WAVELET ANALYSIS BASED ULTRASONIC NONDESTRUCTIVE TESTING OF POLYMER BONDED EXPLOSIVE

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Abstract: Polymer Bonded Explosives (PBX) are well-known explosives for the weapons, especially for the parts of some important weapon. Generally, they first are modelled in cylinder. One of the most important issues in PBX cylinder properties is the detection of its flaw. Each PBX cylinder may have flaws that influence the security, machine-performance and other important physical or chemical performance. Its detection can be made by ultrasonic testing techniques. The ultrasonic (US) testing is based on the fact that the ultrasonic wave is able to distinguish different acoustic impedances when there is the different medium inside the cylinder. The special purpose sensors ranging from 1.25MHz to 5MHz were used to emit/receive the ultrasonic signals. When the US pulse wave propagates from the first surface in the PBX, part of the pulse is propagated back to the transducer owed to the flaw interface. The other part of US pulse wave goes forward and reaches the next surface, this signal eventually goes back to the transducer. These signals containing the flaw information are recorded for analysis. Based on processing the signals by means of the wavelet transform, we can distinguish the flaw with the frequency change of flaw echo and verify the central frequency of the transducer, obtain the accurate part frequency of the signals with which is concerned, and also accurately measure the signal absolute value (amplitude) depending on the effective frequency. The accuracy obtained will encourage its implementation for nondestructive testing of the PBX's flaw.

Introduction: Polymer bonded explosives (PBXs) are the main charge explosives used in nuclear warheads and they are designed to detonate reliably to bring about nuclear implosion. PBXs are highly filled composite materials of crystalline high explosive in a polymeric binder matrix. Generally, they first are molded in cylinder or other shapes. The polymer binder provides structural integrity and mechanical strength. One of the most important issues in PBXs' cylinder properties is the detection of its flaw. The facts implicate that defects (or change of the location density) or flaws in PBX's cylinder will affect its security, machine-performance and other important physical performances. Its detection can be made by ultrasonic testing techniques [1]. This work presents an ultrasonic pulse-echo method based on wavelet analysis, which is developed for determining possible defects or flaws in each JOB-9003 PBX's cylinder or others.

Ultrasonic Methodology Based on Wavelet Analysis: The ultrasonic pulse-echo technique is based on the fact that the ultrasonic wave is able to distinguish different acoustic impedances when there is the different medium inside the JOB-9003 explosive cylinder. When the US pulse wave propagates from the first surface in the JOB-9003 cylinder, part of the pulse is back propagated to the transducer owed to the flaw interface, the other part of US pulse wave goes forward and reaches the next surface, this signal eventually goes back to the transducer. These signals containing the flaw information are recorded for analysis. The utilization of wavelet transform (WT) is widespread and an attractive signal processing technique for nondestructive evaluation of material characterization. The WT has already been shown as a useful tool for the interpretation and the enhancement of ultrasonic data [2,3,4]. In this paper, the WT theory is briefly introduced and its application to ultrasonic testing (UT) of JOB-9003 cylinder is explained. The continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function $\Psi(t)$. Scaling a wavelet simply means stretching (or compressing) it, shifting a wavelet means delaying (or hastening) its onset. The CWT or continuous-time wavelet transform of function $S(t)$ with respect to a wavelet $\Psi(t)$ is defined as follows[5]:

$$S(a,b)=\int_{-\infty}^{+\infty} f(t)\,\bar{\psi}_{a,b}(t)\,dt \tag{1}$$

$$\psi_{a,b}(t)=\frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right),\ a>0 \tag{2}$$

Where a and b are real and the overline denotes complex conjugating. The function *Ψ(t)* is called the analyzing wavelet. It satisfies the admissibility condition on *Ψ(t)*:

$$\int_{-\infty}^{+\infty}\frac{|\hat{\varphi}(\omega)|^2}{|\omega|}d\omega<\infty \tag{3}$$

where $\hat{\varphi}(\omega)$ denotes the Fourier transform. $\hat{\varphi}(\omega)$ defined by:

$$\hat{f}(\omega)=\int_{-\infty}^{+\infty} f(t)e^{-i\omega t}dt \tag{4}$$

Although there are many choices for analyzing wavelet, we adopt the Discrete Wavelet Transform (DWT) from the CWT for signal de-noising, and adopt Gabor function for application to UT, since Gabor function provides the best time frequency resolution. The Gabor wavelet is expressed as:

$$\psi_g(t)=\frac{1}{\sqrt[4]{\pi}}\sqrt{\frac{\omega_0}{\gamma}}\exp\left[-\frac{1}{2}\left(\frac{\omega_0 t}{\gamma}\right)^2\right]\exp(i\omega_0 t) \tag{5}$$

And its Fourier transform is expressed as:

$$\psi_g(\omega)=\frac{\sqrt{2\pi}}{\sqrt[4]{\pi}}\sqrt{\frac{\gamma}{\omega_0}}\exp\left[-\frac{1}{2}\left(\frac{\omega_0 t}{\gamma}\right)^2(\omega-\omega_0)^2\right] \tag{6}$$

Where ω_0 and γ are positive constants.

