OULU UNIVERSITY OF
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LOW FREQUENCY ULTRASOUND PROPAGATION IN METALLIC MEDIA

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Bachelor’s Thesis
Spring 2014
Degree Programme in Information Technology
Oulu University of Applied Sciences

PREFACE

This Bachelor's thesis was offered by Esa Törmäla and Jarno Koskinen from Tuotantostudio Laboratory of Oulu University of Applied Sciences Raahe Campus, it was made under the supervision of Risto Korva, senior lecturer at Oulu University of Applied Sciences. The thesis deals with a low frequency ultrasound propagation in metallic objects, of different type and kind, generated by a piezoelectric transducer. It addresses the possibility of using it as a measurement tool based on the data collected form the testing and experiment of cheaper transducers. All the experiment and testing was done in Tuotantostudio Laboratory. This document was prepared by Melaku Woldesenbet, a prospective Information Technology Engineering student at Oulu University of Applied Sciences as a final year bachelor's thesis 2013\2014 academic year.

Raahe 22 May, 2014

Woldesenbet Melaku Woldeyesus

TIIVISTELMÄ

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Ultraääntä käytetään kuvaamiseen, havaitsemiseen ja mittaamiseen hyvin monilla aloilla. Työssä keskityttiin ultraäänen käyttöön metallikappaleiden tutkimisessa. Aluksi tutustuttiin tehdasvalmisteiseen tarkkuusmittalaitteeseen, jota käytetään ainetta rikkomattomassa eli NDT-tutkimuksessa. Tällaiset mittalaitteet käyttävät korkeita eli megahertsien luokkaa olevia taajuuksia. Nämä mittalaitteet ja niiden anturit ovat kalliita. Työssä tutkittiin edullisten pienitaajuisten ultraäänianturеiden käyttömahdollisuuksia metallikappaleiden tutkimuksessa. Nämä pienitaajuiset anturit on tarkoitettu etäisyysmittauksiin ilmassa ja niillä on rajoituksia silloin, kun väliaineena on metalli.

Työn teoriaosassa esitellään ultraäänen kiinteässä aineessa tapahtuvaan etenemiseen vaikuttavia asioita. Lisäksi kuvataan ultraäänen kehittämiseen ja vastaanottamiseen käytettävien pietsosähköisten kiteiden ominaisuuksia ja toimintaa. Työn toteutusosassa tehtiin joukko mittauksia kuudella ultraäänilähetin ja -vastaanotinkiteellä, joiden taajuudet olivat 40 kHz – 300kHz

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Avainsanat:

Piezoelectric, Oscillator, Amplifier, Curie temperature, Ultrasound,

Acoustic Impedance, NDT

ABSTRACT

Oulu University of Applied Sciences
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Ultrasound is one form of sound wave which is used to measure, detect and examine different kind of applications. Even though there is an already existing industrially made ultrasonic transducer that uses a high frequency ultrasound; it is expensive to get one for a personal use. Learning how to use the Olympus made ultrasonic transducer was a preliminary process before the overall step. On the other hand, there is a relatively cheaper low frequency piezoelectric in the market. Studying and testing it helps to reveal whether it can be used as a substitute in-place of one of the ultrasonic transducer's application which is called Non Destructive Testing (NDT). It is this initial idea that the document addresses about. The property of low frequency ultrasound wave, generated by the piezoelectric (40 kHz - 300 kHz), in a metallic media is the core point. For this particular purpose six samples of piezoelectric (MCUSD18A40S09RS-30C, MCUSD13A300B09RS, MCUSR18A40B12RS MCUSD14A48S09RS-30C, MCUSD14A40S09RS-30C, MCUSD14A58S9RS-30C) were tested in different metallic media. The data collected from the experiment elaborates the analysis made in this study.

