An Onboard Measurement System of Ultrasonic Velocity and Attenuation using the Wavelet Transform

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Abstract: In this paper, we present an ultrasonic velocity and attenuation measurement system. There are many ultrasonic measurement methods that are used in nondestructive testing applications. They include material property determination, microstructural characterization, and flaw detection. Ultrasonic parameters such as velocity and attenuation are most commonly used in them. Advanced signal analysis which is called "time-frequency analysis" has been used widely in nondestructive evaluation applications. Wavelet transform is the most advanced technique for processing signals with time-varying spectra. Using the echo waveform gathered by the designed hardware system, we performed simulation of the signal processing algorithms. Then the algorithm is implemented on the system.

Keywords: nondestructive evaluation, ultrasonic system, wavelet transform, group velocity, attenuation coefficient

1. INTRODUCTION

Using ultrasonic velocity and attenuation, we can estimate mechanical properties such as strength of material, not doing a destructive experiment or fractography of material.

Pulse-echo reflection techniques are used for ultrasonic nondestructive testing in most commercial instruments. The ultrasonic waves, generated by a piezoelectric transducer coupled to the test specimen, propagates through the material and part of its energy is reflected if the wave encounters an inhomogeneity or discontinuity in its path, while the remainder is reflected by the back surface of the sample. To analyze ultrasonic signals, there are many signal processing algorithms. The ultrasonic signal is usually a broadband pulse modulated at the center frequency of the transducer. Therefore the transient signal is usually time- and frequency-limited. For this reason, the utilization of two-dimensional analysis can be more appropriate. And the accuracy and repeatability of testing results are depend on both the hardware used to generate and receive the ultrasonic waves and on the analysis software for calculating these parameters, frequency-dependent phase/group velocity and attenuation. In pulse-echo reflection techniques, it is general that ultrasonic velocity and attenuation coefficient can be measured by time and amplitude of multiple echo pulses from the material with known thickness. Wavelet transform is applied to the time-frequency analysis of ultrasonic echo waveform obtained by an ultrasonic pulse-echo technique.

2. MEASUREMENT SYSTEM

This measurement system is implemented an onboard system. It consists of pulse generator part, receiver part, A/D conversion part, display part, and CPU part shown Fig. 1. It generates a high voltage pulse from pulse generator and the ultrasonic echo signal is received and converted to digital after several signal processing.

The pulse generator part given in fig. 3 consists of voltage generator and controller. Pulse voltage and width are settled by user. The voltage ranges from 40V to 300V in 256 steps and the range of the pulse width allows from 50ns to 728ns in 256 steps. They can be adjustable for good wave form.

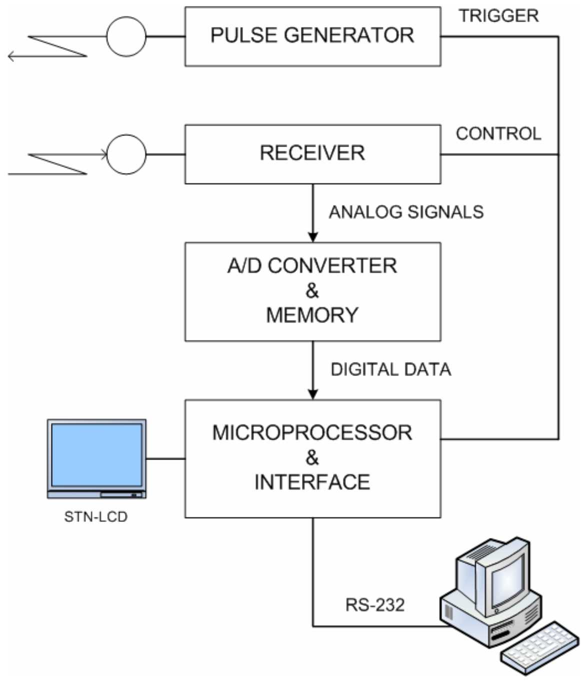

Fig. 1 Block diagram of the hardware.

The receiver part consist of clipper, variable gain amplifier, high pass filter, rectifier, dc-offset and low pass filter given in Fig. 2. A gain of VGA is used to control the amplitude of received signal. It ranges from -20 dB to 60dB at a 0.01 dB step. Adjust the gain until the signal fits in he display without any saturation.

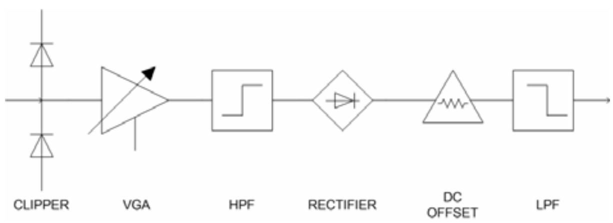

Fig. 2 Block diagram of the receiver.

