Ultrasonic Testing of Composite Structures

I. Introduction

This section of this work defines ultrasound basic concepts and Ultrasonic Technique. It describes the details of how ultrasonic testing works, the advantages and disadvantages of this nondestructive technique, and its applications. The future direction of ultrasonic testing will also be highlighted.

I.1. Ultrasound

Ultrasound is a cyclic sound pressure with a frequency greater than the upper limit of human hearing. Although this limit varies from person to person, it is approximately 20 kilohertz (20,000 hertz) in healthy, young adults and thus, 20 kHz serves as a useful lower limit in describing ultrasound. The production of ultrasound is used in many different fields, typically to penetrate a medium and measure the reflection signature or supply focused energy. The reflection signature can reveal details about the inner structure of the medium[1].

I.2. Ultrasonic Testing

In ultrasonic testing (UT), very short ultrasonic pulse-waves with center frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz are launched into materials to detect internal flaws or to characterize materials[2]. The technique is also commonly used to determine the thickness of the test object, for example, to monitor pipework corrosion. Ultrasonic testing is often performed on steel and other metals and alloys, though it can also be used on concrete, wood and composites, albeit with less resolution. It is a form of non-destructive testing used in many industries including aerospace, automotive and other transportation sectors.

If reflection and transmission at interfaces is followed through the component, only a small percentage of the original energy makes it back to the transducer, even when loss by attenuation is ignored. For example, consider an immersion inspection of a specimen. The sound energy leaves the transducer/receiver, travels through the water, encounters the front surface of the specimen, encounters the back surface of the specimen and reflects back through the front surface on its way back to the transducer/receiver. At the water specimen interface (front surface), 12% of the energy is transmitted. At the back surface, 88% of the 12% that made it through the front surface is reflected. This is 10.6% of the intensity of the initial incident wave. As the wave exits the part back through the front surface, only 12% of 10.6 or 1.3% of the original energy is transmitted back to the transducer/receiver[3]. Figure 1 is a representation of the process of reflections and transmissions of the sound energy.

Figure 2 displays a typical ultrasonic signal that shows the repetitive echo of sound energy received by the oscilloscope.

