinear ultrasonic measurements automatically.

First, the system measures longitudinal and transverse wave velocities. Here, the function generator provides a single-cycle sinusoidal signal. In the measurement of the transverse wave velocity, a pulse-echo signal measured by a 5 MHz transverse transducer is used. Meanwhile, the measurement of the longitudinal wave velocity uses a through-transmission signal measured by 5 MHz and 10 MHz longitudinal transducers, as shown in Fig. 1. And then, auto-correlation signal processing is performed to measure the time-of-flight. Finally, wave velocities are calculated using the values of the specimen thickness and the measured time-of-flight.

Next, the nonlinear ultrasonic measurement is started. Here, the function generator provides a sinusoidal tone-burst signal. This system automatically can change the voltage of the electrical signal sent to the generating transducer to obtain the ultrasonic nonlinearity parameter. The measured tone-burst signals are analyzed by using the fast Fourier transform (FFT) with a Hanning window. And then, the relative acoustic nonlinearity parameter (β') is calculated with a linear fitting function. Finally, the absolute nonlinearity parameter (β) is estimated using the relationship below [5].

$$\beta = \frac{\beta_{ref}}{\beta'_{ref}} \beta' \tag{1}$$

where, β_{ref} and β'_{ref} are the absolute and relative nonlinearity parameters of a reference specimen, respectively.

Furthermore, the system calculates the elastic modulus and Poisson's ratio using the measured values, and then provides the strain-stress relationship in the elastic region.

Figure 2 shows the graphical user interface (GUI) of the developed system. The input parameters include the thickness and density of the specimen, and the absolute and relative nonlinear parameters of the reference specimen. The GUI displays the longitudinal and transverse wave signals, the tone-burst signal and its frequency spectra measured for the nonlinear ultrasonic measurements, the strain-stress curve in the elastic region reconstructed from the measured values, and the calculated material elastic properties.

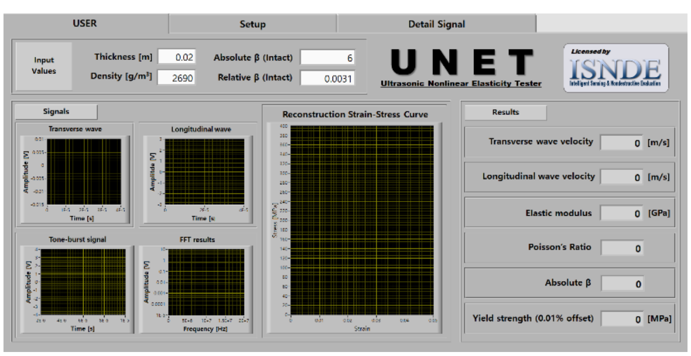

FIGURE 2: GRAPHICAL USER INTERFACE OF THE DEVELOPED ULTRASONIC MEASUREMENT SYSTEM

4. CONCLUSIONS

A Linear/nonlinearity ultrasonic measurement system for evaluation of material elastic properties has been developed. The developed system evaluates and displays longitudinal and transverse velocities, acoustic nonlinear parameter, elastic modulus, Poisson's ratio and strain-stress relationship in the elastic region. One of the main features of this system is to perform sequentially a series of measurements including linear and nonlinear ultrasonic measurements automatically. This system includes signal processing functions of auto-correlation and FFT with a Hanning window, a function of automatically adjusting the input signal voltage, a linear fitting function, and an averaging function. The developed system could be effectively used for the quantitative estimation of material elastic properties of industrial structural materials.

ACKNOWLEDGEMENTS

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (NRF-2013M2A2A9043241).

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