Experimental: A schema of the experimental setup is shown in Fig.1. The JOB-9003 explosives are modelled in cylinder, which depth is about 80mm. The series of commercial type contact longitude wave transducers from 1.25MHz to 5MHz, along with a ultrasonic flaw detector are used to generate and receive the ultrasonic signals. The analog signal was digitized using a PC4120 digital card with a sampling rate of 40MHz. The numerical simulations were performed using the Pentium-4 computer and MATLAB software routines. For each specimen, several measurements were made with the coupling condition during each measurement. The typical ultrasonic flaw echo waveforms are shown in Fig.2. The maximum ultrasonic flaw signal is acquired through the nearest access. We can see that the noise level of signals becomes higher, accompanied with the enhancement of transducer frequency. In order to manifest the reliability of ultrasonic testing, the explosive cylinder was split into some parts. The result of flaws in JOB-9003 explosive cylinder is shown in Fig.3.

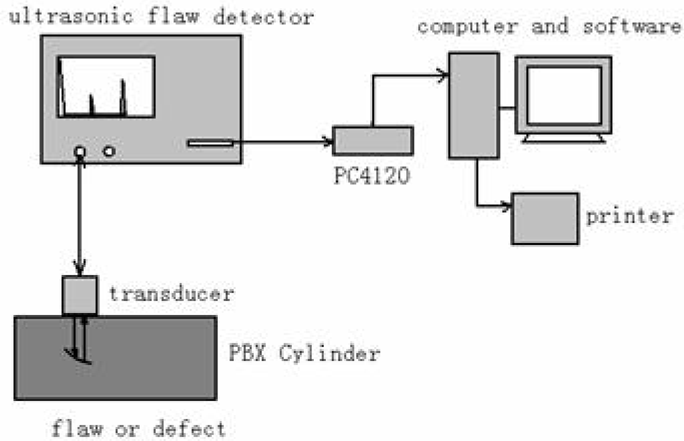
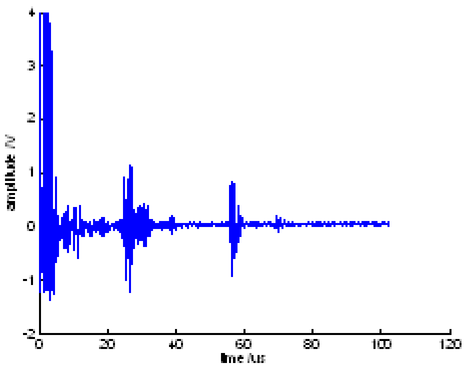
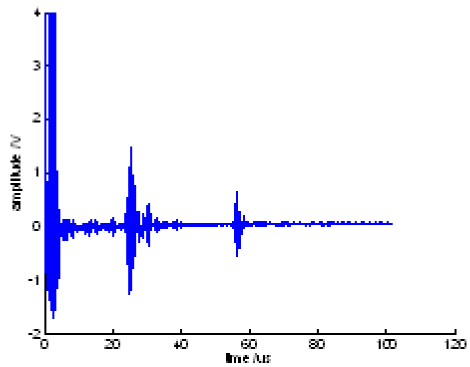


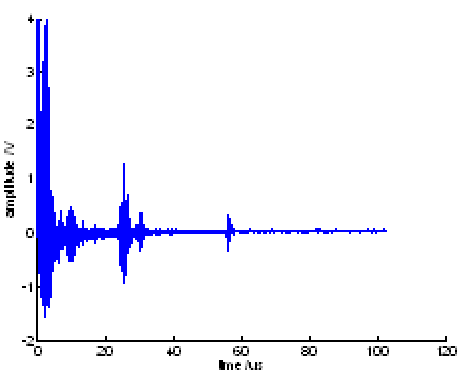
Fig.1 A schema of the experimental setup