HPF and LPF can be used to set up a frequency band to eliminate the noise of unwanted frequencies. They are designed as fourth order butterworth filter using the Sallen-Key Circuit. Adjustable cutoff frequency of HPF is 4.8 MHz, 1.8 MHz, 0.8 MHz, or 0.6 MHz. Adjustable cutoff frequency of LPF is All, 48 MHz, 28 MHz, 18 MHz, 8.8 MHz, 7.5 MHz, 6.7 MHz, or 5.9 MHz.

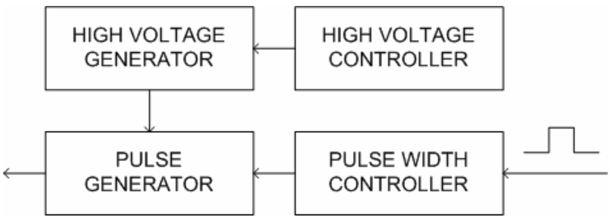

Fig. 3 Block diagram of the pulse generator.

Rectifier allows four choices for the signal parameter. They are full(full wave rectification), +half(positive half of the signal), -half(negative half of the signal) and RF(no rectification). To overcome the signal bandwidth, we designed an active rectifier.

Dc-offset is used to adjust the height of the base line of the signal. It can be adjusted until the base line in the middle of the display window for the RF signal or at the bottom of the display window for full wave, +half, and -half. All control signals are digital provided by microprocessor.

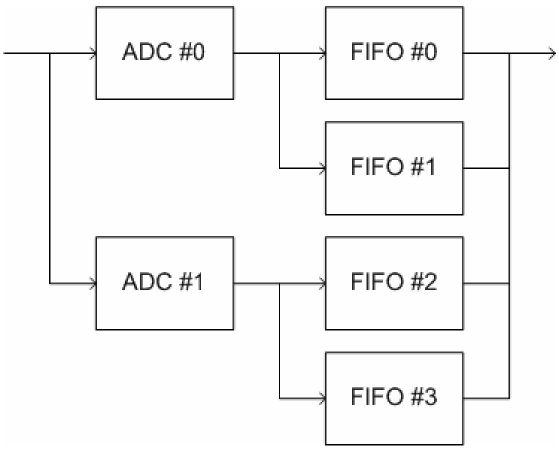

Fig. 4 Block diagram of the A/D conversion.

The A/D conversion part consist of two analog to digital converters and four 8-bit FIFOs(First Input First Output) at each channel given in fig. 4. Their conversion frequency is up to 100 MHz. Using the interleaving method, the echo signal can be sampled up to 200MHz.

STN-LCD(320-by-240, 256 level colors) is used for the display device. It shows analog to digital conversion echo signals. A horizontal axis and vertical axis indicate time-scale and amplitude.

The CPU part is designed S3C44B0X RISC microprocessor. It has 60Mhz ARM7 core. It controlled gain of VGA, cutoff frequency of HPF, select rectifier method, dc-offset value and cutoff frequency of LPF. The program and data can be transferred to PC using the RS-232 interface.

3. SIGNAL PROCESSING USING WAVELET TRANSFORM

The WT(Wavelet Transform) is the correlation between the signal and a set of basic wavelets. An appropriate mother wavelet $h(t)$ is chosen to analyze a specific transient signal of finite energy. Then a complete orthogonal set of daughter wavelet $h_{a,b}(t)$ is generated from the mother wavelet $h(t)$ by dilation(a) and shift(b) operation. The WT expansion coefficients of the signal $h(t)$ is given by:

$$F(a,b) = \int_{\infty}^{\infty} f(t) \cdot \psi_{a,b}^{*}(t) dt, \quad (1)$$

where the function $\psi_{a,b}(t)$ is given by:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right). \quad (2)$$

The mother wavelet can be any function which satisfies the admissibility condition:

$$\int_{\infty}^{\infty} \psi(t) dt = 0. \quad (3)$$

We choose 4-tapped, 5-level Daubechies' Wavelet.

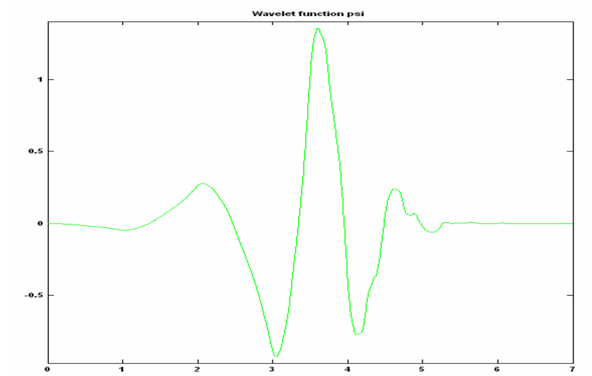

Fig. 5 Daubechies mother wavelet $\psi(t)$.

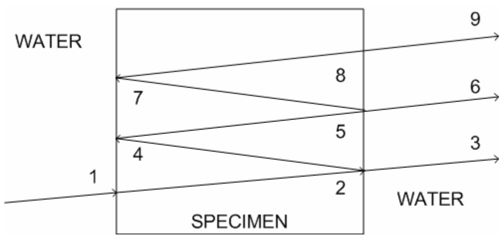

Fig. 6 Reflection and transmission of ultrasonic waves.

