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THEME

Determination of mechanical properties by ultrasonic method

Publicly defended before the jury consisting of:

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UT:	Ultrasonic testing.
NDT:	Nondestructive testing.
f:	Frequency.
λ :	Wave length
c :	Velocity of sound waves
z :	Acoustic impedance
q :	Assemble of elasticity modulus
ρ :	Density
P :	Pressure
A :	Amplitude of particular vibration.
I :	Intensity
Y :	Young’s modulus.
F :	Force.
K :	Spring constants.
σ :	Tensile stress.
ε :	Tensile strain.
a :	Acceleration.
U :	Displacement of particles.
φ :	The overall phase.
k :	Wave vector.
T :	Period.
Subscripts l	Longitudinal.
Subscripts s	Transversal.
Subscripts t	Transmitted.
Subscripts r	Reflected.
Subscripts i	Incident.
G :	Modulus of rigidity.
B:	Bulk modulus

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Dedication

Dedicate this
work to my
precious parents,
and my family
Dedicate to all my
wonderful
teachers and
professors
Dedicate to all my
friends
Dedicate to …

General introduction

Of all the applications of industrial ultrasonic testing, flaw detection is the oldest and the most common applications of industrial ultrasonic testing. Since the 1940s, the laws of physics that govern the propagation of sound waves through solid materials have been used to detect hidden flaws, voids, porosity, and other internal discontinuities in metals, composites, plastics, and ceramics. High frequency sound waves reflect from flaws in predictable ways, producing distinctive echo patterns that can be displayed and recorded by portable instruments. Ultrasonic testing is completely nondestructive and safe, and it is a well-established test method in many basic manufacturing process and service industries, especially in applications involving welds and structural metals.

The purpose of this work is to review fundamentals ultrasonic pulse echo method and the use of the Ultrasonic pulse echo immersion technique to measure the ultrasonic velocity to calculate the elastic constants of some Homogenous Isotropic materials. In the first part we present an introduction and fundamentals of UT. The aim is to highlight the principles underlying UT, based on ultrasonic waves propagation. And we presented simplified overview of the UT system, also the behavior of ultrasonic waves in the matter and the elastic properties of the matter. Where last chapter was devoted to the presentation of the results of our experimental with a parallel discussion and a comparison of these with the available experimental and theoretical results.

Finally, we conclude with a general conclusion that includes all the main results of this work.

Part I: Introduction to physics of ultrasonic testing

1. Theatrical concepts

1.1. Introduction

Ultrasonic testing (UT) is a non-destructive method in which high frequency sound waves are introduced into the material being tested and the sound emerging out of the test specimen is detected and analyzed. Most ultrasonic inspection is done at frequencies between 0.5 and 25 MHz well above the range of human hearing, which is about 20 Hz to 20 kHz. Ultrasonic waves are mechanical vibrations of the particles of the medium in which they travel [1].Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more [2].

The term "Non-destructive testing (NDT)" is used to describe the material testing methods which, without damaging or influencing the usefulness of a material or component, give information about its properties. NDT is concerned with revealing the flaws in an item under inspection. NDT cannot however predict where flaws will develop due to the design itself [3]. NDT testing has become an essential part of every industrial tool box. Building industrial plants or welded structures without NDT today would be like building without measuring or cleaning or welding. Maintaining aircraft, refineries or rotating equipment without NDT would be like maintaining without lubrication or checking for tightness or for corrosion [1].

The objective embedded in this part is to show the behavior of ultrasonic waves in solids, and the relation between it and elasticity constants in solids.

1.2. Definitions

1.2.1. Ultrasonic Waves:

Sound waves are propagation of vibrations of particles of gases, solids or liquids. The audible sound range of frequencies is usually taken from 20 Hz to 20 KHz. Sound waves with frequencies higher than 20 KHz are known as ultrasonic waves. In general ultrasonic waves of frequency range 0.5 MHz to 20 MHz are used for the testing of materials. The most common range for testing metals is from 2 MHz to 5 MHz [4].

1.2.2. Characteristics of Ultrasonic waves:

The characteristics of a sound wave can be described by the following parameters:

Period: the time taken for a particle in the medium through which the wave is traveling to make one complete oscillation about its rest position. (One oscillation is also referred to as a cycle)

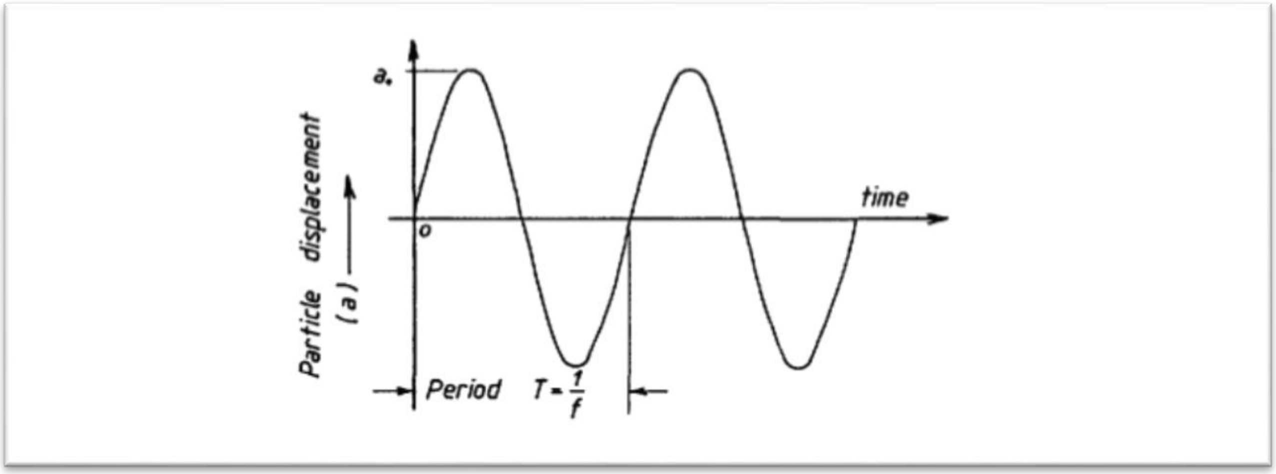


Figure 1.1: A plot of a mechanical propagating wave motion.

Frequency: The frequency of a wave is the same as that of the vibration or oscillation of the atoms of medium in which the wave is travelling. It is usually denoted by the letter f and until recently was expressed as the number of cycles per second. The International term for a cycle per second is named after the physicist H. Hertz and is abbreviated as Hz. When 1Hz = 1 cycle per second.

Wavelength: During the time period of vibration, a wave travels a certain distance in the medium. This distance is defined as the wavelength of the wave and is denoted by the Greek letter λ. Atoms in a medium, separated by distance will be in the same state of motion (i.e. in the same phase) when a wave passes through the medium.

Velocity: The speed with which energy is transported between two points in a medium by the motion of waves is known as the velocity of the waves. It is usually denoted by the letter **c**.

Acoustic Impedance Each medium through which sound waves travel is characterized by an acoustic impedance denoted by 'Z' which is the resistance offered by the medium to the passage of sound through it. Since the values of Z are different for different materials the velocity of sound waves is different in different materials.

Velocity also depends upon the elastic properties of the medium and is given by $c = \sqrt{\frac{q}{\rho}}$ where q is the modulus of elasticity and ρ is the density[5], [6].

$$Z = \rho c \tag{1.1}$$

Acoustic pressure: is the term most often used to denote the amplitude of alternating stresses on a material by a propagating ultrasonic wave. Acoustic pressure P is related to the acoustic impedance Z and the displacement of particle U as:

$$P = ZU \tag{1.2}$$

Where

P = acoustic pressure.

Z = acoustic impedance.

U = Displacement of the particles.

Intensity: The transmission of mechanical energy by ultrasonic waves through a unit cross-section area, which is perpendicular to the direction of propagation of the waves, is called the intensity of the ultrasonic waves. Intensity of the ultrasonic waves is commonly denoted by the letter I. Intensity I of ultrasonic waves is related to the acoustic pressure P, acoustic impedance Z as [3].

$$I = \frac{P^2}{2Z} \tag{1.3}$$

Where

I = intensity.

Bandwidth: The operating frequency range of a transducer assembly is its bandwidth. Tt is defined as the difference between the upper (f_u) and lower (f_l) frequencies. Bandwidth is an important characteristic of ultrasonic transducer. It is usually measured from the amplitude versus frequency using a spectrum analysis software. The apparent bandwidth and details of the spectral response of a transducer assembly are dramatically influenced by the electrical characteristics of the pulser/receiver, cable type and length, electrical matching, target shape, and the attenuation characteristics of the test material. [7]

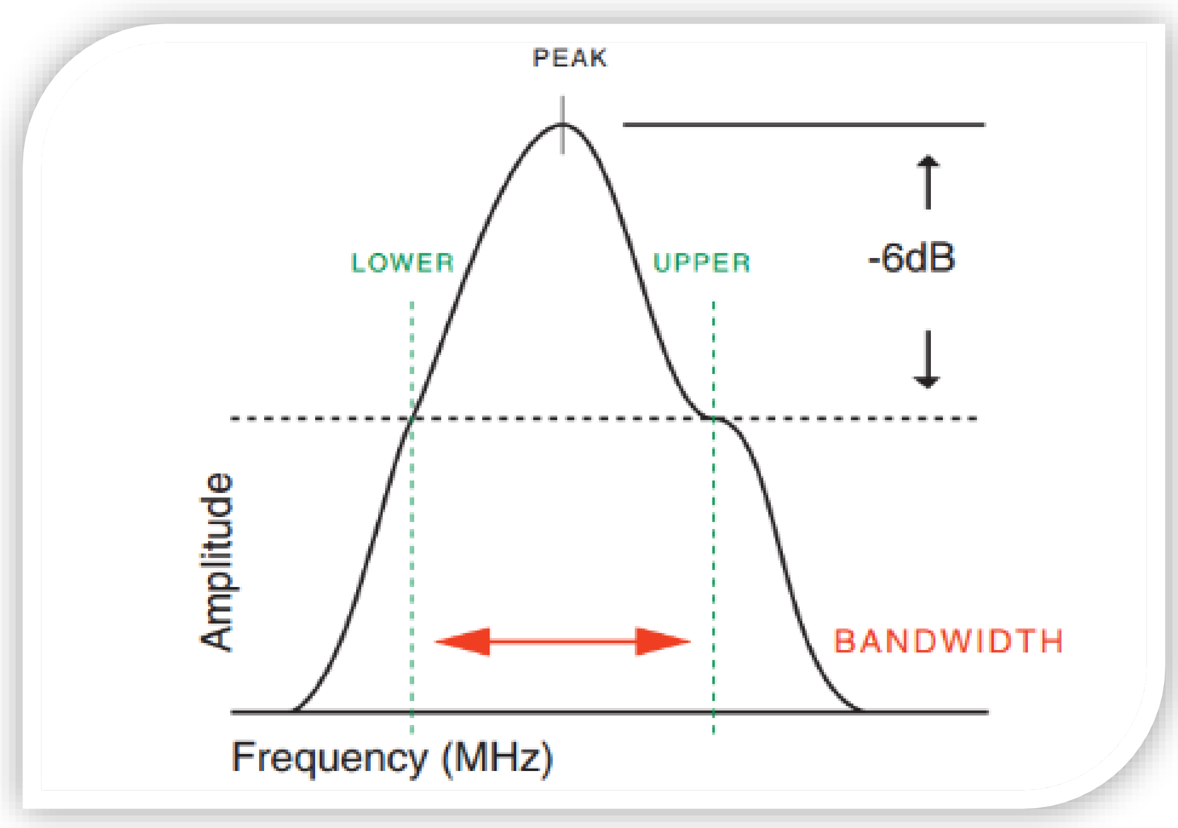


Figure 1.2: Typical frequency response spectrum of pulse-echo transducer

1.2.3.Ultrasonic waves propagation Types

The most common methods of ultrasonic examination utilize either longitudinal waves or shear waves. Other forms of sound propagation exist, including surface waves and Lamb waves.

- **A longitudinal** wave is a compressional wave in which the particle motion is in the same direction as the propagation of the wave.

- **A shear** wave is a wave motion in which the particle motion is perpendicular to the direction of the propagation.

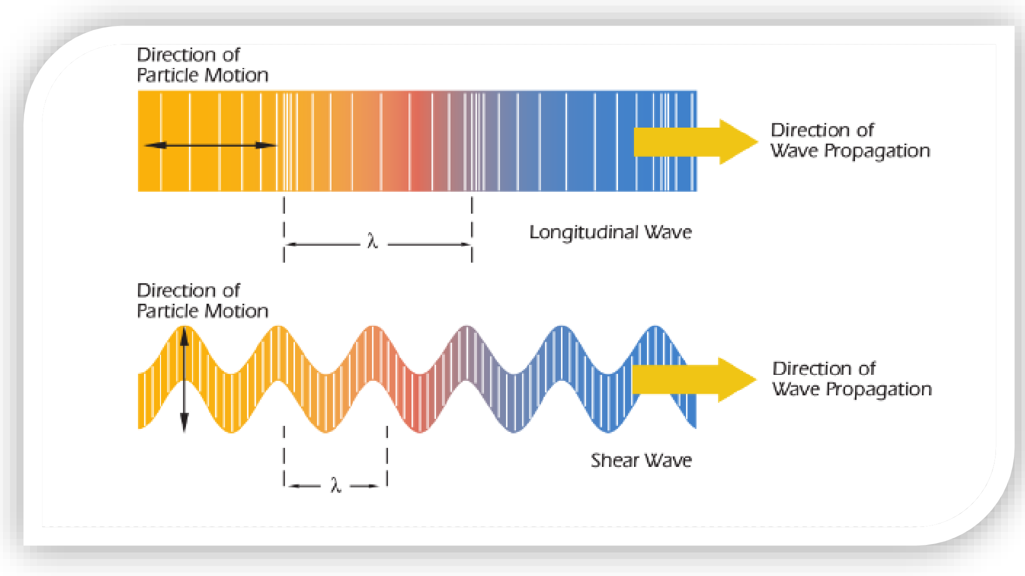


Figure1.3: Illustration of the particle motion versus the direction of wave propagation for longitudinal waves and shear waves.