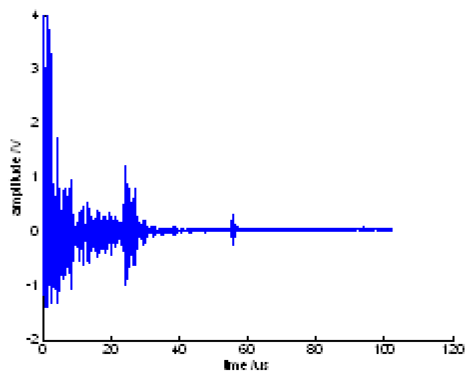
(a) 1.25MHz transducer



(b) 2.00MHz transducer



(c) 2.50MHz transducer



(d) 5.00MHz transducer

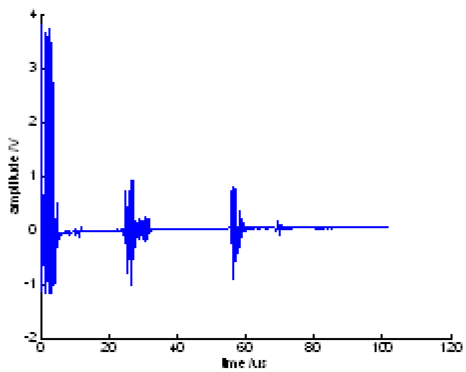
Fig.2 Ultrasonic waveforms of JOB-9003 explosive cylinder

(a) large flaw

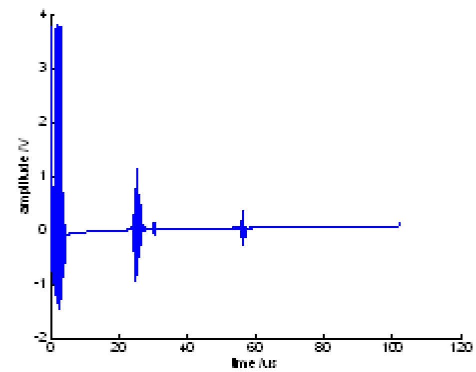
(b) small flaw

Fig. 3 The manifested result of the flaw in JOB-9003 explosive cylinder

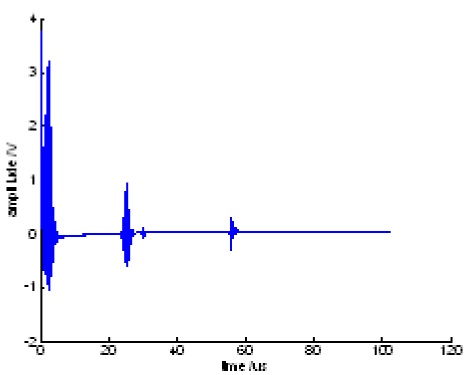
Signal Processing and Application: De-noising of signals is extremely important in ultrasonic flaw detection, as to correctly identifying smaller defects in PBX cylinder. If the amplitude of the signal from the defect is below the detection threshold, the defect will not be found. We must increase the probability of detection without altering or increasing the probability of false call by processing of the signals. Fig.4 shows the results of de-noising of ultrasonic flaw signal using the WT obtained from JOB-9003 explosive cylinder. The signal-to-noise ratio of ultrasonic waveforms containing flaw echo was effectively enhanced. Experimental results show that the WT can suppress noise of ultrasonic flaw signals and to enhance the flaw detection ability for JOB-9003 explosive cylinder.



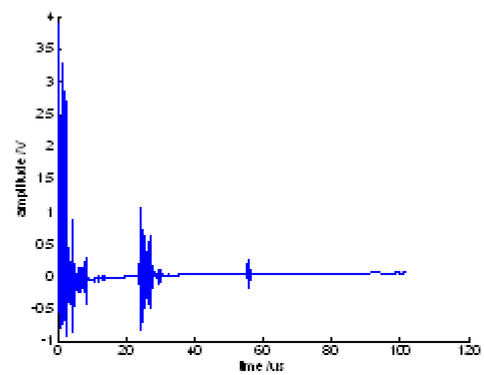
(a) 1.25MHz transducer



(b) 2.00MHz transducer



(c) 2.50MHz transducer



(d) 5.00MHz transducer

Fig.4 The results of de-noising of ultrasonic flaw signal using the WT

For these years, the WT has also applied to the time-frequency analysis of ultrasonic echo waveform [6]. The Gabor function is adopted in analyzing wavelet. Fig.5 shows the energy spectral density and the time-frequency distribution of the magnitude of the WT and its contour plot. Contour plot of the WT in Fig.5 represents the time-scale representation of the signal in Fig.2. The result of 1.25MHz transducer is shown. The frequency of ultrasonic pulse-echo reflected by the flaw, which compares with the central frequency of the transducer and ones by next surface reflected, is shown in Fig.6. From Fig.5 and Fig.6, we can see that the frequency of ultrasonic pulse-echo reflected by the flaw differed from the central frequency of the transducer, and it is nearly equal to the central frequency of ultrasonic pulse-echo reflected by the next surface. The results reveal that we can distinguish the flaw with the frequency change of flaw echo and verified the central frequency of the transducer. We also can obtain the accurate part frequency of the signals with which are concerned.