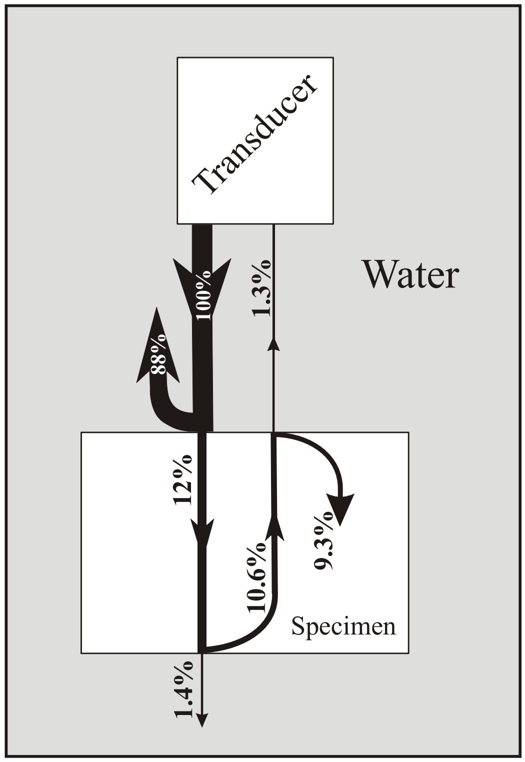


Figure 1. Sound Energy Reflection and Transmission

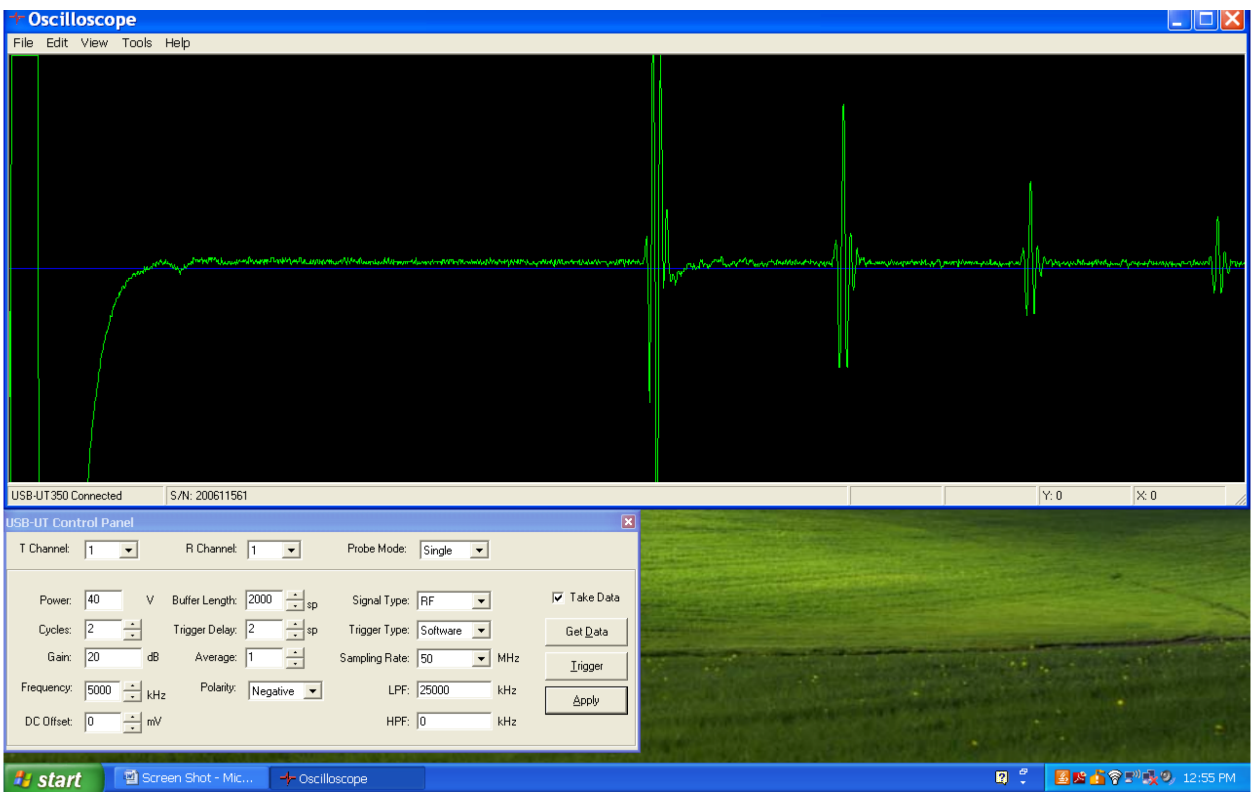


Figure 2. Typical Ultrasonic Signal

In ultrasonic testing, an ultrasound transducer connected to a diagnostic machine is passed over the object being inspected [4-10]. The transducer is typically separated from the test object by a couplant (such as oil) or by water, as in immersion testing. There are two methods of receiving the ultrasound waveform, reflection and attenuation. In reflection (or pulse-echo) mode, the transducer performs both the sending and the receiving of the pulsed waves as the "sound" is reflected back to the device. Reflected ultrasound comes from an interface, such as the back wall of the object or from an imperfection within the object. The diagnostic machine displays these results in the form of a signal with an amplitude representing the intensity of the reflection and the distance, representing the arrival time of the reflection. In attenuation (or through-transmission) mode, a transmitter sends ultrasound through one surface, and a separate receiver detects the amount that has reached it on another surface after traveling through the medium. Imperfections or other conditions in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. Using the couplant increases the efficiency of the process by reducing the losses in the ultrasonic wave energy due to separation between the surfaces.

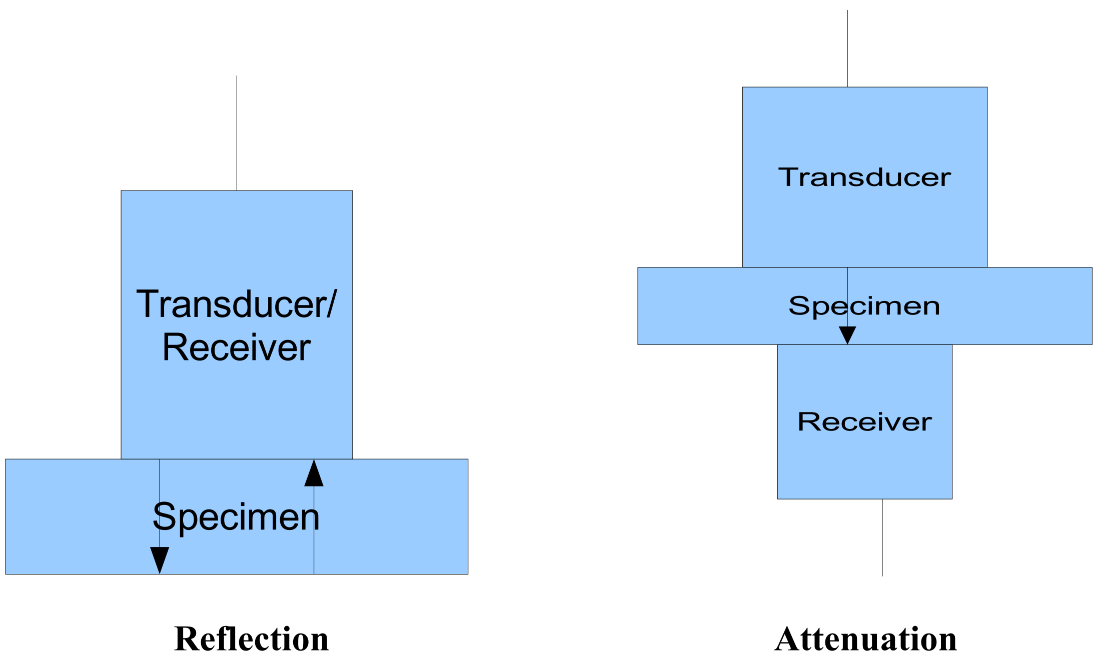


Figure 3. Typical Methods for Receiving the Ultrasound Waveform

I.3. Advantages and Disadvantages

Ultrasonic Technique has several advantages. Among these advantages are:

1. High penetrating power, which allows the detection of flaws deep in the part.
2. High sensitivity, permitting the detection of extremely small flaws.
3. Only one surface need be accessible.