- **Surface (Rayleigh)** waves have an elliptical particle motion and travel across the surface of a material. Their velocity is approximately 90% of the shear wave velocity of the material and their depth of penetration is approximately equal to one wavelength.

Love waves: It is a dispersive wave of transversal polarization which propagates in a medium consisting of a layer and a substrate, under conditions of symmetry and speeds of two materials (layer and substrate) [6], [8].

Stoneley waves: This is a wave that propagates parallel to the interface of two semi-infinite materials in contact [6].

The Love and Stoneley waves will only exist if the transverse velocity in the layer (or semi-infinite material) is less than that in the substrate. In this case, the two modes cannot take place and the only surface mode that appears is that of Rayleigh.

- **Plate (Lamb)** waves have a complex vibration occurring in materials where thickness is less than the wavelength of ultrasound introduced into it.

1.3. Ultrasonic testing system

A typical ultrasonic testing inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices.

1.3.1.The pulser/receiver:

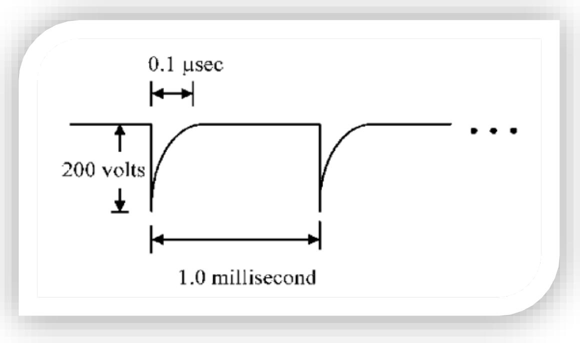


Figure 1.4: Typical output characteristics of an ultrasonic pulser

The pulser/receiver is the driver of the ultrasonic testing system. A spike type of pulser typically puts out very short (approximately 0.1 µs in duration) repetitive electrical pulses (approximately 1 ms apart) having amplitudes on the order of several hundred volts [9].

Typical pulser circuits will apply from 100 volts to 800 volts to a transducer. For this pulser repetition rates range between 100 and 5000 pulses per second or at a rate that can be controlled by an external source [2].

In the receiver section the voltage signals produced by the transducer, which represent the received ultrasonic pulses, are amplified. The amplified radio frequency signal is available as an output for display or capture for signal processing. Control functions associated with the receiver circuit include [2], [9].

- Signal rectification (The RF signal can be viewed as positive half wave, negative half wave or full wave.)
- Filtering to shape and smooth return signals
- Gain, or signal amplification
- Reject control

1.3.2.Transducer:

A transducer is any device that converts one form of energy to another. An ultrasonic transducer converts electrical energy to mechanical energy, in the form of sound, and vice versa. The main components are the active element, backing, and wear plate.[7]

1.3.2.1.The active element

The transducer is a very important part of the ultrasonic system, the active element of ultrasonic transducer is a very thin (approximately 100 µm thick) piezoelectric crystal is plated on both faces and is attached, through a small electrical network contained in the transducer housing. Since the crystal is fragile, a ceramic wear plate protects the front face of the crystal as shown [1].

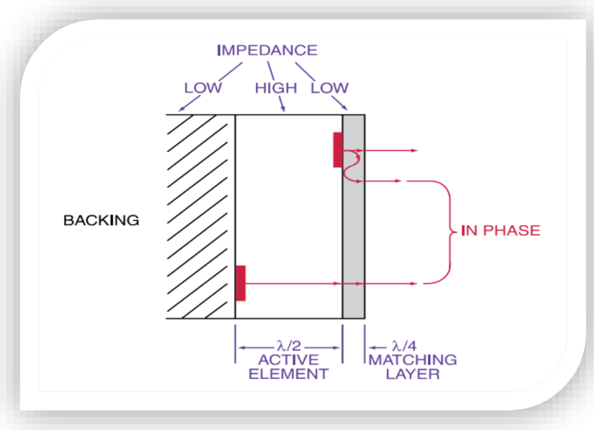


Figure 1.5: The active element and the wear plate, and when they are in phase.

The piezoelectric element is cut to 1/2 the desired wavelength. To get as much energy out of the transducer as possible, an impedance matching is placed between the active element and the face of the transducer. Optimal impedance matching is achieved by sizing the matching layer so that its thickness is 1/4 of the desired wavelength. This keeps waves that were reflected within the matching layer in phase when they exit the layer [2].

- **Piezoelectric effect**

Piezoelectricity first discovered by the Curie brothers in 1880 [3]. Its principle is central to the production of ultrasound beams and states that some materials produce a voltage when deformed by an applied pressure and produce a pressure when deformed by an applied voltage.

Thus, when a voltage is applied to the faces of a crystal, it expands or contracts depending upon the polarity of the voltage applied. The crystal then resonates, converting electricity to ultrasound. The frequency of sound produced is dependent on the thickness of the crystal. Conversely, when the crystal receives an echo, the sound deforms the crystal and a voltage is produced on its faces – this voltage is then analyzed by the system[3].

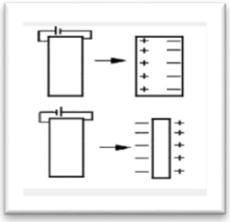


Figure 1.6: Piezoelectric effect: Reversing polarity of voltage Crystal undergoes expansion & contraction

If expansion and contraction occurs more than 20000 times per second, then ultrasound is being produced, which will continue until the applied voltage is discontinued (Continuous wave). If voltage is applied for an extremely short time, then the crystal resonates (rings) at its own frequency and the ringing gradually decays – a pulse is produced. The larger the voltage applied the greater the amplitude of the emitted sound (louder ringing).

The most commonly used materials are polarized ceramics which can be cut in a variety of manners to produce different wave modes. Others commonly used materials are quartz, lithium sulphate, barium titanate and lead metaniobate [3], [10]. New materials such as piezo-polymers and composites are also being employed for applications where they provide benefit to transducer and system performance.

When piezoelectric ceramics were introduced, they soon became the dominant material for transducers due to their good piezoelectric properties and their ease of manufacture into a variety of shapes and sizes. They also operate at low voltage and are usable up to about 300^{o}C.

1.3.2.2.The backing

The backing is high density material that is used to control the vibration of the transducer by absorbing the energy radiating from the back face of the active element.

1.3.2.3. Transducers Frequency

Some transducers are specially fabricated to be more efficient transmitters and others to be more efficient receivers. A transducer that performs well in one application will not always produce the desired results in a different application.

The frequency noted on a transducer is the central or center frequency and depends primarily on the backing material. Highly damped transducers will respond to frequencies above and below the central frequency. It will also define the capabilities of a transducer. Lower frequencies (0.5MHz-

2.25MHz) provide greater energy and penetration in a material, while high frequency crystals (15.0MHz-25.0MHz) provide reduced penetration but greater sensitivity to small discontinuities [2].

1.3.2.4.Transducers types

I. Contact transducers

There are actually two types of contact transducers. They are distinguished by the types of motion generated in the crystal when it is excited by a voltage pulse and the corresponding types of motion subsequently present in the beam of ultrasound launched from the transducer into the part.

1. Normal Beam Contact Type transducer

As the name indicates these probes transmit ultrasonic waves, usually longitudinal, in to the test specimen in a direction perpendicular to the surface of the test specimen.

2. Angle Beam Contact Type transducer

In angle probes, refraction and conversion of wave modes are used to transmit ultrasound in to the test specimen at various angles to the surface. An angle transducer transmits longitudinal waves through a Perspex delay block at a definite angle of incidence to the surface of the specimen. The angle of incidence chosen is greater than the first critical angle so that only transverse waves enter the specimen. The longitudinal portion is reflected back in to the probe and is attenuated by the damping block and thus spurious indications that may arise due to the presence of the longitudinal waves are avoided. The refracted angle for steel specimens and the beam exit point, generally known as the transducer index, are marked on the metal case of the transducer [4].

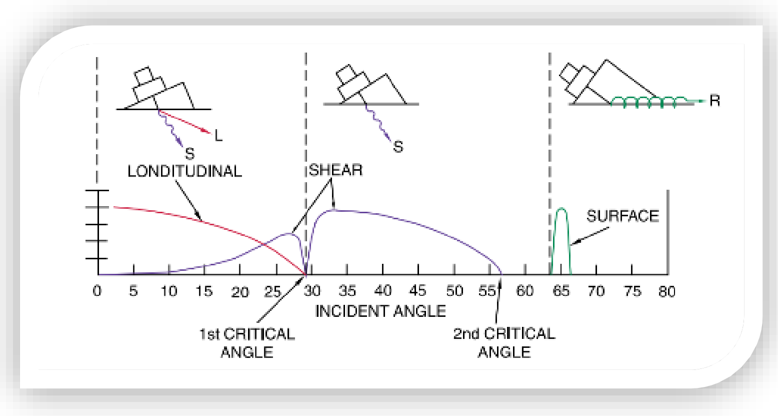


Figure 1.7: The relationship between the incident angle and the relative amplitudes of the refracted or mode converted longitudinal, shear, and surface waves

A surface wave transducer is an angle beam probe insofar as it uses a wedge to position the crystal at an angle to the surface of the specimen. The wedge angle is chosen so that the shear - wave - refraction angle is 90° and the wave resulting from mode conversion travels along the surface.

When an angle beam transducer designed for steel is used for another material, the change in angle of refraction should be taken in to account.

II. Immersion Transducers

Immersion transducers are very similar to contact transducers. However, they are placed at a distance from the tested object and there is a water column between them as a couplet. The main difference is that the ceramic wear plate is replaced by the quarter-wavelength matching layer on its surface. The quarter-wavelength layer is specially designed to allow an efficient transfer of the acoustic energy into the water. Immersion transducers can also have an acoustic lens to focus the acoustic field in one point. The piezoelectric element can also be concave to eliminate the lens [4].

1.3.2.5.Radiation field

The sound that emanates from a piezoelectric transducer does not originate from a point, but instead originates from most of the surface of the piezoelectric element. Round transducers are often referred to as piston source transducers because the sound field resembles a cylindrical mass in front of the transducer. The sound field from a typical piezoelectric transducer is shown below.

The region in which ultrasonic waves are propagated from an ultrasonic transducer is known as the **ultrasonic beam**. Two distinct regions of the beam exist and are classified as the near field region and far field region.

Near Field (Fresnel Zone): The part of the sound field between the transmitting surface of the transducer assembly and the point on the acoustic axis where the past pulse/echo maximum occurs is called the near field. The point at which the last pulse/echo maximum occurs is sometimes designated as the Y_0+ point. We will define this distance as N.

The relation for N is given by formula [4]: $N \approx \frac{d^2}{4\lambda}$ where d is the diameter of discus transducer

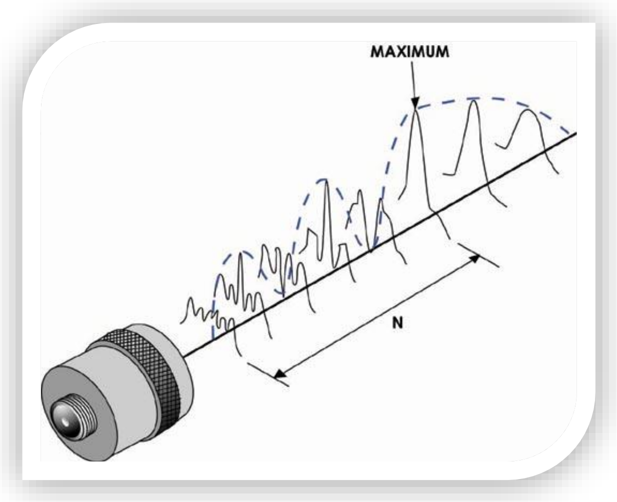


Figure 1.8: Ultrasonic beam, length of near field

Far Field (Fraunhofer Zone): The far field is the region beyond the near field where beam spreading occurs and the pulse/echo signal amplitude from small on-axis reflectors diminishes as 1 / L^2 where L is the distance from the radiating surface of the transducer.

1.3.3.Digitizer

The voltage versus time trace on the oscilloscope screen is an analog signal that needs to be captured in digital form to allow further processing and manipulation via computer.

If a digital oscilloscope is being used, then provided the sampling frequency of the scope is adequate for the very short duration pulses characteristic of ultrasonic signals, this digital conversion process is taken care of automatically. In a real time sampling mode, a very fast (approximately 100 MHz or greater sampling rate) analog to digital converter is used to capture an ultrasonic wave form signal during one repetition cycle, as illustrated in figure 1.9.[9]

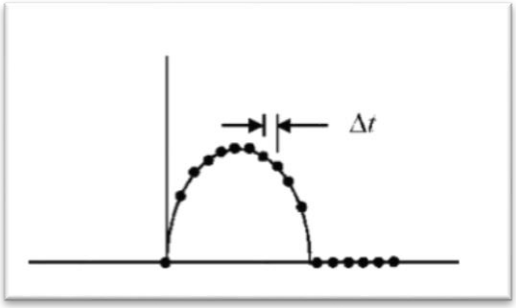


Figure 1.9: A sampled function

simple pulse shape being sampled at a frequency f =1/Δt, where Δt is the time spacing between samples.

