2. Theory

An ultrasonic wave is an elastic mechanical wave that is irrelevant to the electric conductivity, magnetic property, thermal conductivity and optical property of a medium. It can propagate in any elastic material with the propagation behavior related to the elasticity of the material. If the material elasticity is altered, the propagation property of an ultrasonic wave in the material will be disturbed. Based on this information, the internal property of the material can be detected. For any materials that cannot be penetrated by other radiation energy, ultrasound has shown practicability. Compared with x-ray or gamma-ray, ultrasound does not offer higher penetration ability, but it is less harmful to the human body, so it has a broader range of applications.

Ultrasound can be generated by thermal, mechanical, static electric, electromagnetic, magnetic stretch, laser and piezoelectric methods. Among them, the most popular one is piezoelectric. On the contrary, using piezoelectric effect, ultrasonic energy can be transformed into electricity energy, which can be used for receiving ultrasonic waves.

Ultrasonic transducer: a device that transfers other forms of energy into ultrasonic waves. A common transducer used in analysis and measurement can emit and receive ultrasonic waves simultaneously, called reversible probe. Different types of probes are used in practice, such as straight probe, inclined probe, water immersion focusing probe, wheeled probe, mini surface wave probe, dual crystal chips probe and other combinations. The apparatus in this experiment uses a straight probe.

Classification of ultrasound: ultrasound can be classified into longitudinal waves or transversal waves in terms of vibration direction; or into plane waves or spherical waves in terms of wave front profile. It can also be classified into CW waves and pulse waves. The transducer used in this apparatus emits pulsed longitudinal plane waves at a frequency of 2.5 MHz.

Attenuation of ultrasound: when ultrasound propagates in media, its intensity will reduce over the distance traveled due to beam divergence and media absorption.

Reflection of ultrasound: if the acoustic impedance in media differs by a large amount, such as ultrasonic wave propagating at the interface of solid-air or liquid-air, total reflection occurs.

Display of ultrasonic echo signal: amplitude modulation (type A), brightness modulation (types B, C, M, P, and so on), and combinations of amplitude and brightness modulations. A-type display uses the amplitude of echo pulse to represent the reflection rate at interface (horizontal axis represents the depth of the object under test while vertical axis represents the amplitude of the echo signal). The scale of the horizontal axis is either time or distance, which represents the depth of the interface where echo occurs. This apparatus uses type-A display.

The biological effect, mechanical effect, thermal effect, chemical effect and other effects of the ultrasound can be harmful to human tissue. In general, the safe dose (intensity) of ultrasound on human body is under 100 mW/cm^2 while the ultrasonic intensity of the apparatus in this experiment is less than 10 mW/cm^2, so it is safe to use.

1) Medical type-A ultrasound

Medical type-A ultrasound analyzes the location and shape of a human tissue by displaying the echo signal based on the chronological sequence. This technique can be used to measure the position and thickness of intra-abdominal organs of human body and diagnose brain lesions. As shown in Figure 1, ultrasonic waves are emitted from a probe, and pass through the outer and inner surfaces of the abdominal cavity and the organ.

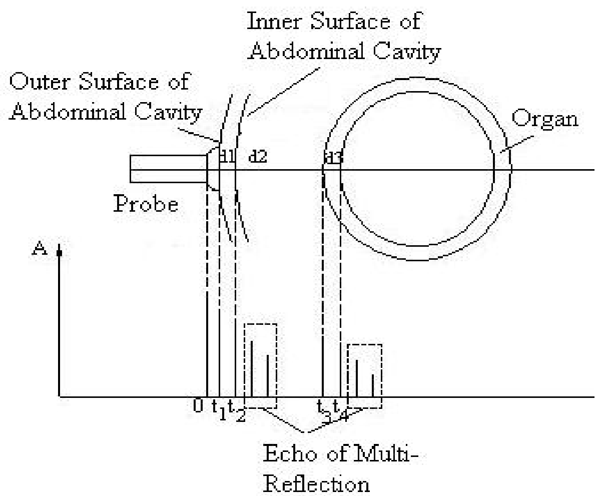

Figure 1 Schematic of type-A ultrasound diagnosis

If t is the time of the detected echo signal by the probe as displayed on the horizontal axis of an oscilloscope, u_1, u_2, and u_3 are the propagation velocities of the ultrasound in the abdominal wall, abdominal cavity and the organ, respectively, the thickness of the abdominal wall can be calculated as:

$$d_1 = u_1(t_2 - t_1)/2 \quad (1)$$

The distance between the organ and the inner surface of abdominal cavity is:

$$d_2 = u_2(t_3 - t_2)/2 \quad (2)$$

The thickness of the organ wall is:

$$d_3 = u_3(t_4 - t_3)/2 \quad (3)$$

2) Crack detection by means of ultrasonic pulse reflection

For a work piece with internal crack defect, the ultrasonic echo from the crack will differ from that from the bottom of the work piece, commonly known as defect echo as seen in Figure 2.

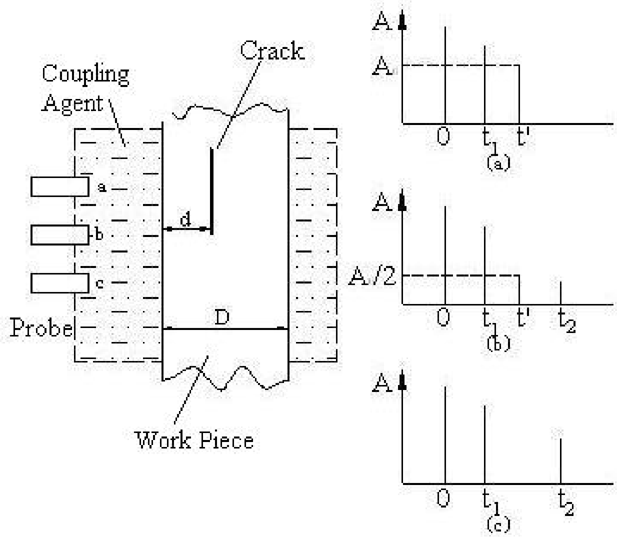

Figure 2 Principle of crack detection using ultrasonic pulse-echo technique

In Figure 2, (a), (b) and (c) represent the ultrasonic reflection at three different positions a, b and c, respectively. At position a, ultrasonic signal is fully reflected by the defect, leading to the highest amplitude A_0 of the echo signal; at position c, since there is no defect, ultrasound is totally reflected by the back surface of the work piece; at position b, ultrasound is reflected half by the defect and half by the back surface, resulting in a reduced amplitude ($A_0/2$) of the echo signal. Hence, position b is the edge of the defect. This method for determining defect border is called half-height method.

By measuring the thickness *D* of the work piece, and recording the time of the echo signals, t_1, t_2 and t', from the front and back surfaces of the work piece, and the defect, the depth and position of the defect can be determined by using the half-height method.

The timing resolution of the detection instrument is determined by the frequency characteristics of the ultrasonic probe and the property of the pulsed signal source. Generally speaking, the higher timing resolution the detection instrument is; the closer defects it can discriminate.

3. Structure and Working Principle

1) Structure of apparatus

The apparatus consists of a main unit, a digital oscilloscope (provided by user), a plastic water tank, and an accessory box (containing two sample holders, one horizontal rail, one horizontal slider, samples of aluminum, crown glass, and plastic glass in different heights, one resolution test sample, one work piece sample). Figure 3 shows a picture of the apparatus and Figure 4 is the schematic of the front panel of the main unit.