4. Greater accuracy than other nondestructive methods in determining the depth of internal flaws and the thickness of parts with parallel surfaces.
5. Some capability of estimating the size, orientation, shape and nature of defects.
6. Nonhazardous to operations or to nearby personnel and has no effect on equipment and materials in the vicinity.
7. Capable of portable or highly automated operation.

On the other hand, the main disadvantages of the Ultrasonic Techniques are:

1. Manual operation requires careful attention by experienced technicians
2. Extensive technical knowledge is required for the development of inspection procedures.
3. Parts that are rough, irregular in shape, very small or thin, or not homogeneous are difficult to inspect.
4. Surface must be prepared by cleaning and removing loose scale, paint, etc., although paint that is properly bonded to a surface need not be removed.
5. Couplants are needed to provide effective transfer of ultrasonic wave energy between transducers and parts being inspected unless a non-contact technique is used. Non-contact techniques include Laser and Electro Magnetic Acoustic Transducers (EMAT).
6. Inspected items must be water resistant, when using water based couplants that do not contain rust inhibitors.

I.4. Ultrasonic Applications

Ultrasound has several different applications [11]. Among these applications are:

Scientific

Ultrasound in the scientific application is use to: measure the flow of fluid in fluid mechanics; generate tiny light bursts through a process known as sonoluminescence, which is being explored for its possible application in the chemical process of bubble fusion; accurately measure the distance of something for purposes of surveying, accurately aiming a given weapon, and helping determine focus in photography, a process known as SONAR(Sound Navigation and Ranging); cause or stir a chemical difference in a process known as cavitation i.e. the generation of vapor bubbles of a liquid that is flowing in an area where the liquid pressure drops beneath its vapor pressure, a process known as sonochemistry.

Industrial

Ultrasound in the industrial application is use to: produce heat through friction for use in welding of plastics; measure the thickness of products and objects and find flaws in different materials through non-invasive testing; facilitate heat transfer in liquids thus enhance the production of ethanol; enhance the health of animals and the production ability by determining intramuscular fats in cattle, fat in the eye area and generally the fat thickness; make items such as jewelry, watches, surgical instruments, dental instruments, industrial parts and diving regulators pure.

Medical

Ultrasound in the medical application is use to: stimulate the growth of bone; clean teeth during dental treatments; enhance the effectiveness of antibiotics in eradicating bacteria; aid in liposuction (process of body fat dismissal); stir the blood-brain barrier to make drug deliver effective; break down gallstones and kidney stones into fragments to make it easy for them to be flushed out of the body; conduct Cataract surgery (phacoemulsification), a process where the internal lens of the human eye is blended with an ultrasonic hand-piece and then aspirated out of the eye.

I.5. Future Trends

Looking to the future, those in the field of NDE see an exciting new set of opportunities. The defense and nuclear power industries have played a major role in the emergence of NDE. Increasing global competition has led to dramatic changes in product development and business cycles. At the same time, aging infrastructure, from roads to buildings and aircraft, present a new set of measurement and monitoring challenges for engineers as well as technicians[12].

Among the new applications of NDE spawned by these changes is the increased emphasis on the use of NDE to improve the productivity of manufacturing processes. Quantitative nondestructive evaluation (QNDE) both increases the amount of information about failure modes and the speed with which information can be obtained and facilitates the development of in-line measurements for process control.

The phrase, "you cannot inspect in quality, you must build it in," exemplifies the industry's focus on avoiding the formation of flaws. Nevertheless, manufacturing flaws will never be completely eliminated and material damage will continue to occur in-service so continual development of flaw detection and characterization techniques is necessary.

Advanced simulation tools that are designed for inspectability and their integration into quantitative strategies for life management will contribute to increase the number and types of engineering applications of NDE. With growth in engineering applications for NDE, there will be a need to expand the knowledge base of technicians performing the evaluations. Advanced simulation tools used in the design for inspectability may be used to provide technical students with a greater understanding of sound behavior in materials.

As globalization continues, companies will seek to develop, with ever increasing frequency, uniform international practices. In the area of NDE, this trend will drive the emphasis on standards, enhanced educational offerings, and simulations that can be communicated electronically. The coming years will be exciting as NDE will continue to emerge as a full-fledged engineering discipline.

II. Ultrasonic Testing

This section describes the use of the Ultrasonic Technique (UT) in determining thicknesses and detecting flaws. It also describes the UT equipment, testing procedures, equations, and calculations.