Because the total time required to capture the signal in a real time mode is very small, most digitizers operating in this mode can also do averaging of the signals received over many repetition cycles to reduce electronic noise.

In an equivalent time sampling mode, on the other hand, advantage is taken of the fact that the ultrasonic signal received is actually a repetitive signal. This allows us to capture only a portion of the signal during each repetition. as shown in **figure 1.10**.[9]

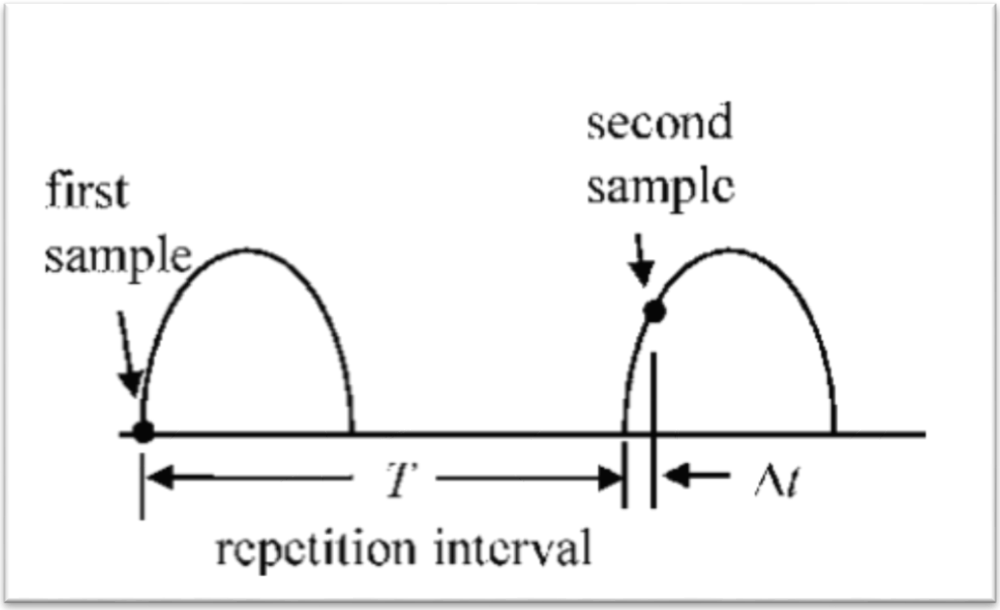


Figure 1.10: Equivalent time sampling

If the first point on the wave form is captured at time t=0 during one repetition cycle and subsequent single points captured at times T +nΔt during the next n cycles, where T is the pulser repetition period and Δt is a small time shift, then the entire wave form can be built up, one sample at a time, using an analog-to-digital converter operating at a frequency of only 1/T samples/s. The equivalent sampling rate of such a process is still, however, 1/Δt since Δt is the time separation between successively sampled point on the wave form.

Once a wave form signal is digitized, transfer to a computer allows further processing and analysis of the signal. A common processing step used in many systems is to compute the frequency components of the signal using Fourier analysis.

2. Ultrasonic waves in matter

2.1. Equations of motion

2.1.1. Ultrasonic Wave equations in homogeneous fluid:

Consider a volume V of an ideal compressible fluid in motion. By applying the second low of newton we find [9]:

$$\int_V F(x,t)dV(x) - \int_S P(x_s,t)n(x_s)dS(x_s) = \int_V \rho(x,t)a(x,t)dV(x) \qquad (2.5)$$

Where:

P(x,t): the pressure at any point x and any time t

F: forces acting in V and on surface S

ρ: density of fluid medium.

X_s: an arbitrary point on the surface S of V whose outward normal is the unit vector n.

a: acceleration of fluid.

If we apply Ostrogradskiy's theorem to the previous equation we find:

$$\int_V [-\nabla P(x,t) + F(x,t) - \rho a(x,t)]dV(x) = 0 \qquad (2.6)$$

i.e.

$$-\nabla P(x,t) + F(x,t) = \rho a(x,t)$$

The acceleration $a = \frac{\partial^2 U}{\partial t^2}$ where U is the displacement vector. Under these conditions equation. becomes

$$-\nabla P(x,t) + F(x,t) = \rho \frac{\partial^2 U}{\partial t^2} \qquad (2.7)$$

For an ideal compressible fluid we have [9]

$$P = -q\nabla \cdot U \qquad (2.8)$$

Where q is assemble of elastic modulus

i.e. the pressure is proportional to the divergence of the displacement vector, also known as the dilatation of the fluid.

By apply the equation 2.8 which called **constitutive equation** we find

$$\nabla^2 U - \frac{1}{c_f^2}\frac{\partial^2 U}{\partial t^2} + \mathrm{f} = 0 \tag{2.9}$$

Where $\mathrm{f} = -\nabla \mathrm{F}$ is a scalar body force term and the quantity $c = \sqrt{\frac{q}{\rho}}$ is the velocity of sound in fluid.

2.1.2.Ultrasonic wave function

When a mechanical wave traverses a medium, the displacement of a particle of the medium from its equilibrium position at any time t in case of harmonic regime unidirectional is given by [3]

$$U = A\cos(\omega t - kx) \tag{2.10}$$

Where

U = Displacement of the particle at any time t,

A = Amplitude of vibration of the particle,

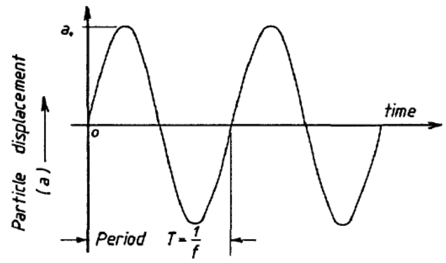


Figure 2.11: Graphical representation of equation

The overall phase φ of the wave is defined by

$\varphi = \omega t - kx$

The wave number k determine the variation of φ with distance x at given time t, and the frequency ω determine the vibration of φ with the time t at given point x.

A sinusoidal plan wave can be expressed in complex notation as [8]

$$U = Ae^{i(\omega t - kx)} \tag{2.11}$$

In the time period T, a mechanical wave of velocity c travels a distance in a medium, therefore we have:

$$\lambda = cT \tag{2.12}$$

But the time period T is related to the frequency f by:

$$f = \frac{1}{T} \tag{2.13}$$

Combining equations 1.12 and 1.13 we have the fundamental equation of all wave motion i.e.

$$c = \lambda f \tag{2.14}$$

2.1.3.Wave equations in homogeneous solids

In the solid two modes of waves are generated, one longitudinal and the other shear. According to the Helmholtz theorem [6]. The total movement U of the particle is considered As the sum of two displacements one U_l longitudinal and the other transverse U_s,

As:

$$\vec{U} = \overrightarrow{U_l} + \overrightarrow{U_s} \tag{2.15}$$

The U_l displacement is parallel to the direction of excitation (traction or compression). It is therefore a ' irrotational ' in view of the uniqueness of the dimension, and thereafter $\nabla \times U_l = 0$, which equals$\overrightarrow{U_l} = \overrightarrow{grad}(\Phi)$, where Φ is a scalar potential.

On the other hand, the U_s shift is directed in one of the two transverse directions and represents Therefore a ' rotational ' of a potential vector $\vec{\Psi}$, i.e. $\vec{U_s} = \overrightarrow{rot}(\vec{\Psi})$. Its divergence is zero $div(U_s) = 0$

To this end, the general solution of the equation can be written [6]:

$$\vec{U} = \overrightarrow{grad}(\Phi) + \overrightarrow{rot}(\vec{\Psi}) \tag{2.16}$$

The scalar Φ describes the propagation of the longitudinal mode with V_l speed.

The vector $\vec{\Psi}$ describes the propagation of the transverse wave with V_s speed.

2.2. Reflection and transmission of sound waves

2.2.1.Reflection and Transmission at Normal Incidence:

When ultrasonic waves are incidence at right angles to the boundary the amount of ultrasonic energy that is reflected or transmitted depends on the difference between the acoustic impedances of the two media. The amount of reflected intensity known as the reflection coefficient, it can be calculated with the equation [1]

$$R = \frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \tag{2.17}$$

Where I_r and I_i are the reflected and incident intensities Z_2 and Z_1 are the acoustic impedances of the mediums 2 and 1.

The amount of energy that is transmitted across the boundary is given by the relation [3]

$$T = \frac{I_t}{I_i} = \frac{4Z_2Z_1}{(Z_2 + Z_1)^2} \tag{2.18}$$

Since the amount of reflected energy plus the transmitted energy must equal the total amount of incident energy: 1=T+R

2.2.2.Reflection and Transmission at Oblique Incidence

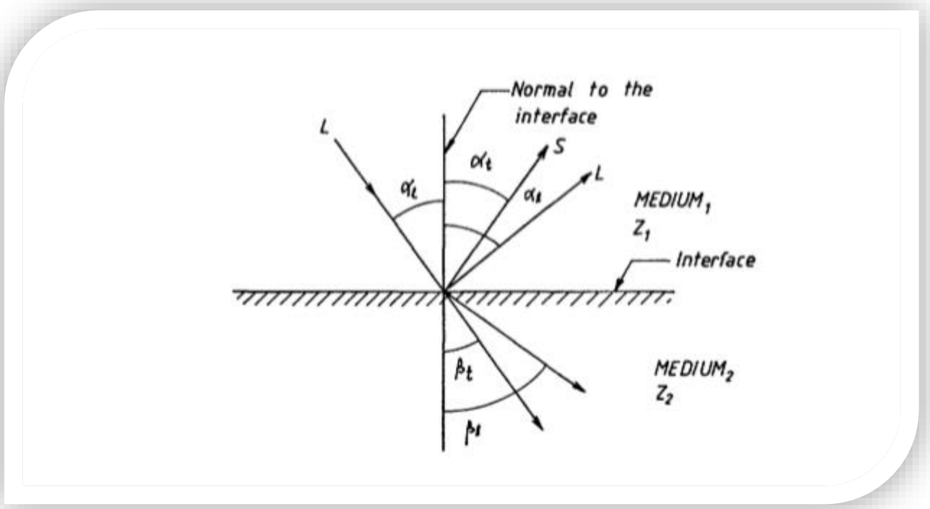


Figure 2.12: Phenomena of reflection and refraction for an incident wave.

α_l: Angle of incidence of longitudinal wave.

α_t: Angle of reflection of transverse wave.

β_l: Angle of refraction of transverse wave.

β_t: Angle of refraction of longitudinal wave.

When an ultrasonic wave is incident on the boundary of two materials at an angle other than normal, the phenomenon of mode conversion (changing in the nature of the wave motion i.e. longitudinal to transverse and vice versa.) and refraction (a change in the direction of wave propagation) occur must be considered. [1]

There is no reflected transverse component or refracted transverse component if either medium 1 or medium 2 is not solid.

2.2.2.1.Snell's Law.

The general law that, for a certain incident ultrasonic wave on a boundary, determines the directions of the reflected and refracted waves is known as Snell's Law. According to this law the ratio of the sine of the angle of incidence to the sine of the angle of reflection or refraction equals the ratio of the corresponding velocities of the incident, and reflected or refracted waves. Mathematically Snell's Law is expressed as [4]

$$\frac{sin(\alpha)}{sin(\beta)} = \frac{c_1}{c_2} \tag{2.19}$$

where

α: the angle of incidence.

β:the angle of reflection or refraction.

c_1:velocity of incident wave.

c_2:velocity of refracted waves.

Both α and β are measured from a line normal to the boundary.

Snell's Law holds true for shear waves as well as longitudinal waves and can be written down as follows:

$$\frac{sin\,\Theta_{L1}}{c_{L1}} = \frac{sin\,\Theta_{L2}}{c_{L2}} = \frac{sin\,\Theta_{S1}}{c_{S1}} = \frac{sin\,\Theta_{S2}}{c_{S2}} \tag{2.20}$$

Where C_l and C_s stands for longitudinal and shear velocity respectively in the materials.

2.2.2.2.First and second critical angle

When a longitudinal wave moves from a slower to a faster material, there is an incident angle that makes the angle of refraction for the wave 90^o. This is known as the first critical angle. The first critical angle can be found from Snell's law by putting in an angle of 90° for the angle of the refracted ray. [10]

If the angle of incidence α_L is further increased the angle of refraction for the transverse wave also approaches 90°. The value of α_L for which the angle of refraction of the transverse wave is exactly 90° is called the second critical angle. At the second critical angle the refracted transverse wave emerges from the medium and travels parallel to the boundary. The transverse wave has thus become a surface or Raleigh wave. [3]

2.3.The elastic properties of matter

2.3.1.Hooke's law

All materials are made of atoms (molecules) which are connected to each other by inter atomic forces. These atomic forces are elastic i.e. the atoms can be considered to be connected to each other as if by means of springs.