The test specimen is in a cistern filled with water. Pulser and receiver are attached on the surface of a wall inside the cistern. Pulser generates ultrasonic wave and the system gathers echo wave. And it transfers waveform data to PC for simulation. The performance of the algorithm is tested on a PC using MATLAB software routines.

Ultrasonic pulse sent from the pulser travels different paths in fig. 6 to the receiver. Using the designed system, we obtained the ultrasonic echo waveform. The sampling rate is 50MHz and the resolution has 8-bits quantization levels.

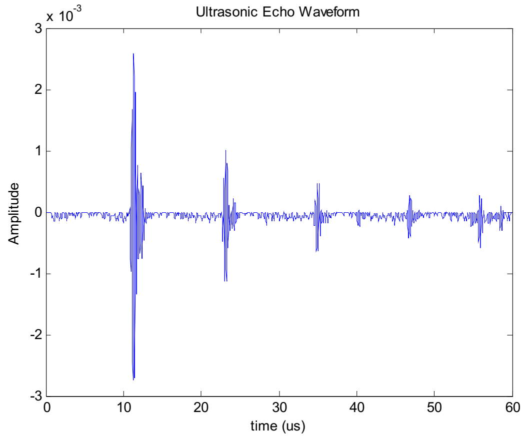

Fig. 7 Echo waveform $f(t)$.

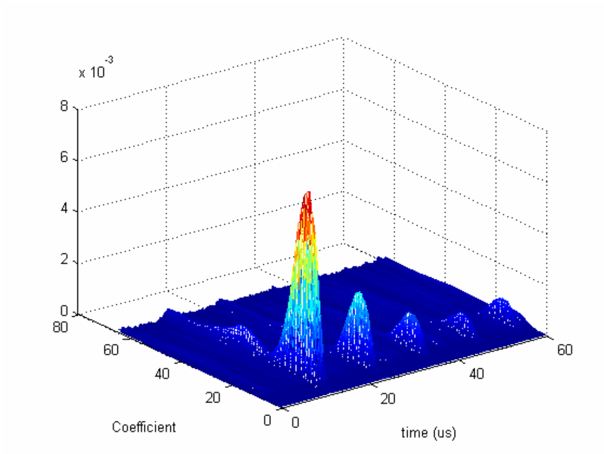

Fig. 8 3D plot of the wavelet transform of Echo waveform.

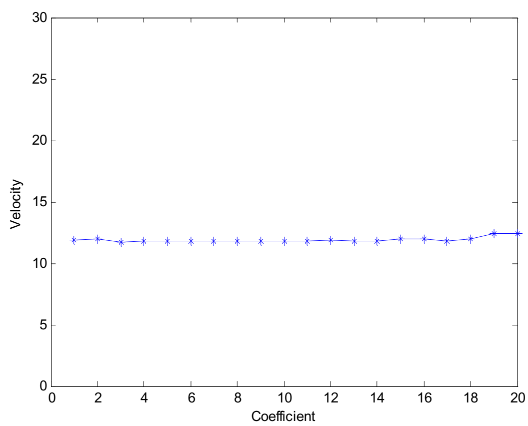

Fig. 9 Group velocity.

The known length of the specimen and the time between the first and the second local maxima point of the transformed echo waveform in fig. 8 are used for calculation of the velocity of the waveform. The group delays versus each frequency are given in fig. 9.

For measurement of the precise attenuation coefficients and their frequency dependence, it is needed to calculate the attenuation coefficients with each frequency component. Each peak time of the echo pulse in fig. 8 and its amplitude are used to calculate the group velocity as varying frequency. The result given in fig. 10.

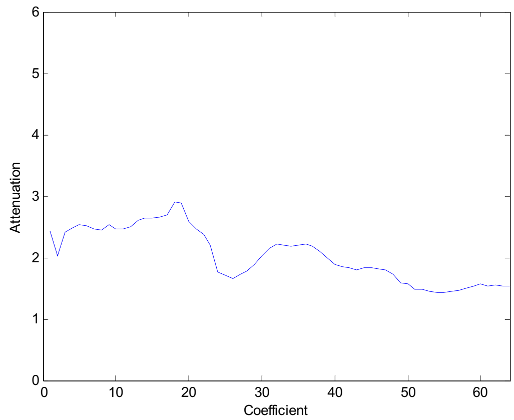

Fig. 10 Attenuation coefficient.

The algorithm is implemented on the system. And the parameters (group velocity and attenuation coefficient) measured by the system is similar to the simulation results

4. CONCLUSION

An onboard measurement system of ultrasonic velocity and attenuation using the wavelet transform was presented. Although we had simulation of the algorithm and tested with a real specimen, it is necessary that many test are needed on various specimen. The group velocity and the attenuation coefficient are different with the condition of metal specimen. Furthermore, though we adopted the Daubechies mother wavelet, it is important to find proper mother wavelet. And then we expect that the system can be useful instrument in many nondestructive testing applications.

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