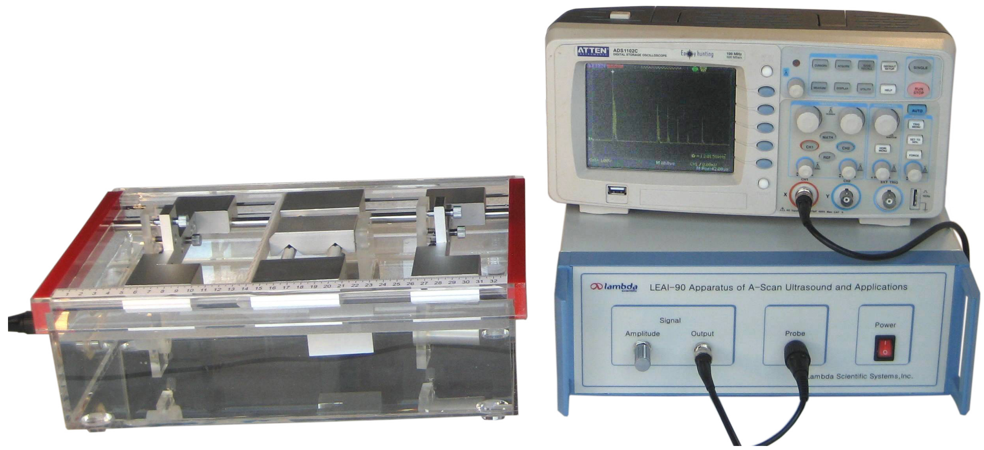

Figure 3 Photo of experimental apparatus

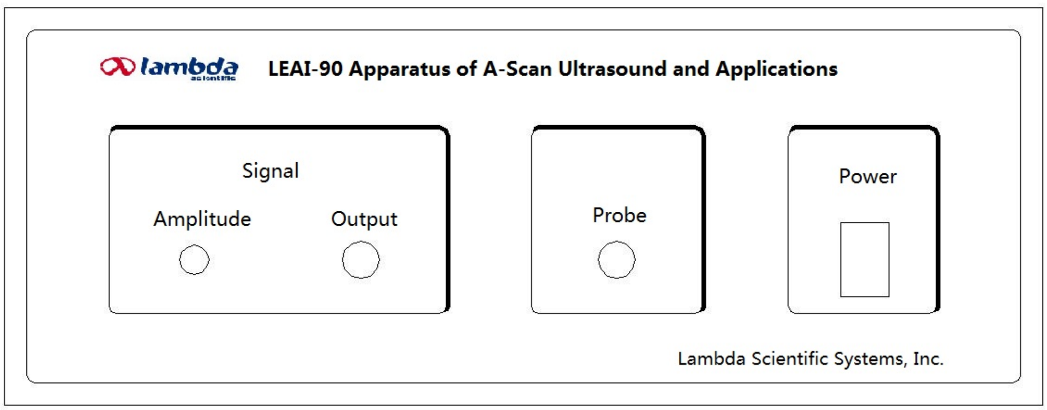

Figure 4 Front panel of main unit

2) Working principle of main machine

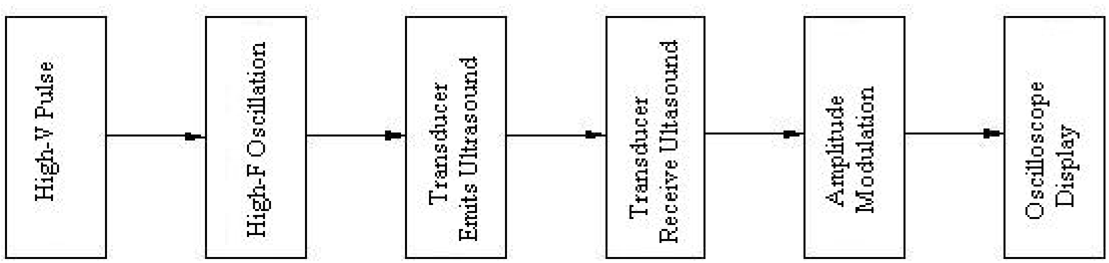

Figure 5 Block diagram of working principle

The transducer receives a high-speed high-voltage pulse from the system with pulse amplitude decreasing exponentially. The pulse serves two roles: one is used as the sampling signal input to the oscilloscope as the starting pulse; the other is used as the ultrasound vibration source to excite ultrasound with frequency at the resonant frequency (2.5 MHz). The ultrasound reflected first is received by the same probe and sent to the oscilloscope as the first echo after processing. There may exist the second time echo and multi-time echo depending on the media.