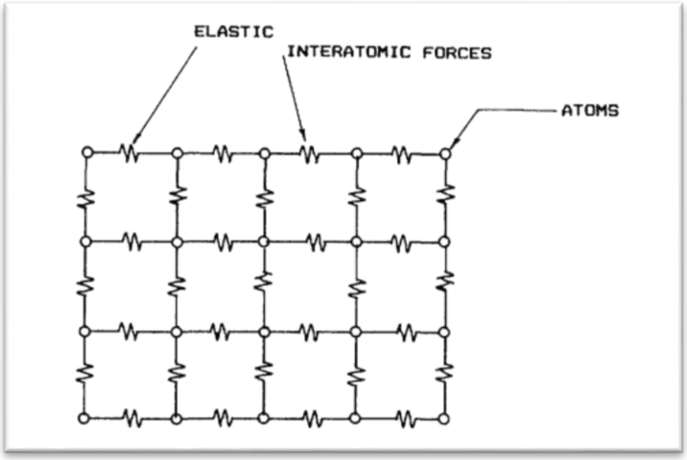


Figure 2.13: Model of elastic body

So if an atom of the material is displaced from its original position by any applied stress, it would start to vibrate. Because of inter atomic coupling, vibration of this atom will also cause the adjacent atoms to vibrate. When the adjacent atoms have started to vibrate, the vibratory movement is transmitted to their neighboring atoms and so forth. If all the atoms were inter connected rigidly, they would all start their movement simultaneously and remain constantly in the same state of motion i.e. in the same phase but since the atoms of a material are connected to each other by elastic forces instead, the vibration requires a certain time to be transmitted and the atoms reached later lag in phase behind those first excited. **Hooke's law** states that there is proportionality between force and extension [1]:

$$F = kx \tag{2.21}$$

Where

F: The excitation force

x : The displacement caused by force F.

k: The spring constant.

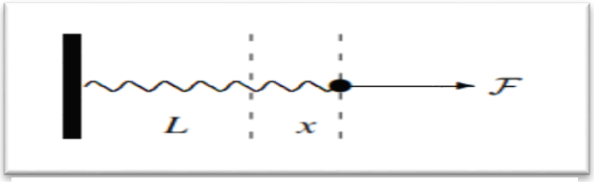


Figure 2.14: A spring of relaxed length L anchored at the left and pulled towards the right by an external force $\mathcal{F}$

2.3.2.Young’s modulus

Consider a stretched wire (figure 2.15). Suppose we have the wire that has a length L and radius r, and suppose a load F is applied to the taut wire to produce an elongation of [11]

$$\varepsilon = \frac{\Delta L}{L} \tag{2.22}$$

Where ε is the strain

Note: The stress by definition is the force exerted on the surface unit of the solid [12].

$$\sigma = \frac{F_{\perp}}{A} \tag{2.23}$$

Where σ is the stress

$F_{\perp}$: Force perpendicular for the surface A.

Since ΔL and L have the same dimensions, strain is dimensionless quantity, normally quoted either as decimal fraction or as a percentage. Typical values for strain in a metallic rod might be of the order of magnitude of 10^{-4} or 0.01%. [11]

From Hooke’s law, stress is proportional to strain,

$$\frac{F}{A} = Y\frac{\Delta L}{L} \tag{2.24}$$

Where Y is the elastic constant of proportionality for a distortion in length and is called **Young's modulus**. Solving for Y, we get [13]

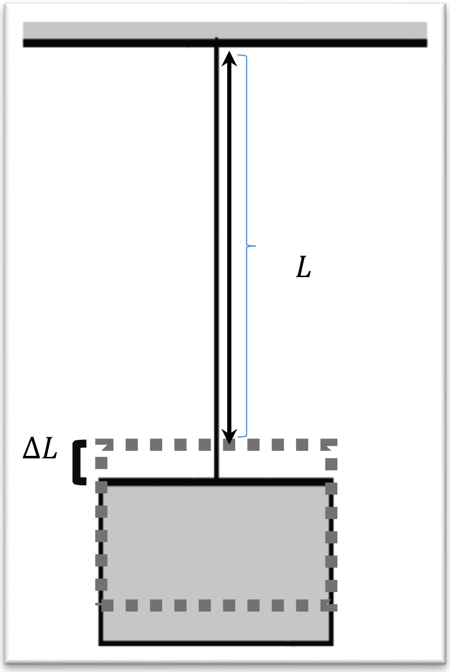


Figure 2.15: Steel wire subjected to stretching weight

$$Y = \frac{\frac{F}{A}}{\frac{\Delta L}{L}} = \frac{\sigma}{\varepsilon} \tag{2.25}$$

The young’s modulus of a material allows us to find what stress is required to produce a given strain. Since ε is dimensionless, Y must have the same unit as P. Typical values of Young’s modulus for a metal are of the order of 10^{10} to 10^{11}. Table below gives approximate values of young modules for some common materials. [11]

Table 1.1: Values of young's modulus for some common materials

Material	*Y/10^{10} N/m^2*
Diamond	83
Steel	20
Aluminum	7.0
Copper	11
Quartz	7.1
Graphite	1.0
Nylon	0.36

2.3.3.Bulk Modulus

Suppose that a specimen such as a sphere is placed in a liquid upon which the pressure can be increased by a force applied to the piston. The change in volume of the Sphere is a function of the stress applied [13].

The stress become $\sigma_{vol} = F/A = pressure\ applied$

Strain become $\varepsilon_{vol} = \Delta V/V$

From hook’s low $\sigma_{vol} = B \times \varepsilon_{vol}$

Where B is the constant of proportionality and is called the bulk modulus. Then,

$$B = \frac{stress}{strain} = P\frac{V}{\Delta V} \tag{2.26}$$

Deformation of volume can occur in gases, liquids, and solids. Bulk modulus of liquids and solids are high and of the same order of magnitude. Gases are easiest to compress and hence have the lowest bulk modulus. We often speak of the compressibility of a material which is the reciprocal (1/B) of its bulk modulus.

Table 1.2: Typical values of Bulk's modulus for some common materials.

Material	*$B/10^{10}$ N/m^2*
Aluminum	7.5
Copper	13.0
Steel	16.5
Nylon	0.59
bone	1.0
iron	12.0
mercury	2.5
water	0.22

2.3.4.Elasticity modulus

We showed in the previous part the elasticity constants that is a relation between stress and strain $\sigma = q\varepsilon$ (equation 2.25) where σ is tensile stress, ε is tensile stain and q is assembles of elasticity constants. It also represented by tensor.

XX	1
YY	2
ZZ	3
YZ=ZY	4
ZX=XZ	5
XY=YX	6

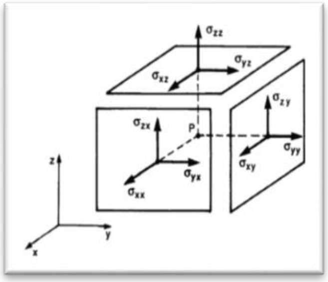


Figure 3.29: Components of stress tensor

So last equation (2.25) can
be written as

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}=\begin{bmatrix}c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16}\\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26}\\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & c_{36}\\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & c_{46}\\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56}\\ c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & c_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}$$

For Isotropy materials

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}=\begin{bmatrix}c_{11} & c_{12} & c_{13} & 0 & 0 & 0\\ c_{21} & c_{22} & c_{23} & 0 & 0 & 0\\ c_{31} & c_{32} & c_{33} & 0 & 0 & 0\\ 0 & 0 & 0 & c_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & c_{44} & 0\\ 0 & 0 & 0 & 0 & 0 & c_{44}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}$$

For isotropic solids the tensor q is independent of the propagation direction, so the relation between it and acoustic wave velocities V_l and V_s given by [6]

$$V_s=\sqrt{\frac{c_{44}}{\rho}}=\sqrt{\frac{c_{11}-c_{12}}{2\rho}} \tag{2.27}$$

$$V_l=\sqrt{\frac{c_{11}}{\rho}} \tag{2.28}$$

- The Young modulus and shear modulus can be calculated from the longitudinal and transversal velocities by applying the following two relationships

Young modulus $$Y=\frac{\rho c_s^2(3c_l^2-4c_s^2)}{c_l^2-c_s^2} \tag{2.29}$$

Shear modulus $$G=\rho c_s^2 \tag{2.30}$$

Poisson ratio $$\nu=\frac{c_l^2-2c_s^2}{2(c_l^2-c_s^2)} \tag{2.31}$$

2.3.5.Elasticity limits:

The elasticity limit of a material depends on several factors, the main ones being [14]:

- Interatomic forces.

- The crystalline structure.
- The atoms strangers block dislocations.
- Dislocations are blocked by grain boundaries.
- The elastic limit also depends on the temperature.

The relationship between stress and strain is known as the loading curve since it depicts the behavior of the material under the load of an applied force [11].

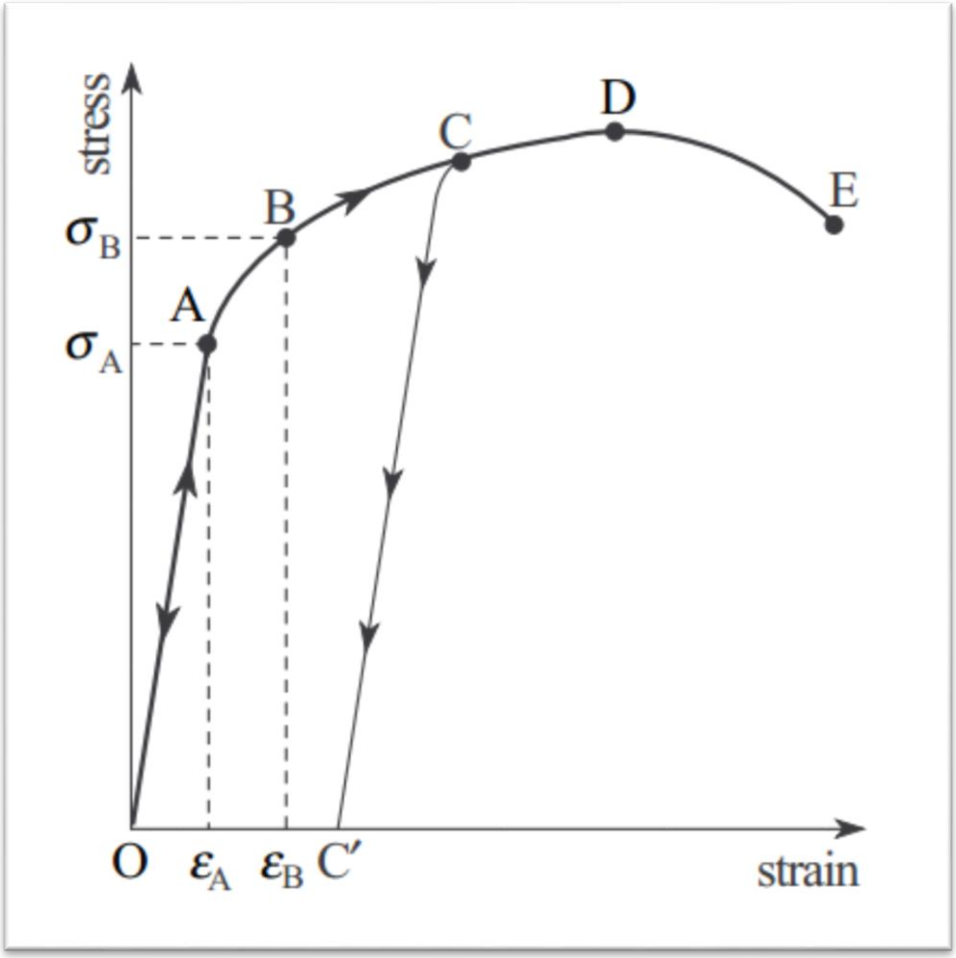


Figure 2.16: The loading curve of stress against strain for a typical material

The region from O to A is the region in which is proportional to the stress, this is range of validity of Hooke’s law. Between A and B the material continues to behave as an elastic material, in that its strain no longer related linearly. The elastic region from O and B where stress and strain are uniquely related, the behavior is reproducible and, if the stress is reduced, the material moves back along the curve to its previous state. The point B, which marks the end of the elastic region, is called the elastic limit or yield point.

If the stress is increased beyond point B, the material enter the plastic region or ductile region. This region is characterized by the material exhibiting plasticity and having large increases in strain resulting from relatively small increases in stress. In plastic region the material becomes permanently deformed. For instance, if the material reaches the C point and then the stress is reduced the material does not retrace the loading curve but will remain strained, maintaining the value of strain at c' even in the absence of stress.

If the load in curve is extended beyond point D then the state becomes time-dependent and the strain will continue to increase without further increase in stress. This phenomenon is known as creep. at this stage the strain will continue to increase even if the stress is reduced, as known by the downward part of the curve beyond D. finally at the point E, the breaking point (or maximum stress), the specimen breaks apart.

2.4. Simulation

Consider an ultrasonic plane wave whose temporal variations are those of a sinusoid modulated by a Gaussian, as in equation below [15]

$$U(t) = \frac{1}{\sqrt{4\pi b}} e^{\frac{-(t-t_0)^2}{4b}} sin(2\pi f_0 t) \qquad (2.32)$$

Where b is the bandwidth at 50% of the amplitude, i.e. at -6 dB, around the nominal frequency of the transducer f_0 which is of the order of a few megahertz. The displacement obtained at the output is calculated by convoluting U (t) and the impulse response of the propagation filter.

