Measuring The Acoustical Properties of Fluids and Solid Materials Via Dealing With A-SCAN (GAMPT) Ultrasonic

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Abstract. This article displays a general overview about the measurements of acoustical properties (speed of sound and attenuation) for both the fluids and solid materials via dealing with A-scan or A-mode GAMPT mbH ultrasound technique (ultrasound transmission and reception). In addition, measuring the thickness of protective layer of the probe and its influence on the speed of sound and attenuation of fluids and solids materials by applying the Pulse Echo ultrasound speed method and its formula. However, this method used to measure the distilled water and Doppler dummy fluid as a liquid items and acrylic plate with different sizes as solid materials. The outcomes resulted from the study were the speed of sound and attenuation measurements of both the fluids and solid materials via dealing with A-scan GAMPT mbH ultrasound technique were suitable. Furthermore, the protective layer thickness of the probe was influenced on the speed of sound measurements. So, we can remove the influence of inaccuracy by knowing the protective layer thickness and this way can increase the precise in ultrasonic speed.

1. Introduction

The fixing of the acoustical properties of fluids and solid materials is fundamental for medical process innovation. For instance, measuring the acoustical properties of blood or blood mimicking fluids (BMF) and its components. Also, measuring the acoustical properties of tissue mimicking material (TMM) as a solid material [1]. Theoretically, fluids and solids content can be measured by applying the analysis test of the ultrasonic features of the materials. The interaction of fluids or solids with ultrasonic wave alters the speed of the ultrasonic wave because of the reflection and absorption which occurs during this interaction. This alteration was studied and searched to measure the acoustical properties of fluids and solids. Studies on the relationship between pulse echo ultrasonic speed and fluids like BMF and solids like TMM have been carried out [2-7].

Generally, measurement of liquids and solids applying ultrasound method is done via the Amplitude modification analysis (A-mode). In A-scan, determination of ultrasound speed in materials can be done by Pulse Echo (PE) mode of ultrasound traveling mode. The ultrasonic speed of item is known as the proportion of the distance propagated by the ultrasound signal and the time of traveling
that is also called the time of flight (TOF). The equation that is used to measure the ultrasound speed for pulse echo (PE) represented is

$$SS = \frac{2xt}{t}$$  \hspace{1cm} (1)

Where SS indicates the ultrasonic speed, L is the travel distance of ultrasonic wave of the sample, while t represents the time of flight. The digit 2 is two times of echo go and return during the sample.

Typically, the precision of acoustical measurement applying ultrasonic speed rely on two main factors; the method and equipment of ultrasonic features. Ultrasonic wave propagates or travels two times in distance for pulse echo (PE) mode. Because of the much longer distance, the influence of both the refraction and reflection of the ultrasonic signal pulse is more important for PE [8].

Ultrasound probe made of piezoelectric crystal layer and then protective layer above the piezoelectric crystal layer as a coating layer to protect it. The presence of the protective layer increases attention on its influence during the determination of ultrasonic speed. The influence of the protective layer on ultrasonic speed measurements has been debated by Konrad W. Nowak [9] in his research on ultrasonic speed measurement way. The ultrasonic signal wave will be generated then travel within the protective layer of the probe before going to the medium or region of interest (experiment specimen). The protective layer of the probe with a constant thickness will produce the overvaluation of the present time of flight (TOF) measurement with fixed time delay [10, 11]. For precise ultrasonic speeds measurement, the influence of the protective layer must be completely removed through the measurement.

2. Materials and Methods

The initial researches were done by applying two acrylics plate structure with thickness or depth of 40 and 80 mm respectively and speed of sound 2700 m/s. The acrylic plate which utilized in this experiment was a homogeneous material. In addition, both the distilled water and Doppler dummy fluid were tested and examined their acoustical properties.