II.1. Ultrasonic Equipment:

The main components used in Ultrasonic Technique (UT) are composed of:

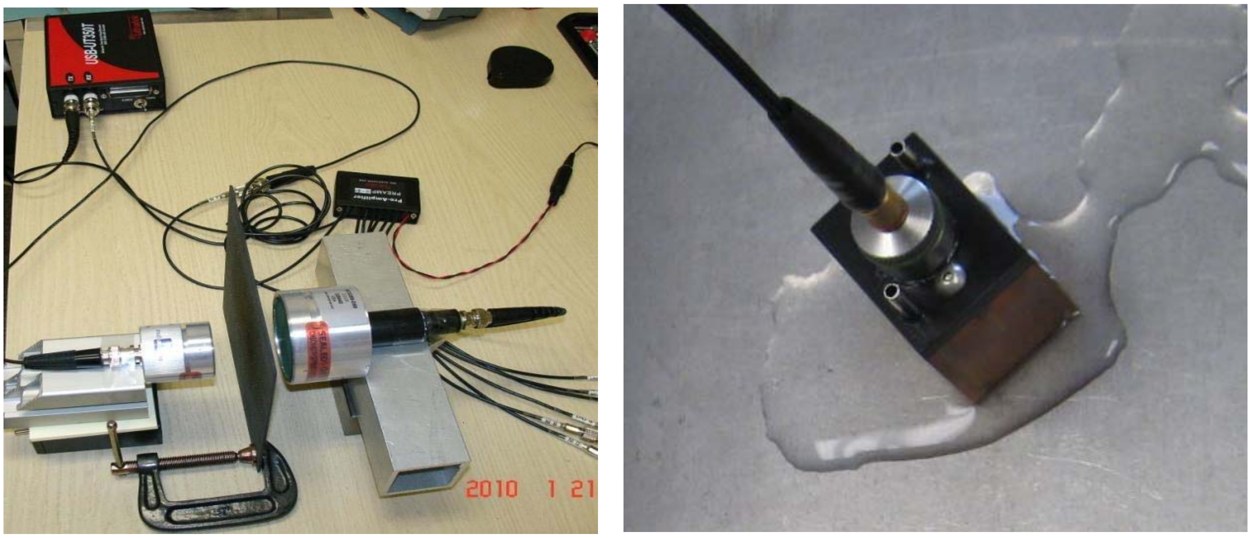
- Computer (Figure 4) equipped with UT driver and software for data recording and analysis

- Oscilloscope (Figure 2.) for viewing the signal that repeats itself or changes slowly over time.

- Ultrasonic Unit equipped with the electronics that are necessary for generating shorts bursts of sound energy (see the red box in Figure 4). Moreover, the instrument monitors and analyzes reflected or transmitted wave patterns to generate test results.

Figure 4. Ultrasonic Technique Setup

- Ultrasonic Transducers (Figure 5) for sending and receiving the reflected or transmitted wave patterns. These transducers are manufactured for a variety of applications and can be custom fabricated when necessary. Careful attention must be paid to selecting the proper transducer for the application. It is important to choose transducers that have the desired frequency, bandwidth, and focusing to optimize inspection capability.



(a) (b)

Figure 5. Ultrasonic Transducers for a) Noncontact Testing and b) Contact Testing

II.2. Testing Procedure:

The main testing procedures could be summarized in the following:

- Turn on the Laptop
- Turn on the Ultrasonic Unite. Please note that you must hear a beep sound when you turn on the unit.
- Connect the Ultrasonic unite with the laptop using the USB (Figure 4).
- Run the oscilloscope software that came with the device. On the USB-UT Control Panel, select the variables. The recommending setting for metals are (Figure 2):
    - Power : 40v
    - Cycles: 2
    - Gain: 15-25 db
    - Frequency: 5000 kHz
    - Buffer Length: 2500 sp
    - Average: 5
    - Polarity: Negative
    - Probe Mode: Single
    - Sampling Rate: 50 MHz

These setting will be changed based on the different thicknesses and materials.

- Determine the time to travel through the thickness (t). It should be noted that the horizontal length on the oscilloscope represents the sampling points based on the sampling rate. For example, if the sampling points between two peaks are 150 points, the time between the two peaks is the division of these sampling points by the sampling rate. This time is the travelling time of the signal from the surface to the bottom and coming back to the surface (i.e. this time represents twice the time to travel through the thickness). Hence, the time to travel through the thickness (t) = (½) (Sampling Points / Sampling rate)

  $t = (½) (150/ (50 \times 10^6)) = 150 \times 10^{-8}$ sec

- Save the data: a) go to Edit tab and press copy, b) click on File tab and save the data file in Excel format.
- Determine the values of the peaks from the saved data.

II.3. Theoretical Analysis:

The time required to travel through the thickness (t) is determined from the following relation:

$$\text{Time} = \frac{\text{Sampling Points } (X_2 - X_1)}{2 \text{ x Sampling Rate}}$$

$$t = \frac{\Delta N}{2f} \qquad (1)$$

where:

ΔN = the difference between the two peaks

f = sampling rate

The velocity of sound (V_c) can be calculated using the relationship below,

$$\text{Velocity of Sound} = \frac{\text{Thickness}}{\text{Time}}$$

$$V_c = \frac{\delta}{t} \qquad (2)$$

where:

δ=thickness (m)

t = Time (sec) (see equation 1)

It should be noted that, the thickness of an object could be determined from the following formula:

Thickness = Time x Velocity of Sound

$$\delta = t\, V_c \tag{3}$$

II.4. Testing and Calculations:

Different Ultrasonic testing has been performed to demonstrate how the system works and to determine different thicknesses. Samples made of aluminum are tested and evaluated.

a) Determining the Velocity of Sound in Aluminum

A specimen of 12.66 mm has been used to determine the velocity of sound. Experimental values for this experiment are shown below in Figures 6 and 7. From the experimental data, the sampling points are 198 and the sampling rate is 50 MHz. Using equation (1), the time (t) is:

$$t = \frac{198}{2 \text{ x } 50\text{x}10^{6}} = 198 \text{ x } 10^{-8} \text{ sec}$$

The velocity of sound in Aluminum is obtained from equation (2).

$$V_c = \frac{12.66 \text{ x } 10^{-3}}{198 \text{ x } 10^{-8}} = 6393.939 \text{ m/sec}$$

Once the velocity of sound is determined, any thickness made from the same material would be determined.

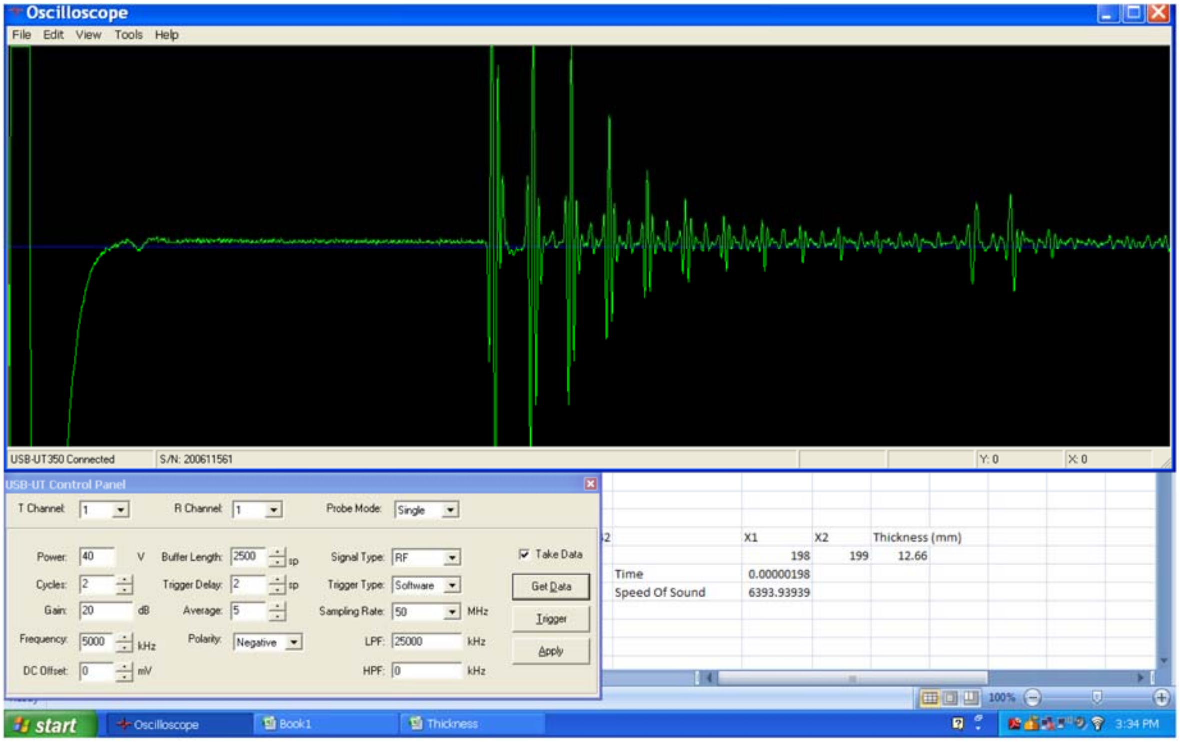


Figure 6. Screen shot of the signal

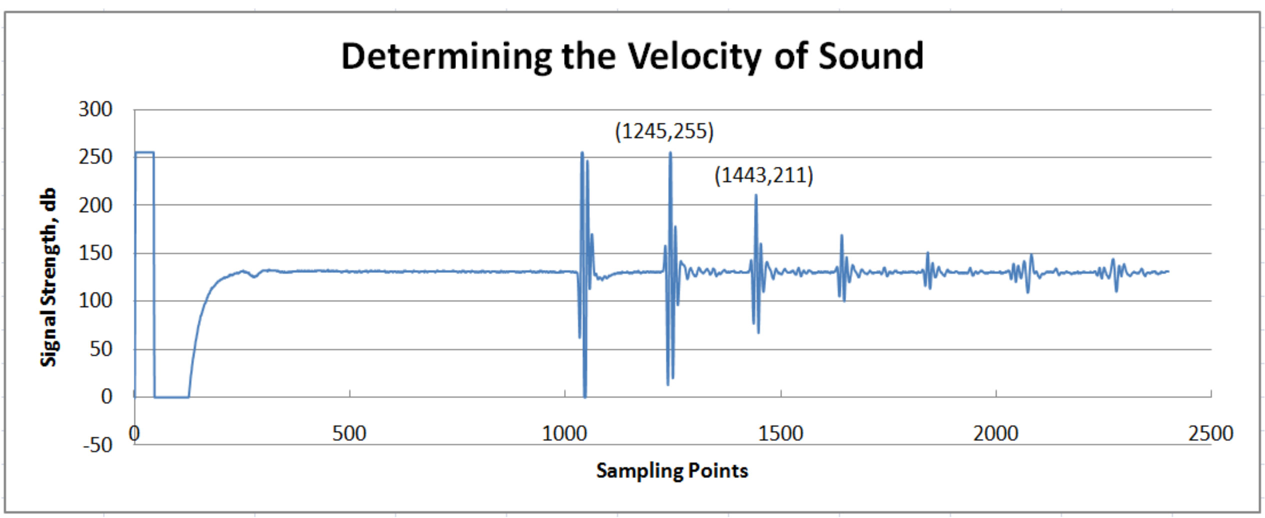
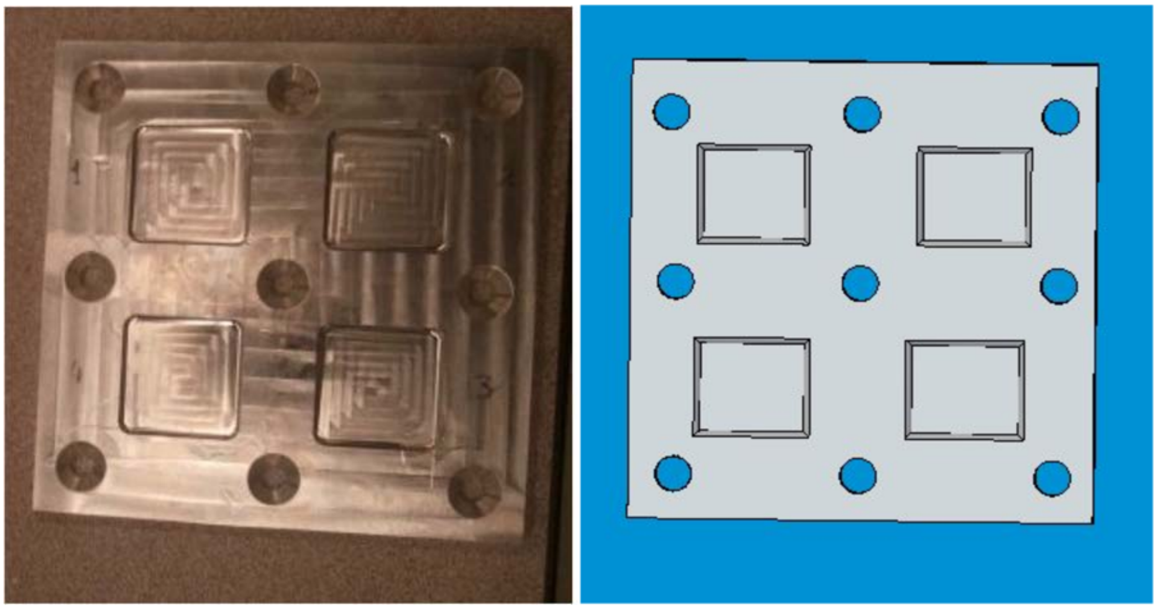


Figure 7. Sampling Data for the 12.66 mm Specimen

b) Determining Hidden Thicknesses

A test specimen made out of the same material, which is used to determine the velocity of sound in the previous section, Figure 8. The specimen has four sections that have been machined to four different thicknesses from one side. The machined side has been hidden and the ultrasonic Technique has been used to determine these hidden thicknesses. The transducer has been placed on the un-machined side and the data have been recorded and saved in Excel format.



Actual Aluminum specimen　　　　Solid Edge Aluminum specimen

Figure 8. Test Specimen with Different Thicknesses

Sample # 1

The data for sample #1 are presented in Figure 9. Two points were chosen from the excel data file. Using equation (1), we calculated the time.

$$t = \frac{1374-1292}{2*50*10^6} = 8.2 \text{ x } 10^{-7} \text{ sec}$$

Since the speed of sound is 6393.939 m/sec, then the thickness is calculated using equation (3).

$$\delta = t\, V_c = 8.2 \text{ x } 10^{-7} \text{x } 6393.939 = .005243\text{m or } 5.243 \text{ mm}$$