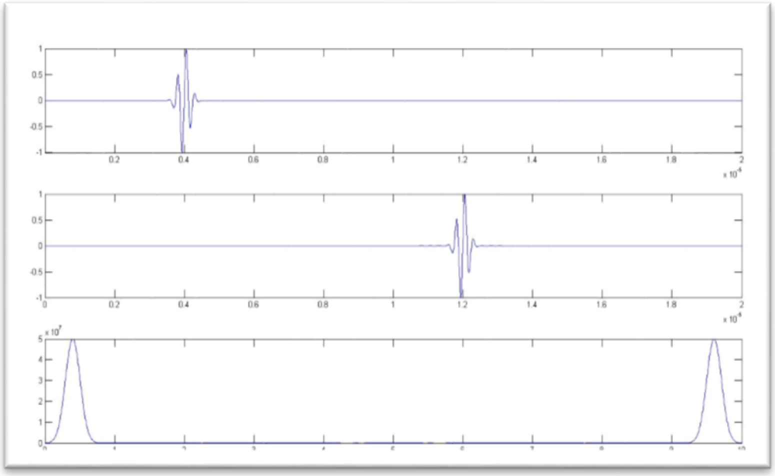


Figure 2.17 Two pulses with 8 µs time difference between them and thier FFT plotted by Matlab; b=2.4 MHz and f_0=5 MHz

The different functions involved in the numerical calculation procedure are shown in figure (2.17)

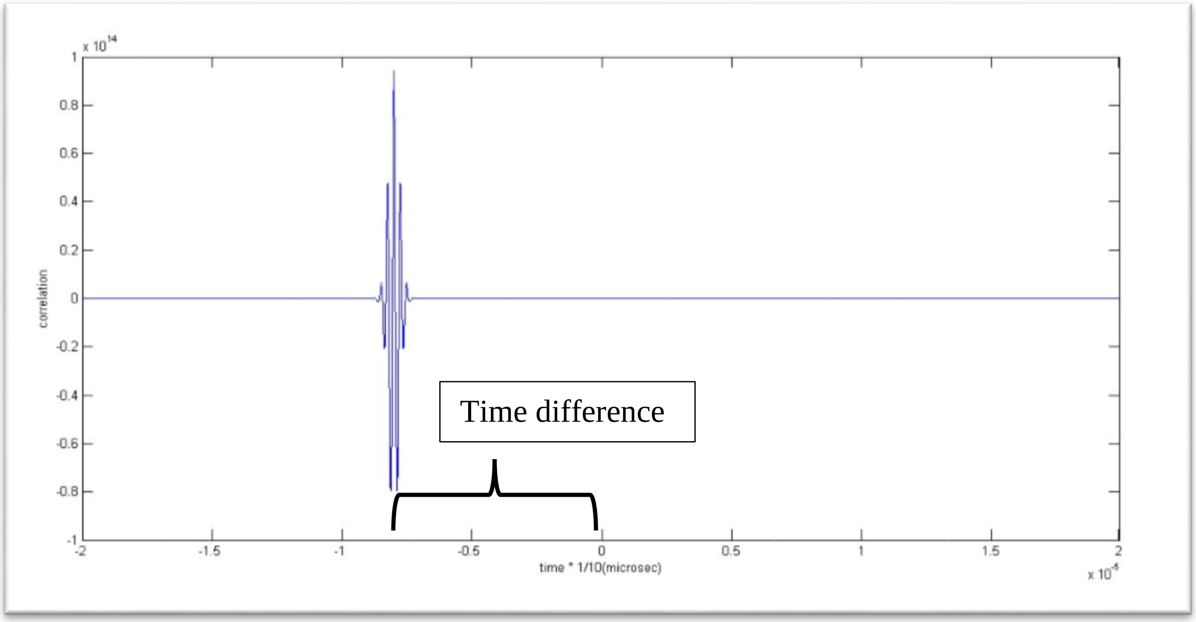


Figure 2.18: The cross-correlation function plotted by Matlab

This simulation, carried out under Matlab, highlighted the effect of the bandwidth of the excitation signal on the shape of the wave. We also used the simulation to verify the method of calculation of velocity and the time difference. The figure 2.18 is a simulation of calculation the time difference between two pulses. We used for that calculation the cross-correlation function.

The results of these simulations allowed us to justify the choice of function of the frequency and the non-dispersive medium. The limits of this model are essentially related to the appearance of a low frequency noise.

The maximum of the cross-correlation function is reached for a time t equal to time difference between the two pulses (figure 2.18). This maximum gives a very accurate measurement of the delay time between two signals of similar spectral content.

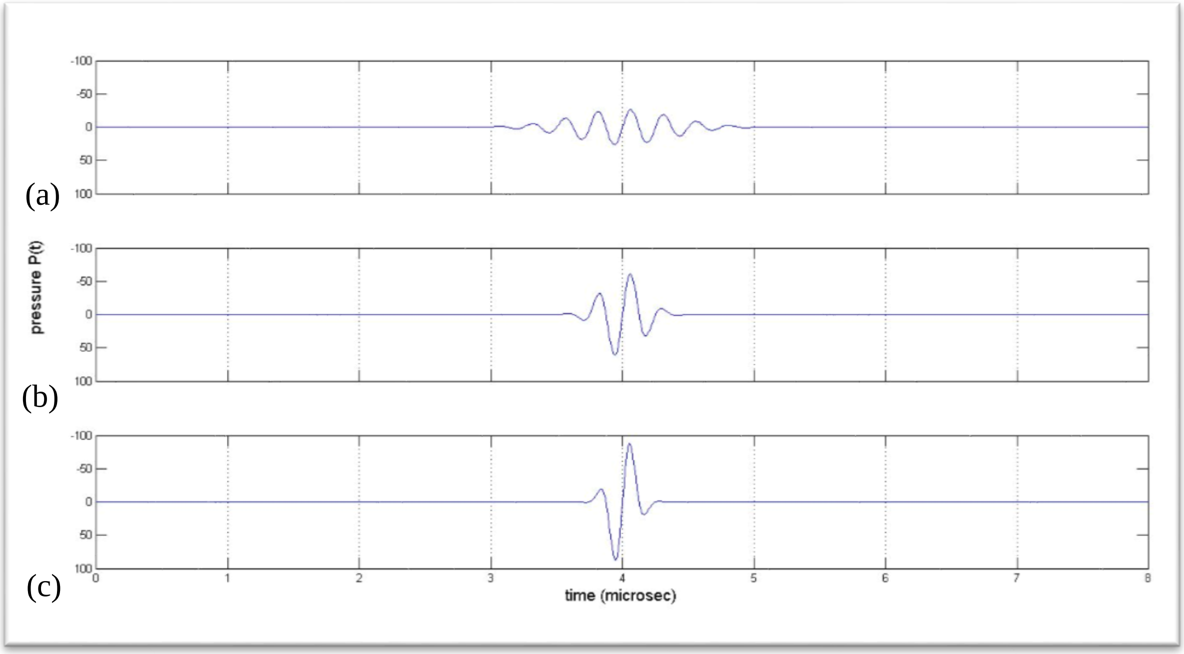


Figure 2.19: The variation of pressure by time

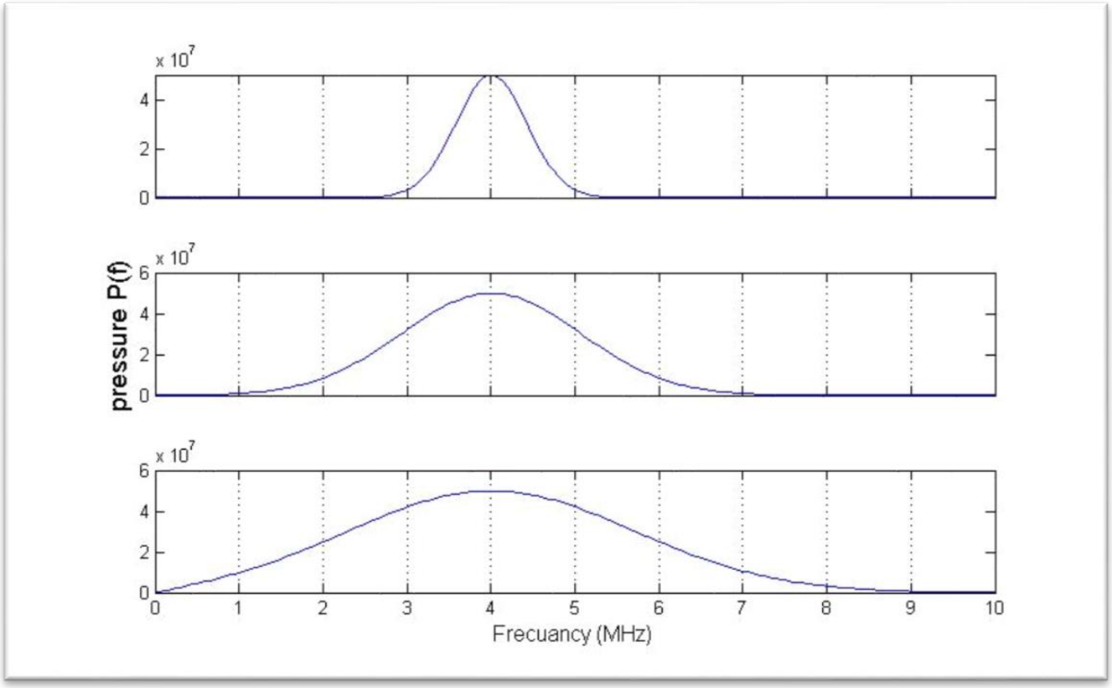


Figure 2.20: Variation of pressure by frequency

As known, the wider band in the spectrum in frequency domain in figure 2.20 gives the shorter signal in time domain figure 2.19.

Part II: Experimental study

3. Experimental study

3.1. Introduction

This chapter is divided into two parts. The first part is devoted to the experimental procedure, the description of the experimental setup used and the description of the measurement procedures. The second part is dedicated to the presentation of the experimental results. Our objective is the determination of the **velocity** of ultrasound in a homogeneous and isotropic materials.

There is many methods of Ultrasonic testing the inspection method selected according to the recommended result. In this part we talk about the **Pulse-Echo Method**, which is a common used in the industrial field to examine the quality of materials without damaging them.

The principle of ultrasonic Pulse-Echo method focused in the propagation of ultrasound waves in the material medium and the detection of reflected or scattered signals. We used one immersion circular planner transducer which generate and emit the ultrasonic pulse and receive it.

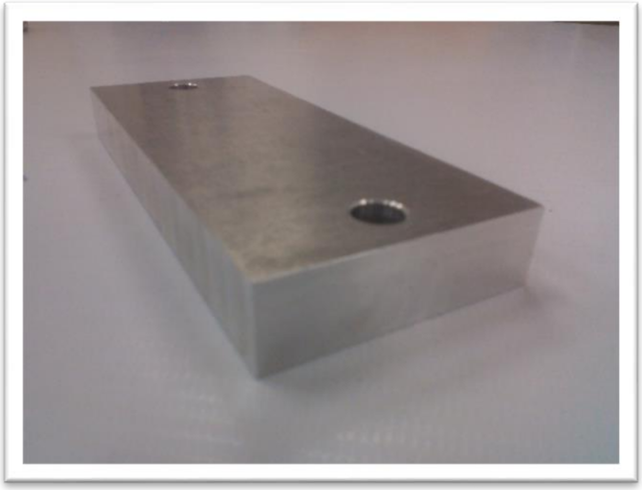
These signals are characterized by their amplitudes and their arrival times. During its propagation through a medium, the acoustic signal is delayed or attenuated due to its interaction with the medium. The velocity is determined from the measurement of the propagation time for a given length of the sample to be characterized.

Impulse methods offer the advantage of being fast, flexible and efficient because, unlike harmonic methods, a single measurement makes it possible to exploit a wide range of frequencies. For the pulse method used in our study, it is a question of harvesting two signals that have traveled two different distances in the same medium to be characterized.

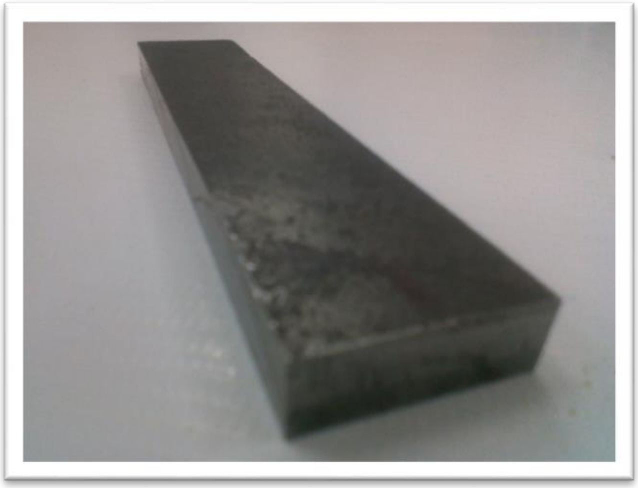
The reflection method was chosen because it offers the following advantages:

- The use of a single side of the sample
- There is no problem of alignment that can cause a particular difficulty of alignment of the transducers.
- It is easier to implement.

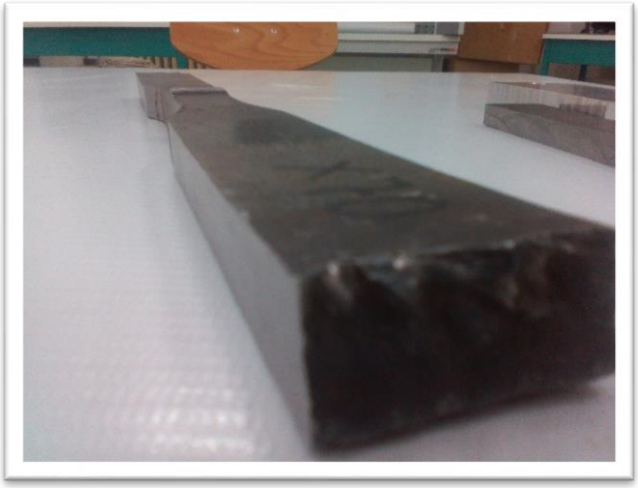
Pulse-Echo method allows the determination of the propagation characteristics of the volume



Aluminum Alloy (AlMgSi0,5)



Steel X52 Pipeline



Steel X70 Pipeline

Figure 03.21: Samples for testing by ultrasound

waves (phase velocity and attenuation) related to the mechanical properties of the medium.