2.1 Handled and Processed Ultrasonic Pulse Echo (Preliminary Experimental Set-Up)

The echoscope and its parts were prepared. Then, the echoscope has been connected to the PC and switched on. The front panel of the device was controlled and examined. Echoscope supplied the electrical signal to send and receive ultrasound echo pulses. To begin with, reflection transducer plug connected with 1-5 MHz (red transducer) with 2.7 cm diameter. The centre frequency of this probe is 2 MHz. The knob which is responsible for reflection pulse in the device switched on to "Reflection" not "Transmission" mode, which authorizes the sonar ranging mode (Pulse echo). In the pulse echo (A-Scan) mode, the same probe sends brief or concise ultrasound pulses and then works as a receiver to discover the reflecting or returning echo signal. The amplification of transmission and receiving can be set. A low value of transmitter power was chosen, and the receiver amplifier power was increased until the highest signal peak amplitude, which is about 80% of maximum scale.

2.2 Ultrasonic Transducer (probes) used in Ultrasonic GAMPT Scan

The ultrasonic transducers used in this research was red colour transducers with frequency 1-5 MHz Figure 1. The ultrasonic transducers were coupled with powerful snap-in-connectors. The frequency of the transducer is automatically known from the appliance. With the assistance of the adjustable sending and receiving power, it can appropriate the ultrasound signal to almost each arbitrary realization object [12].
2.3 Measure the Velocity (Speed) of Sound and Protective Layer Thickness of the Probe

The typical formula for determining the speed of ultrasound using pulse echo (PE) method was displayed in equation 1. Thus, the speed of ultrasound can be measured by using PE method, by measuring the time of flight (TOF) between the highest two following peaks (peak to peak) of transmitted and received wave and then use the depth or distance of the sample. In addition, the speed of ultrasound can be measured by measuring the time of flight (TOF) between two identical peak signal pulses. Furthermore, the average measurements between the highest two following peaks and two identical peak signal pulses of transmitted and received wave were taken in account. However, the protective layer of the transducer can affect the TOF, because the measured value of TOF does not just point to the travelled time of ultrasound signal wave in the specimen, but it also represents the travelled time in the protective layer of transducer [13].

For good precision of ultrasonic speed measurement, protective layer thickness should be measured first by following the Equation 2. To measure the thickness of transducer protective layer, we have used two similar homogeneous acrylic transparent plates with a thickness of 40mm and 80mm. To correct the A-scan system before measuring the acoustic properties of fluid samples and solids, the speed of sound and attenuation in distilled water and in Doppler dummy fluid in our experimental setup system was measured. To measure the velocity of sound of distilled water without the thickness of the protective layer by applying Equation 1. Moreover, for measuring the velocity of sound of distilled water with thickness of protective layer by applying Equation 3.

\[ SS = \frac{2x}{t} \]  
\[ d_{pl} = \frac{t_1 da_2 - da_1}{2(t_1 - t_2)} \]  
\[ SS = \frac{2(l + dpl)}{t} \]

Where \( l \) is sample thickness or distance, \( d_{pl} \) is the thickness of transducer protective layer, \( da_1 \) is the thickness of acrylic plate (40mm), \( da_2 \) is the thickness of acrylic plate (80mm), \( t_1 \) is the time of flight of acrylic plate (40mm) and \( t_2 \) is the time of flight of acrylic plate (80mm).

For measuring the protective layer thickness of the probe, two acrylic plates have been used. Because the ultrasonic probe was used as an emitting and receiving at the same time, so, it was placed above the 40 and 80 mm of the acrylic plate. TOF for both two acrylic plates were registered. By applying Equation 2., the thickness of probe protective layer (\( d_{pl} \)) was measured and the calculated value of the thickness of the protective layer was 0.515 mm.

For attenuation measurements, the frequency-based attenuation of the individual signal was measured by proceeding a Fast Fourier Transform (FFT) on the radio frequency (RF) signal from the reflector. Attenuation unit in dB, it was calculated by the natural log (In) difference between the signal waves by using Equation 4. After knowing the speed of sound of the sample, inserting the value in pulse-
echo techniques (A-scan system) to calculate the attenuation coefficient of the sample (distilled water) by the following equation:

\[ \alpha = \frac{1}{x_1-x_2} \ln \frac{A_2}{A_1} \]  

(4)

Where \( \alpha \) is the attenuation coefficient of sample, \( x_1 \) and \( x_2 \) is the difference in distance or depth of sample in mm, \( A_1 \) is the power signal amplitude at frequency \( f \) and \( x, y \) position of (reference signal) with no presence sample (amplitude of transmitted signal wave), \( A_2 \) is the power signal amplitude at frequency \( f \) and \( x, y \) position through the sample (amplitude of received signal wave).