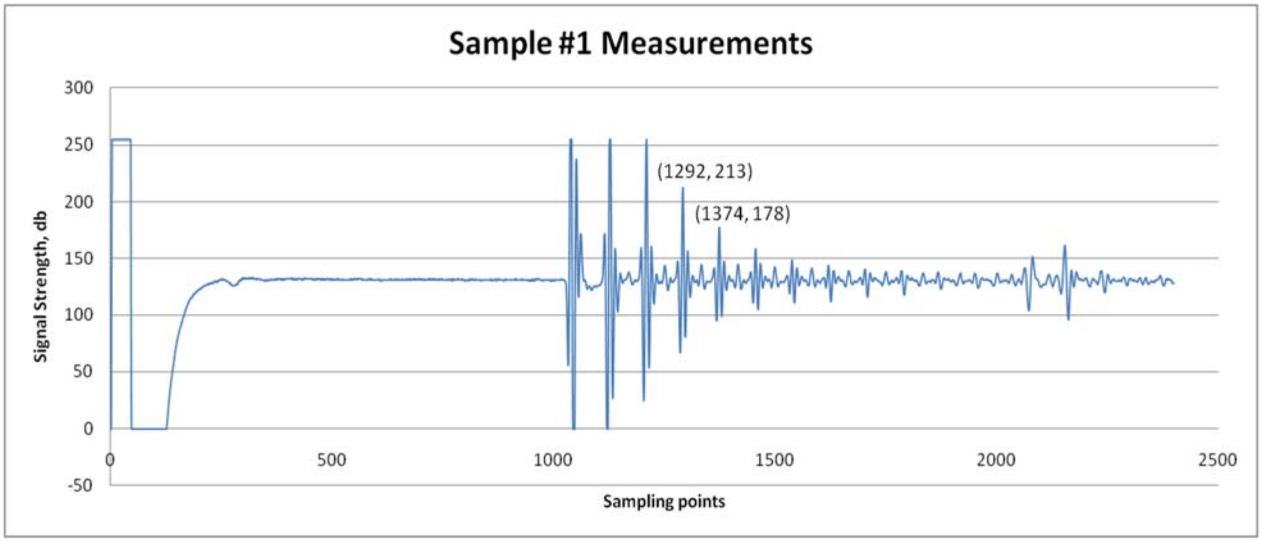


Figure 9. Test Data for Sample # 1

Sample # 2

The data for sample #2 are presented in Figure 10. Two points were chosen from the excel data file. Using equation (1), we calculated the time.

$$t = \frac{1311-1245}{2*50*10^6} = 6.6 \text{ x } 10^{-7} \text{ sec}$$

Since the speed of sound is 6393.939 m/sec, then the thickness is calculated using equation (3).

$$\delta = t V_c = 6.6 \text{ x } 10^{-7} \text{x } 6393.939 = .00422 \text{ m or } 4.22 \text{ mm}$$

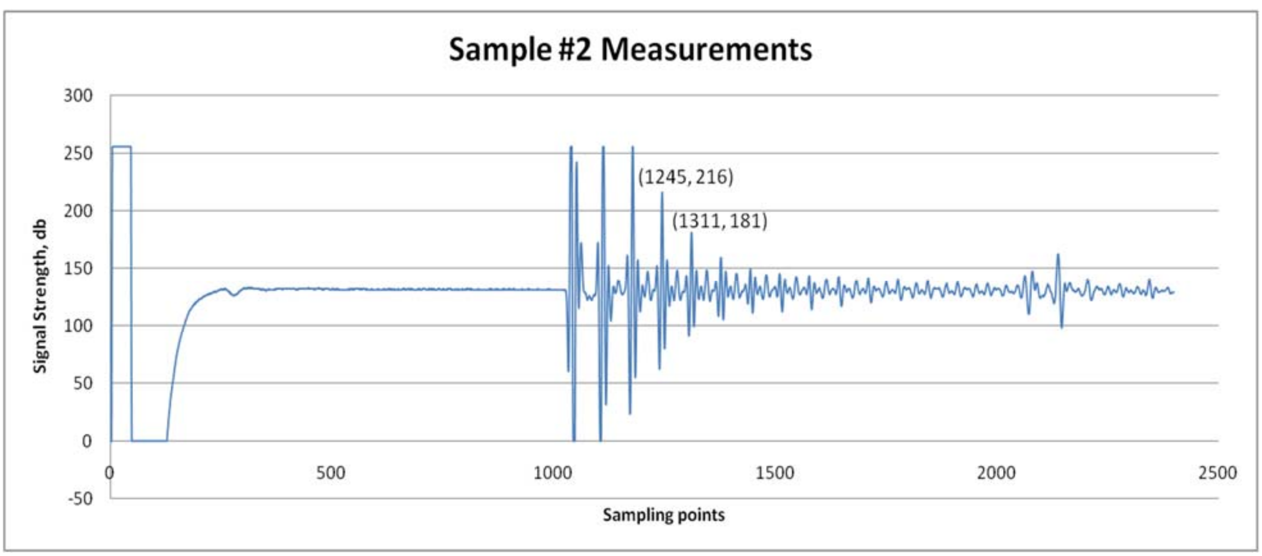


Figure 10. Test Data for Sample # 2

Sample # 3

The data for sample #3 are presented in Figure 11. Two points were chosen from the excel data file. Using equation (1), we calculated the time.

$$t = \frac{1247-1197}{2*50*10^6} = 5.0 \text{ x } 10^{-7} \text{ sec}$$

Since the speed of sound is 6393.939 m/sec, then the thickness is calculated using equation (3).

$$\delta = t V_c = 5.0 \text{ x } 10^{-7} \text{x } 6393.939 = .003197 \text{ m or } 3.197 \text{ mm}$$