3.2.Experimental instruments

Figure (3.1) shows the experimental setup. It consists of a tank filled with water, at the bottom of which we place a metal plate (figure 3.21). And a transducer, planar, circular About 3.5 MHz nominal frequency is used. It is connected to a pulser/receiver. The generator transmits the signal received from the transducer to a digital oscilloscope, with a bandwidth of about 2 MHz, and allowing sampling of the signal received at 300000 points. The oscilloscope is Built-in a computer, allowing the acquisition of signals and their processing using programs developed under MATLAB.

Table 3.1: Available data on samples stadied

	Density (Kg/m^3)	c_l (m/s)	c_s (m/s)	Y (GPa)	ν
Aluminum alloy	2700[i]	6420[iv]	3040[iv]	69[i]	0.34[iv]
Steel X52	7850[ii]	/	/	200[ii]	0.39[ii]
Steel X70	7800	5980[iv]	3297[iv]	200[iii]	/

i. *[16]*
ii. *[17], [18]*
iii. *[19]*
iv. [20], [21]

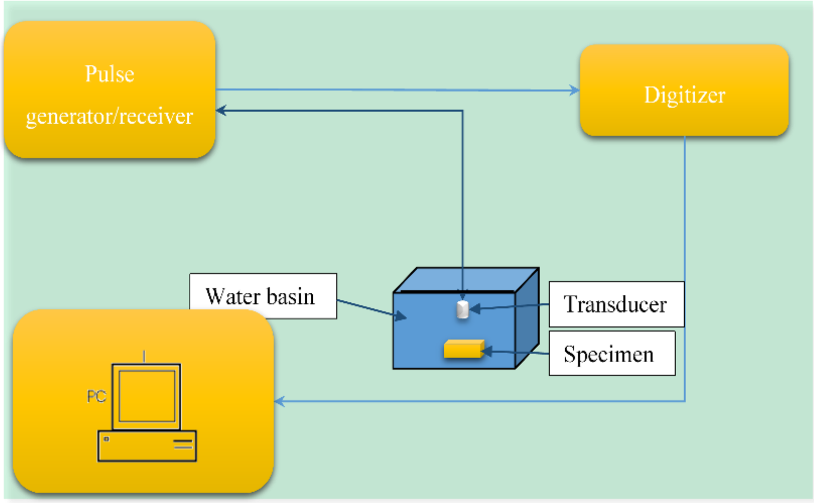
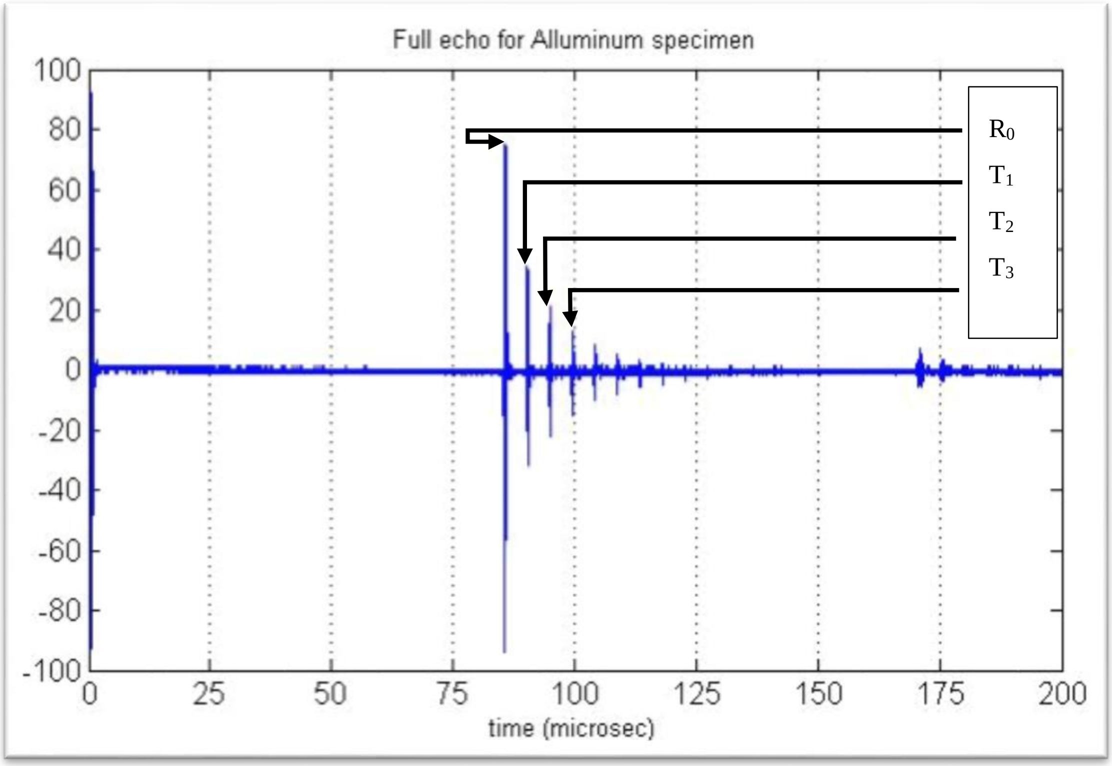


Figure 3.22: An ultrasonic testing system with: one immersion emitter/receiver transducer

Using mechanical mechanism, the transducer was routed and soaked in the tank where the sample was placed. After making sure that its surface is free of air bubbles and that it is in a completely vertical position on the sample surface we have run the system. We got a curve that changes the intensity of the acoustic compression in time.

Figure 03.23: The piezoelectric transducer which we used in the eperimental

Figure 3.24: the UT instrument from Fraunhofer, which we used



R_0 : Reflected amount by first boundary of specimen

T_n :Transmitted amount n+1 times; n= 1,2,3… (see figure 3.25)

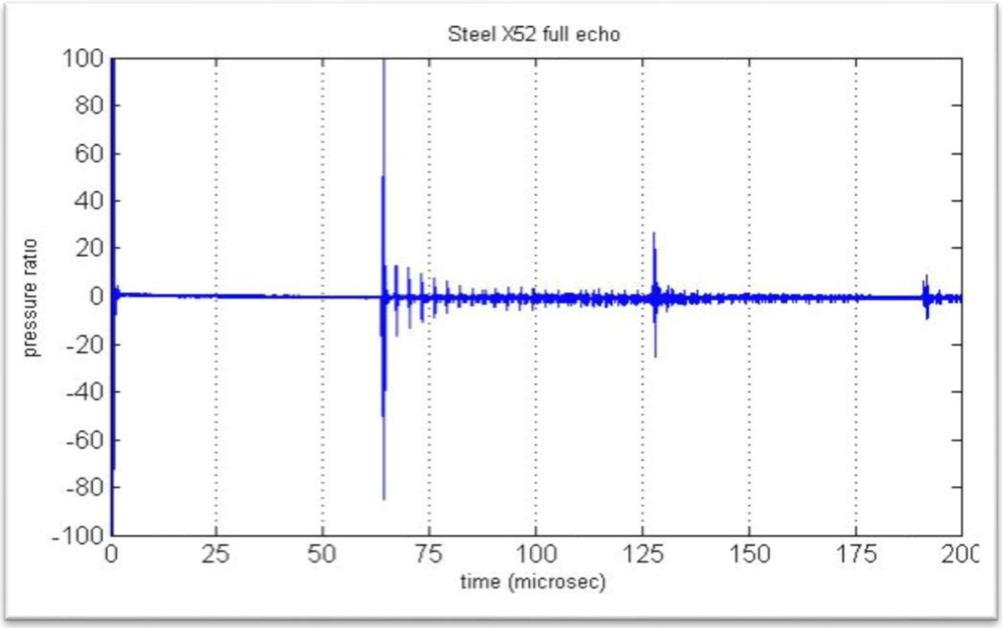


Figure 3.25: Obtained curves by ultrasonic pulse-echo method experiment

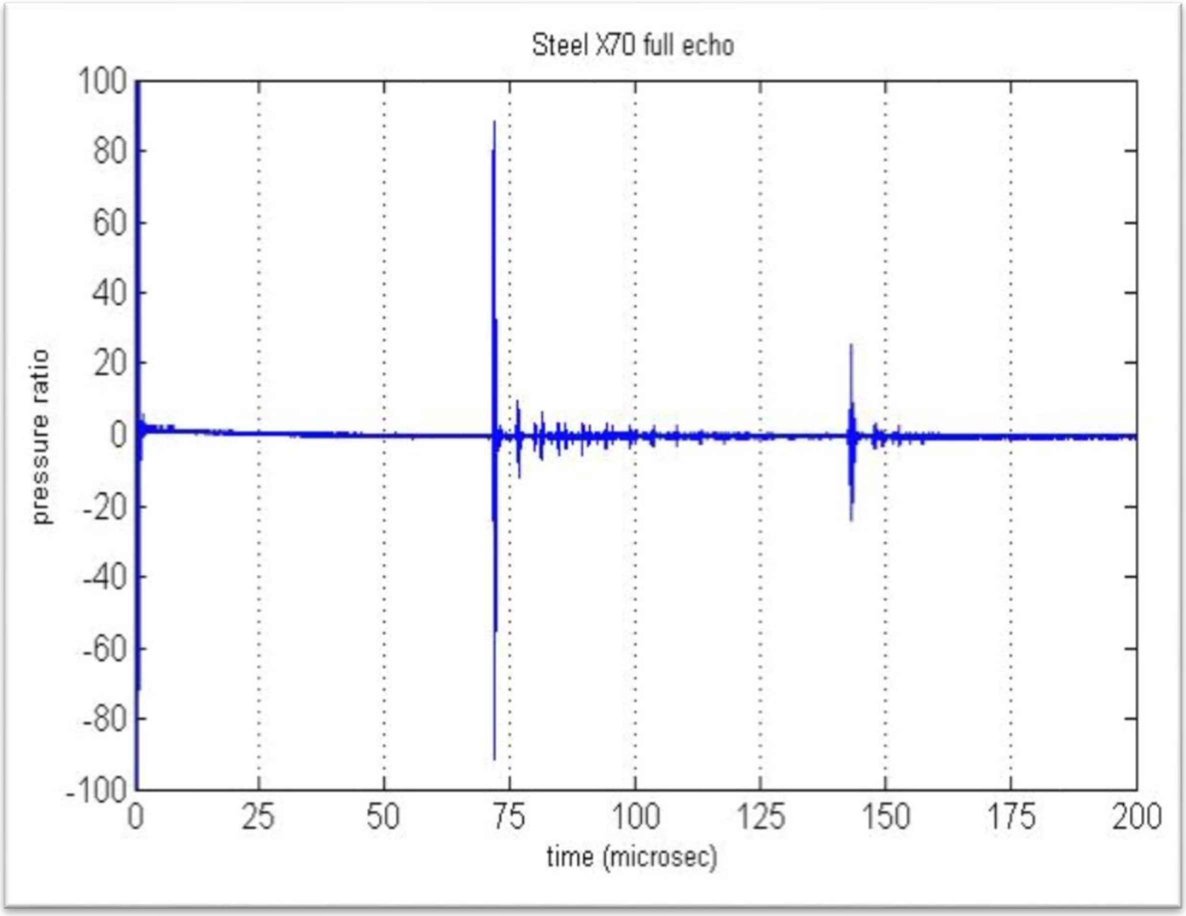


Figure 3.26: Obtained curves by ultrasonic pulse-echo method experiment

3.3. Velocity measurement

The velocity is determined from the measurement of the propagation time for a given length of the sample to be characterized. So it obtained from:

$$c = \frac{2l}{\Delta t} \tag{1.28}$$

Where: l is the distance between transducer and the boundary that reflect the pulse.

To calculate the pulse velocity in the sample we need to know the flight time within the sample, we know that

$$t_{R_0} = \frac{2l_1}{c_1} \tag{1.29}$$

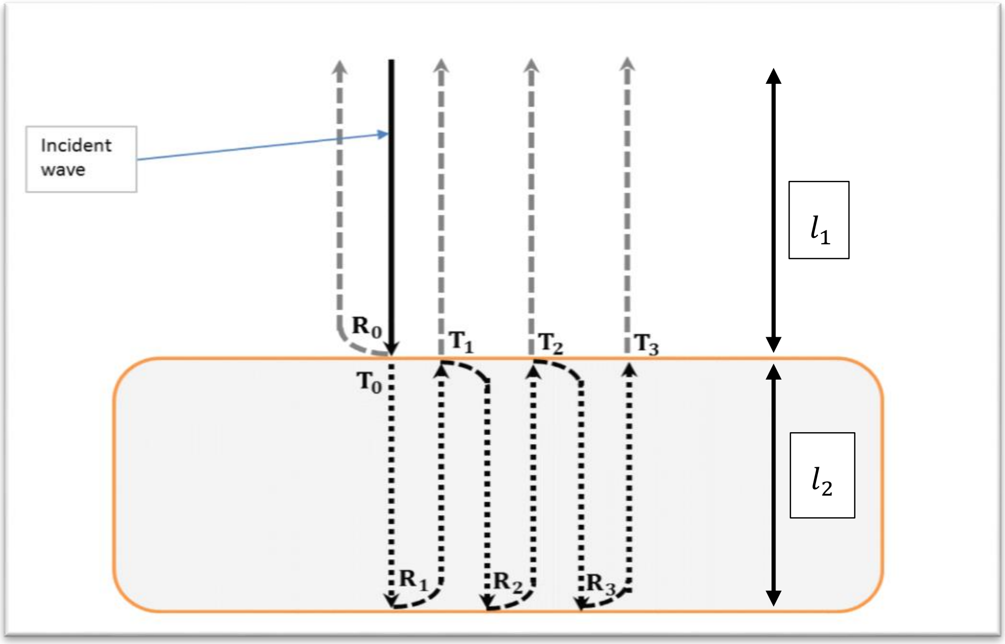


Figure 3.27: A diagram showing the sources of reflected pulses from the specimen

Where l_1 and c_2 are the distance between transducer and the specimen and the velocity of pulse respectively.

$$t_{T_n} = \frac{2l_1}{c_1} + \frac{2nl_2}{c_2} \tag{3.30}$$

Where: n=1,2,3… is number of pulse reflection. And l_2 is thickness of the specimen and c_2 is velocity of pulse in the specimen.