3. Results and Discussion

From the initial study, the overall calculated value of the protective layer thickness is 1.03 mm, because the ultrasonic signal wave travelled two times into the protective layer (go and return), thus the half distance was wrapped by the ultrasonic wave signal in the protective layer was 0.515 mm. In addition, the speed of sound measurements that resulted of TOF by using PE method between the average highest two following peaks of transmitted and received wave were the same speed of sound measurements that resulted of TOF between the average identical or similar peaks. See Figures 1. and 2. Furthermore, the protective layer thickness of this probe in our research study (0.512 mm) different from protective layer thickness of previous literature review which was around (0.57 mm) [13]. Thus, the protective layer thickness of each probe should be measured. Moreover, in this research study, we found that the effectiveness of the protective layer thickness of the probe can be removed by measuring the two-similar material but difference in the thickness.

Figure 3(a). Transmission and reflection wavelength of distilled water at temperature 37±0.8°C for measurement of TOF by using PE method between the highest two following peaks of transmitted and received wave.
The speed sound in distilled water was measured in water tank container with using of ultrasonic echoscope. The ultrasonic transducer was fixed on the middle region of the water tank (Plexiglas) with using ultrasonic gel or directly above the sample without using ultrasonic gel. The transmitted signal wave is reflected due to the inhomogeneities of sound impedance and compressibility in water or fluids in general. Then, the reflected signal wave was discovered by the same transducer. Since the distance (d) (depth) of sample (water tank container) and the time of flight also measured, the longitudinal speed of sound can be measured by following Equation 1. using PE methods between the highest two following peaks of transmitted and received wave or by using the distance of the sample between two identical signal pulses. The water had been measured initially before the velocity of sound of mixture samples was measured. Firstly, we have measured speed of sound in water without taking into consider the protective layer thickness of the probe. The result was 1474 m/s without the protective layer thickness and 1508m/s with the thickness of the protective layer, and the difference is 34 m/s (see Figs. 1 and 2). From this result we can notice that the protective layer of the probe can affect the speed of sound result for the samples. However, the calculated value of the thickness of the protective layer is 0.515 mm. Because the ultrasonic signal wave propagates two times in the protective layer of the probe, the overall distance wrapped by the ultrasonic signal wave in the protective layer is 1.03 mm. Furthermore, the velocity of sound in Doppler dummy fluid measured in Plexiglas tank container with using of ultrasonic echoscope and using the same method of speed of sound measurement in distilled water. Thus, the velocity of sound was 1687 m/s without measuring the protective layer thickness of probe while it was 1810 m/s with measuring the protective layer thickness of probe, and the difference was 123 m/s. However, speed of sound measurement of distilled water and Doppler dummy fluid was repeated many times with adjusting temperature of mixture fluid to be like the human body temperature as much as possible, because the velocity of sound changes with temperature changes. In addition, the attenuation coefficient measurements changes with temperature changes. Thus, the acoustical properties in blood mimicking fluid were measured at temperature like the human body temperature.

From previous measurements of both distilled water and Doppler dummy we can note that the speed of sound measurements with measuring the thickness of the protective layer of probe are better than without the thickness of protective layer since the speed of sound in distilled water is1480 ±30 m/s [6]and in Doppler dummy fluid is 1800 ±30 m/s [14]. Moreover, in this research study, we found that the acoustical properties can be measured not only through the two identical signal waves, but between the two highest signal waves.

Figure 3(b). Transmission and reflection wavelength of distilled water at temperature 37±0.8°C. Measurement of distilled water ultrasonic speed using PE between two identical signal waves.
4. Conclusion
Results from the initial search study pointed out that we can measure the acoustical properties (speed of sound and attenuation) of both solid materials and liquids by dealing with A-scan GAMPT technique. As a conclusion, the acoustical features of the liquid and solid materials were corresponding to the standard values. In addition, we can measure the longitudinal speed of sound by using PE method, not only between the highest two following peaks of transmitted and received wave but also between two identical signal pulses. Furthermore, we can remove the influence of inaccuracy by knowing the protective layer thickness. Thus, we can increase the precise in ultrasonic speed.

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