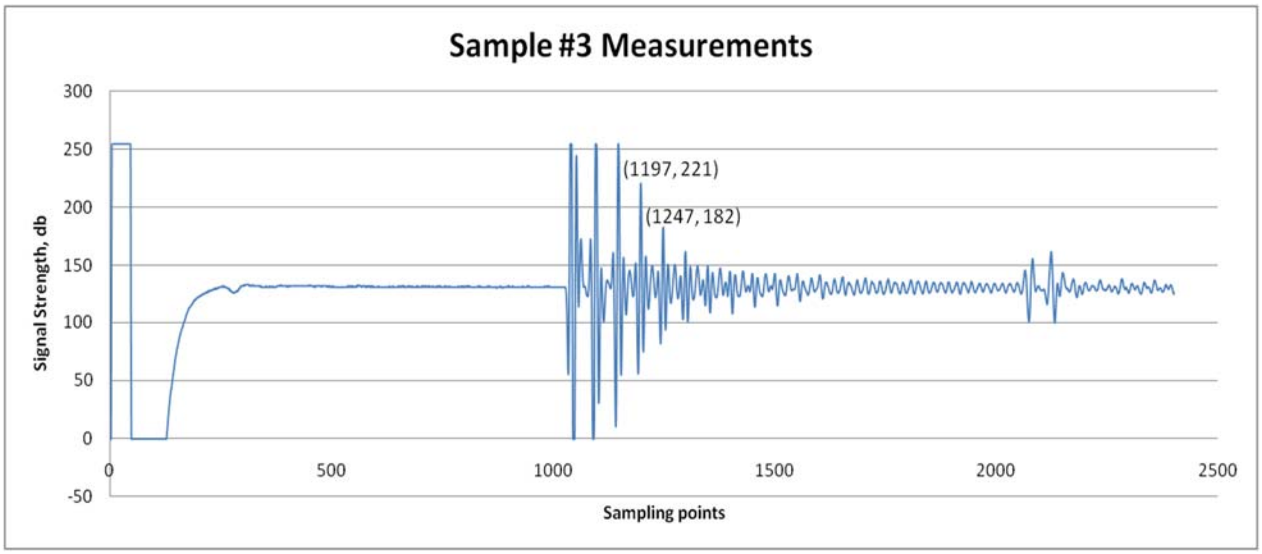


Figure 11. Test Data for Sample # 3

Sample # 4

The data for sample #4 are presented in Figure 12. Two points were chosen from the excel data file. Using equation (1), we calculated the time.

$$t = \frac{1185-1150}{2*50*10^6} = 3.5 \text{ x } 10^{-7} \text{ sec}$$

Since the speed of sound is 6393.939 m/sec, then the thickness is calculated using equation (3).

$$\delta = t V_c = 3.5 \text{ x } 10^{-7} \text{x } 6393.939 = .002238 \text{ m or } 2.238 \text{ mm}$$

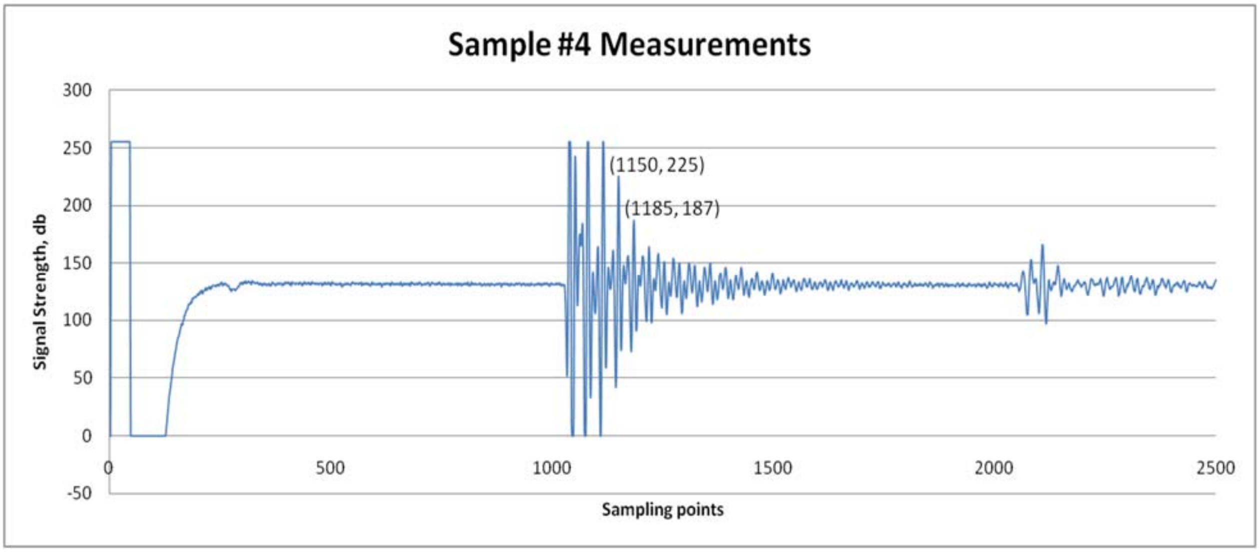


Figure 12. Test Data for Sample # 4