So time the time difference is

$$\Delta t = t_{T_n} - t_{R_0} = \frac{2nl_2}{c_2} \tag{3.31}$$

And the velocity of sound in the specimen is

$$c_2 = \frac{2nl_2}{\Delta t} \tag{3.32}$$

Note: Calculation of sample height, velocity, attenuation, and dispersion requires the calculation of the flight time difference (the time the wave makes to travel from the transmitter to the receiver). Its determination is possible thanks to three methods:

* The first consists in the direct reading of the flight time for each signal,

* The second one uses the Hilbert transform,

* The last one uses the cross-correlation between the two signals. This latter method is used in our work. It is based on the calculation of the inter-correlation function between two signals s1 (t) and s2 (t) defined by [22]

$$C_{S_1S_2}(t) = \int_{-\infty}^{+\infty} S_1(\tau)S_2(t+\tau)d\tau \tag{3.33}$$

The maximum of this function is reached for a time t equal to τ. This maximum gives a very accurate measurement of the delay time between two signals of similar spectral content.

Error in measure

In order to calculate longitudinal velocity, several measurement were taken as shown in table (3.2), so we have several velocity value, the difference in values indicates that there are error in measurement. Therefore, most probable value for this measurements is the mean value.

$$\bar{c} = \frac{1}{N}\sum_{i=1}^{N} c_i \tag{3.34}$$

To estimate the **standard error**, we used the relationship

$$\delta_c = \pm\sqrt{\frac{\sum_{i=1}^{N}(c_i - \bar{c})}{N-1}} \tag{3.35}$$

Where c_i and $\bar{c}$ are: the measured value and man value, respectively.

The standard error of the mean value is written by relationship

$$\delta_{\bar{c}} = \pm\frac{\delta_c}{\sqrt{N}} \tag{3.36}$$

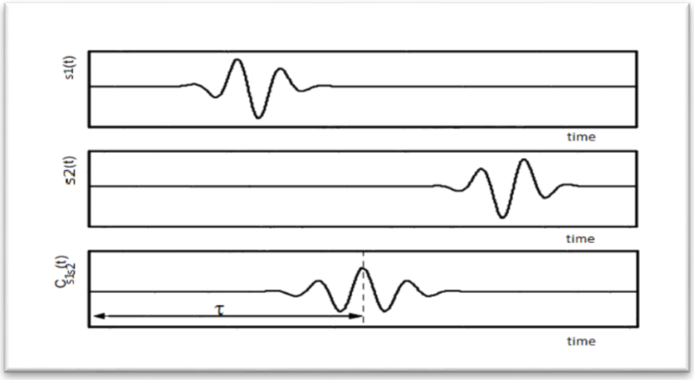


Figure 3.28: Representation of the inter-correlation method. Signals s$_{1.2}$ (t) with signal $C_{s_1s_2}$

3.4. Obtained result

We created ensemble of scripts in Matlab (see Appendix B) to calculate time difference, longitudinal and transversal velocities, results are arranged in the table (3.37)

Table 3.29: Longitudinal, time difference transversal velocities and calculated by our script Matlab

Aluminum specimen			
Measurements	Time difference (µs)	Longitudinal Velocity (m/s)	Transversal Velocity (m/s)
R0-T1	4.74	6332	3638
T1-T2	4.59	6525	3775
T1-T3	9.2	6522	3772
R0-T0	13.94	6458	3727
Mean value	/	6485	3728
Steel_X52 specimen			
R0-T1	3.13	5739	3220
T1-T2	2.98	6644	3858
R0-T2	5.8	6142	3504

R0-T3	8.8	6203	3547
Mean value	/	6182	3532
Steel_X70 specimen			
R0-T1	4.9	5922	3349
T1-T2	4.73	6133	3497
R0-T2	9.62	6025	3422
T1-T4	14.2	6127	3494
Mean value	/	6052	3440

Note: we obtained the transversal velocity by applying fitting function which is compacted in Matlab (see Appendix A).

Table 3.3: Comparaison between our results and literatur results of logitudinal vlocities (m/s)

	Measured value	Literature value	e* (%)
Aluminum (AlMg0.5)	6484(±48)	6420	0.99
Steel_X52	6182(±175)	/	/
Steel_X70	6052(±49)	5980	1.2

* The ratio between our value and the literature value, it calculated by relationship

$$e = \frac{|C - C_r|}{C_r} \times 100 \tag{3.38}$$

Were C and C_r are the calculated value and reference value respectively.

The calculated values of elasticity tensor (see part II: 2.3.4) are arranged in the table 3.4

Table 3.4 Common elements of tensor elastic

specimen	C_{11} (GPa)	C_{44} (GPa)	C_{12} (MPa)
aluminum	113	38	-2.74
Steel_X52	336	109	-7.6
Steel_X70	319	103	-7.2

So let us present the calculated elasticity modulus

Table 3.5: Measured modulus of elasticity

Elastic modulus	Y (GPa)			G (GPa)			B(GPa)	υ		
	literature	measured	e (%)	literature	measured	e (%)	measured	literature	measured	e (%)
Aluminum	69[i]	94	36	26[i]	38	46	38	0.34[iv]	0.25	26
Steel_X52	200[ii]	275	37	/	109	/	112	0.39[ii]	0.26	33
Steel_X70	200[iii]	259	29	/	103	/	106	/	0.26	/

3.5. Discussion

The mechanical properties of three samples were studied under the normal temperature of the laboratory (25º). The longitudinal velocities in the samples obtained after extracting the necessary information from the curves obtained from the experiment.

The results obtained (longitudinal velocity) enabled us to calculate the transversal velocity and elastic modulus of the studied samples.

To verify the measured results, they were compared to other experimental results but due to measurement errors, there is a difference between the measured values and the other. This is due to: Sampling accuracy, variability of the sample, measurement time of flight using the cross-correlation function and approximation of the transversal velocity by fitting experimental values of velocities. The difference in values may be due to the state condition of the samples, the number of tests and the method of manufacture. The difference can also be attributed to the calculation method.

General conclusion

In the first part of the thesis, we considered the theoretical concepts of UT, starting with an introduction to ultrasound physics, then an overview of the testing system, how to generate and detect sound waves with piezoelectric effect, and then we saw the behavior of waves especially in solids, and the relationship between them and their elastic properties. Where we focused on isotropic homogenous materials and we saw how the constants of elasticity become simple and relate only to the velocity of sound waves and material density. In the second section, we presented the experimental structure of our work and then the results we have obtained. We have already seen how the elasticity constants obtained from the experimental results, (speed calculation only) are close to the reference results calculated by other authors. It can be said that the method of echo test, despite the lack of accuracy of its results is a good way to know the mechanical properties of the material, because of the speed obtaining the results and the simplicity of their relationship, we have been able to calculate the modulus of Young.

Initially we aim to calculate the attenuation, as to get more information about the samples, and we could also calculate the phase velocity from the experimental curves, but due to the lack of time and unavailability of samples, the objective has declined. To study attenuation, at least two samples must be tested with different thicknesses and then the difference in time between them should be calculated as well as the difference in pressure intensity, to obtain an absorption relationship.

The pulse echo UT is commonly used to detect sub-surface flaw using the obtained echo curve from the samples.

References

[1] International Atomic Energy Agency, *Non-destructive testing: Aguidebook for industrial management and quality control personnel*. Vienna, 1999.

[2] NDT Rcource center, *Introduction to Ultrasonic Testing*. https://www.nde-ed.org, 2018.

[3] International Atomic Energy Agency, *Ultrasonic testing of materials at level 2*. Vienna, 1988.

[4] Tomasz Lukomski, *Ultrasonic non-destructive methods in inspection of steel*. Krakow, 2012: Uppsala University.

[5] Adrian Contantin, Joachim Escher, *wave motion*. U.S.A. 2004.

[6] Daniel Royer, *Elastic waves in solids I*, English translated by David P.Morgan. paris, 1996.

[7] *Tom Nelligan, An Introduction to Ultrasonic Flaw Detection, https://www.olympus-ims.com, 05/2018. .*

[8] J. Billingham, A. C. King, *Wave motion_theory and applications*. Cambridge University Press, 2001.

[9] Lester W.Schmerr,Jr, *Fundametals of Ultrasonic non-destructive evaluation*, 2 ط. U.S.A. 2016.

[10]Nicolas J.Carino,Mary Sansalone, *Pulse-echo method for flaw detection in concete*. U.S. 1984: DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary NATIONAL BUREAU OF STANDARDS.

[11]The open university, *Mechanical proprieties of matter*, م module P7.6. 1998: F.L.A.P.

[12]Alberto Cocco,Sergio Cesare Masin, *The law of elasticity*. Italy, 2010: University of Padua.

[13]*F3Chapter_13 | Elasticity (Physics) | Deformation (Engineering)", https://www.scribd.com,2018.* .

[14]KHEMLOUL Fakhereddine, *Simulation par les calculs de premiers principes ’ ab initio’ des propriétés structurales, électroniques, optiques et élastiques des pérovskites ATiO 3 (A=Ba, Sr, Pb)*. LAGHOUAT, 2016: UNIVERSITE AMAR TELIDJI.

[15]MAGHLAOUI Nadir, "ETUDE THEORIQUE ET EXPERIMENTALE DE LA PROPAGATION DES ONDES ULTRASONORES DANS LES SOLIDES POLYMERES", HOUARI BOUMEDIENE (U.S.T.H.B / ALGER), Alger, 2006.

[16]aluminco.com, *Aluminium Alloy EN-AW 6060 (AlMgSi0,5)*. Inofita Viotia, 32011, Greece.

[17]A. BELALIA, *DYNAMIC CHARACTERIZATION OF API 5L X52 PIPELINE STEEL*, م Vol. 498, pp 15–30. 2012.

[18]Thyssen Krupp Materials International, *Steel pipes for pipelines for combustible fluids*. 10/2011: Material Data Sheet.

[19]علي حيدرى، محمد رضا فروزان, *بروسي تاثير فرانيدهاي هيدروتست و كوئنجينك لولةهاي API 5L-X70 بر روي تنشهاي بسماند حاصل از جوشكاري زيروبردري به كمك روش اجزاى محدود*. طهران 1,شهريور 1388: شركة لوله وتجهيزات سديد،.

[20]*M. F. Ashby, D. R. H. Jones. Matériaux 1. Propriétés et applications. Dunod, France, 1992, 278 p. .*

[21]*H. Coelho-Mandes. Microscopie acoustique, influence des ondes latérales sur la signature acoustique. Thèse de doctorat de l’université de Montpellier II, 1990, 104 p. .*

[22]NOUIOUA ISMAÏL, *Contribution a l’etude de l’absorbtion des ultrasons dan les materiaux imitant les tissus biologiques mous*. Alger, 2010: UNIVERSITE DES SCIENCES ET DE LA TECHNOLOGIE HOUARI BOUMEDIENE.

Appendix A

Table 1:Densities, sound velocities and acoustic impedances of some common materials

Material	Density (kg/m3)	c_l (m/s)	c_s (m/s)	Z /10^3 $(\frac{kg}{s}\cdot m^2)$
Aluminum	2700	6320	3130	17064
Copper	8900	4700	2260	41830
Quartz melted	2200	5970	3765	13134
Steel	7850	5940	3250	46629
Nylon	1100	2620	1080	2882
Beryllium	1846	12890	8880	23794.94
Chrome	7194	6608	4005	47537.95
Copper	8933	4759	2325	42512.15
Indium	7290	2560		18662.4
Lead	11343	2160	700	24500.88
Pure Nickel	8800	6530	2960	57464
Platinum	21450	3260	1730	69927
Silver	10500	3704	1628	38892
Thorium	11725	2400	1560	28140
Uranium	19050	3370	1940	64198.5
Zirconium	6507	4650	2250	30257.55
Silicon carbide	3210	12099	7485	38837.79
Tungsten carbonate	15000	6655	3984	99825
Water	1000	1480	-	1480
Gold	19300	3240	1200	62532

* Y. Bar-Cohen, A. K. Mal. Ultrasonic inspection. In: ASM Handbook, 1996, vol. 17, pp. 231-277.