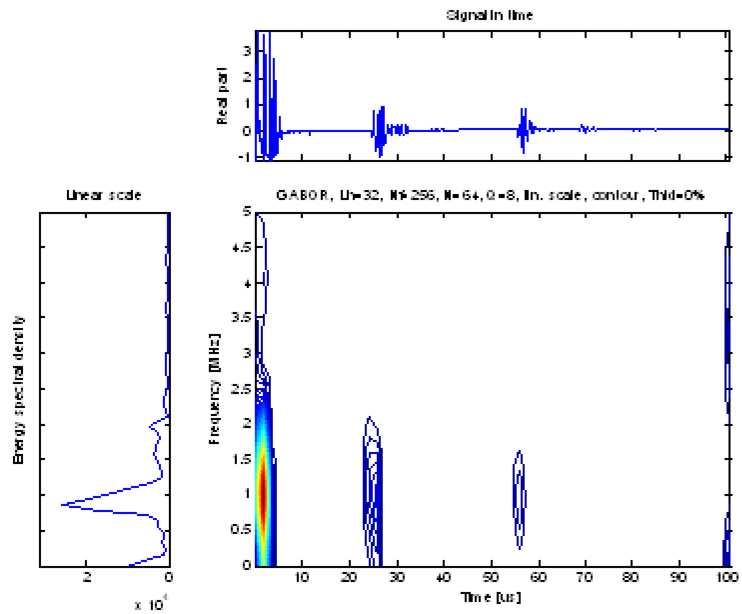


Fig.5 The energy spectral density and the time-frequency distribution of the ultrasonic signal

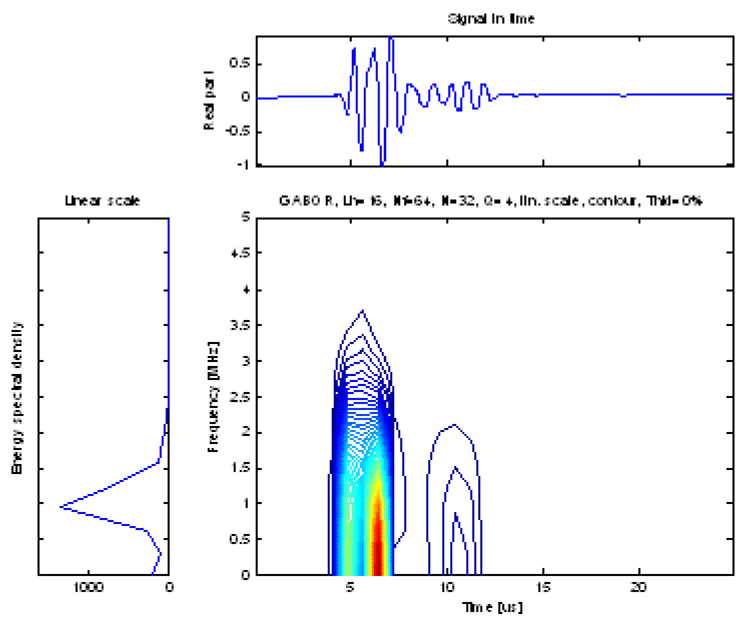


Fig.6 The accurate frequency of ultrasonic pulse echo reflected by flaw

Additionally, We can accurately measure the signal absolute value (amplitude) depending on the effective frequency using WT with the signals from testing other explosive cylinder like TNT explosive, the results are showed in Fig.7. The result can provide the gist to choice match frequency for detection defect in PBX cylinder.

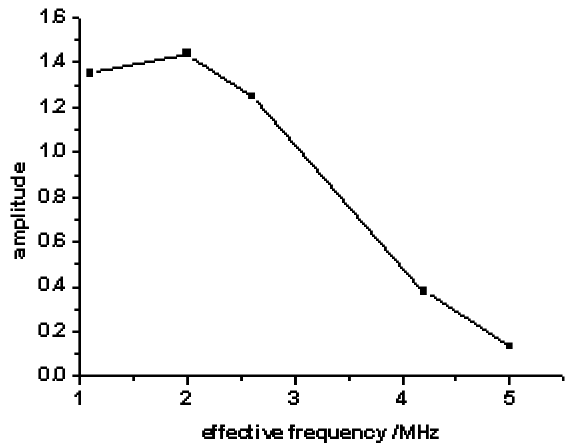


Fig.7 The absolute signal value (amplitude) depending on the effective frequency

Conclusions: The reliability of noise suppression of ultrasonic flaw signal and UT of PBXs cylinder using wavelet analysis of ultrasonic echo waveform has been verified experimentally. Based on the WT, we can distinguish the flaw with the frequency change of flaw echo and verify the central frequency of the transducer, obtain the accurate part frequency of the signals with which is concerned, and also accurately measure the signal absolute value (amplitude) depending on the effective frequency. The accuracy obtained will encourage its implementation for nondestructive testing of PBXs' flaw.

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