Fitting velocities, transversal vs longitudinal

First, and from the data available in material handbook (table 1) Concerning the velocities of acoustic waves in materials, we determined by curve fitting an empirical relation, between c_l and c_s , on a set of about 20 materials of different classes (metals, glasses, ceramics, polymers, ...). The computation of the regression coefficients of different fitting (linear, quadratic, ...) allows us to accept the linear approximation (regression coefficient equal to 0.7048 for the relation c_s - c_l and (figure 1). These empirical relationships are expressed as follows:

$$c_s = 0.7048c_l - 824.8 \tag{A.1}$$

Table 2:Fitting result in Matlab program

```
fitresult =

     Linear model Poly1:

     fitresult(x) = p1*x + p2

     Coefficients (with 95% confidence bounds):

       p1 =       0.7048  (0.637, 0.7725)

       p2 =       -824.8  (-1243, -407.1)
```

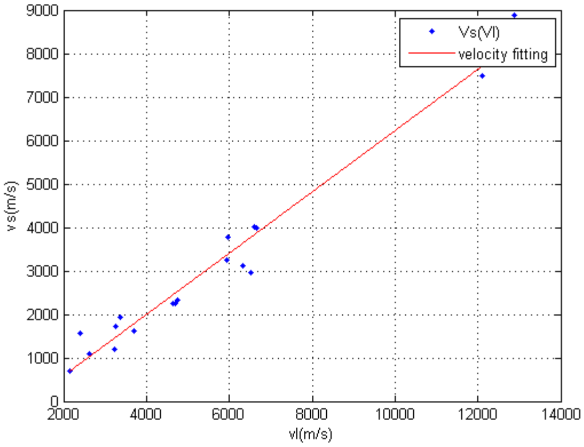
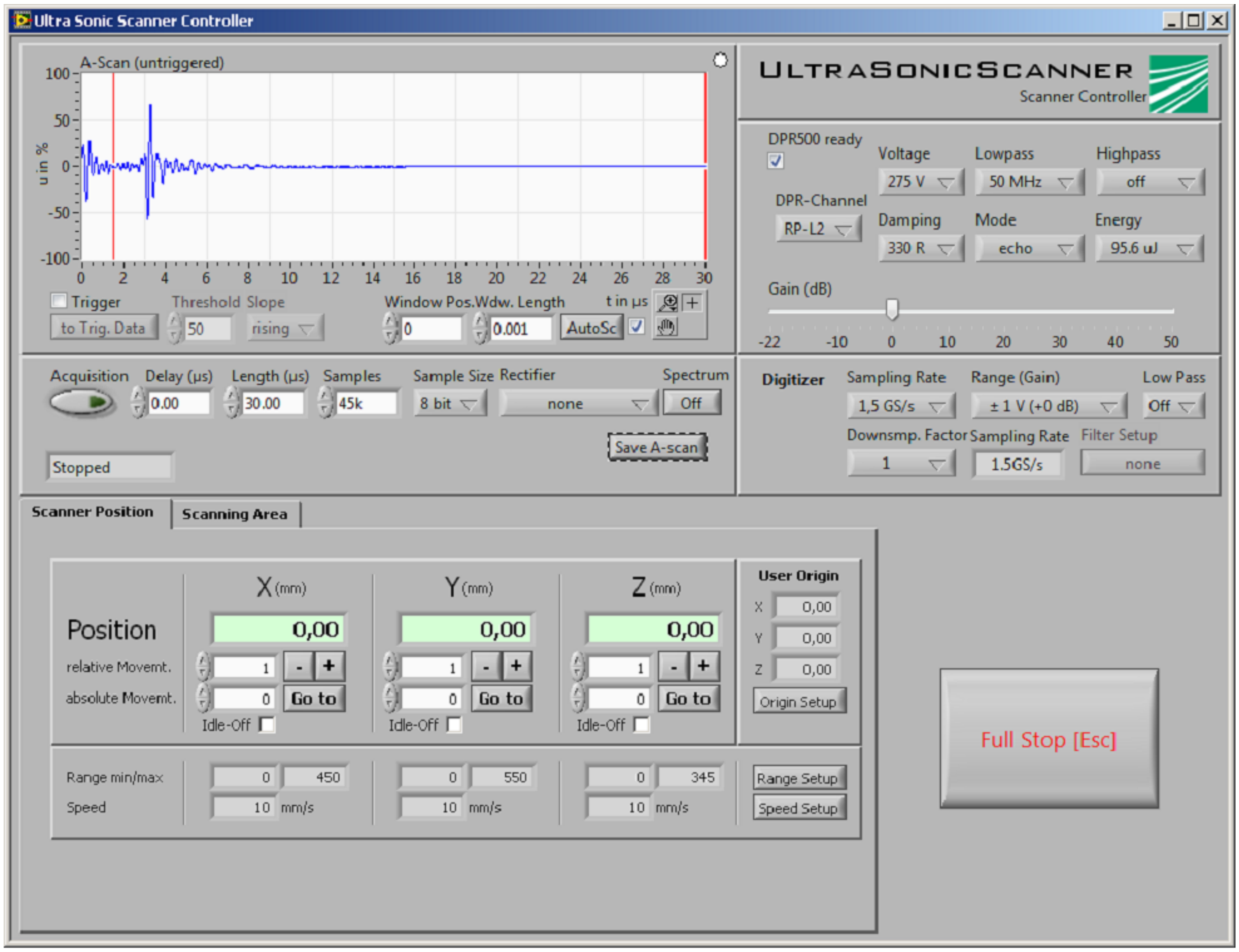


Figure 1: Relation between the different speeds of the modes, for a set of homogeneous and isotropic materials. $c_s = f(c_l)$

Appendix B

Velocity measurement program

In order to calculate the longitudinal velocity, from the curve taken from the scanner software (figure 1), we created an algorithm for process it



DPR500 ready ☑

DPR-Channel: RP-L2

Voltage: 275 V

Lowpass: 50 MHz

Highpass: off

Damping: 330 R

Mode: echo

Energy: 95.6 uJ

☐ Trigger: to Trig. Data

Threshold: 50

Slope: rising

Window Pos.: 0

Wdw. Length: 0.001

Acquisition

Delay (µs): 0.00

Length (µs): 30.00

Samples: 45k

Sample Size: 8 bit

Rectifier: none

Spectrum: Off

Stopped

Digitizer

Sampling Rate: 1,5 GS/s

Range (Gain): ± 1 V (+0 dB)

Low Pass: Off

Downsmp. Factor: 1

Sampling Rate: 1.5GS/s

Filter Setup: none

	X (mm)	Y (mm)	Z (mm)
Position	0,00	0,00	0,00
relative Movemt.	1	1	1
absolute Movemt.	0	0	0
Idle-Off	☐	☐	☐
Range min/max	0 450	0 550	0 345
Speed	10 mm/s	10 mm/s	10 mm/s

User Origin

X 0,00

Y 0,00

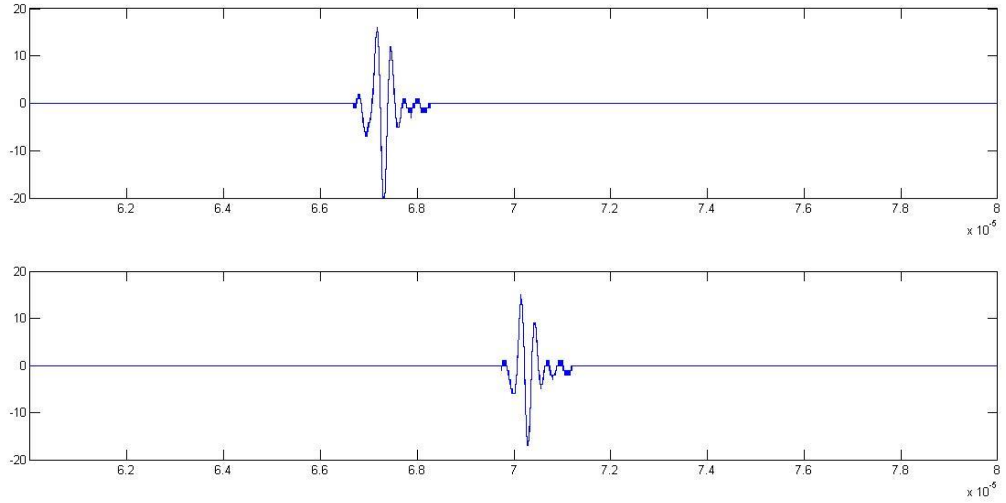
Z 0,00

Figure 1 : Scanner software - main window

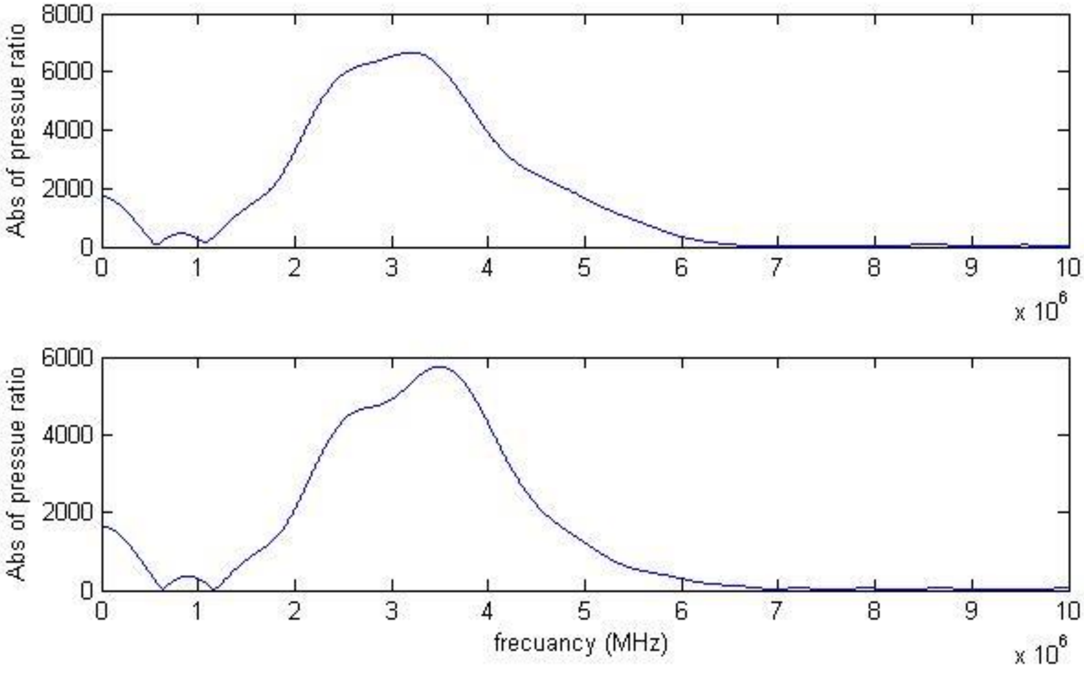
1. Start by making a window by multiplying the pressure vector which named “Ascan” by the scanner software, in function H, which is defined as the following relationship

$$H(t) = \begin{cases} 0 \text{ for } t < a \,; t > b \\ 1 \; for \; t \; \in [a, b] \end{cases} \qquad \text{(B.1)}$$

Where a and b are the beginning and end of the pulse, and are determined by our side



(a)



(b)

Figure 2: (a).Two pulses in difference time x-zoomed to $2*10^{-6}$ µs; (b): FFT for the previous pulses respectively.

2. Now we can draw the pressure curve in dependent of frequency,

3. After the previous operation we use the cross-correlation function (part II 3.3) to calculate the time difference between the pulses

4. The program displays the longitudinal velocity and the transversal velocity values calculated with the following relations respectively.

$$V_l = \frac{\Delta L}{\Delta t} \tag{B.2}$$

$$V_s = 0.705V_l - 824 \tag{B.3}$$

Relationship (B.3) obtained from the speed adjustment process (see Appendix A).

The algorithm is programmed to rerun several times, and record the values of the longitudinal velocity, and then calculate the mean value and standard error of the set of values taken.

ملخص

يتطرق هذا العمل إلى الدراسة التجريبية لبعض العينات، (سبيكة ألمنيوم، قطعة فولاذ كاربوني x52، وقطعة فولاذ كاربوني x70) من أجل تحديد الخصائص الميكانيكية باستخدام الأمواج فوق الصوتية. بالاعتماد على نتائج محاكاة الإشارة الصوتية المستقبلة بواسطة المسبار الصوتي، تمكننا من استغلال الإشارة التي تم الحصول عليها تجريبيا، وباستخدام علاقات السرعة الطولية والعرضية التي تربطها بمعاملات المرونة تمكننا من حساب معامل يونغ، معامل القص ونسبة بواسون للعينات المدروسة.

الكلمات المفتاحية: فوق صوتي، اختبار غير إتلافي، إشارة صوتية، معامل مرونة، الثوابت المونة، معامل يونغ، معامل القص، مسبار صوتي، نظام اختبار.

Abstract

This work deals with the experimental study of some samples (Aluminum alloy, steel X52 and steel X70), in order to determine the mechanical properties using ultrasound. Based on the results of the simulation of the acoustic signal received by the sonic probe, we can exploit the signal obtained experimentally, using the longitudinal and transverse velocity relationships that enable it to calculate the young modulus, the shear modulus and the Poisson ratio of the studied samples.

Keywords: NDT, ultrasonic testing, acoustic waves, elastic waves, elasticity modulus, young's modulus.

Résumé

Cette étude porte sur l'étude expérimentale de quelques échantillons, d'un alliage d'aluminium, d'une pièce d'acier au carbone X52 et d'une pièce d'acier au carbone X70 afin de déterminer les propriétés mécaniques à l'aide d'ultrasons. En utilisant les relations de vitesse longitudinale et transversale, nous pouvons calculer le coefficient de Young, le coefficient de cisaillement et le coefficient de Poisson des échantillons étudiés.

Mots clé : CND, control par ultrasons, ondes acoustiques, ondes élastiques, module d'élasticité, module de Young, vitesse longitudinale, vitesse transversale.