Keywords:
Piezoelectric, Oscillator, Amplifier, Curie temperature, Ultrasound, Acoustic Impedance, NDT

CONTENTS

1 INTRODUCTION

Sound is a mechanical wave of compressible media that can be perceived with or without the help of sensor. The initial input energy is the vibration of physical body which causes the pressure and displacement of the particles in a medium that helps in transporting the wave. The medium could be either sold, liquid or gas. The science that studies the mechanical wave of sound is called acoustics. According to this disciplinary sound can be categorised into three based on the frequency range. These are infrared sound (less than 20 Hz), acoustic sound (between 20 Hz and 20 kHz) and ultrasound (above 20 kHz). The piezoelectric generated sound is therefore grouped under ultrasound.

Like any other sound wave ultrasound needs a medium to be transported. Its propagation type depends on the nature of the medium. Mainly in liquid and gas it is transmitted as longitudinal while in solid it is both longitudinal and transverse. In this project a couple of low frequency piezoelectric transducers which are available in the market are tested. It particularly analyses the nature of the wave propagation which is generated using these transducers through different kind and type of metallic media. (Wikipedia 2014, Date of retrieval 22.05.2014).

1.1 What is Ultrasound

As the name itself implies Ultrasound is a sound above the human hearing frequency range. The normal limit is about 20 kHz. Although it is similar to an audible sound Ultrasound has a much shorter wave length compared to it. This makes Ultrasound able to be reflected off even on very small surfaces. Ultrasound is used in different devices for different purposes, from the familiar ultrasound scanner for imaging a fetus in the womb to measurement and cleaning are some to mention. (Olympus 2006, Date of retrieval 22.05.2014).

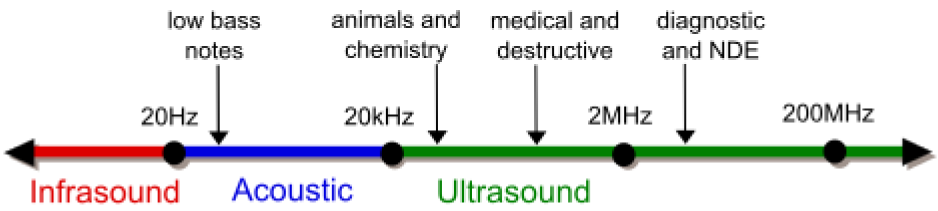

FIGURE 1. Acoustic spectrum (Wikipedia 2014b, Ultrasound range diagram, Date of retrieval 22.05.2014)

1.2 Piezoelectricity and Generation of Ultrasound

Piezoelectricity is an electrical charge which is generated in a crystal when it is pressured by a mechanical stress under its elasticity. Materials like crystals and certain ceramics generate piezoelectricity when deformed from their static structure.

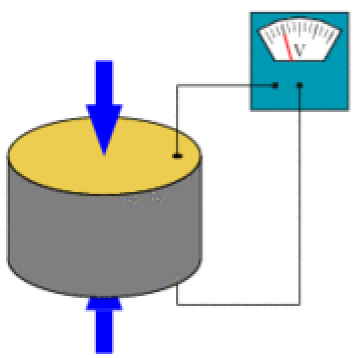

FIGURE 2. Deformation of piezoelectric disc generates a voltage (Wikipedia 2007, SchemaPiezo, Date of retrieval 22.05.2014)

Piezoelectricity was discovered by Jacques and Pierre Curie in 1880. The electromechanical interaction between a mechanical and electrical state in crystalline materials which is known as a piezoelectric effect, relates the two linearly. It is a reversible process in which the electric charge resulting from the mechanical stress also develops an internal mechanical strain when applied with an electric field. This process is used in the production of ultrasound waves. (PI Ceramic 1996-2014, Date of retrieval 22.05.2014).

Piezoelectric effect is the basic principle behind a piezoelectric diaphragm (substrate) which is the sound source in a piezoelectric sound. The diaphragm consists of a piezoelectric ceramic plate. It is this diaphragm’s oscillation that produces the ultrasound in a piezoelectric component. (Murata 2012, Date of retrieval 22.05.2014.)

2 THE WORK ENVIRONMENT

The overall study began by listing out the cheapest low frequency piezoelectric transducers available in the market. After choosing six of them, the purchasing was done. Just only possessing the piezoelectric does not help in the process of generating an ultrasound wave. It needs an external circuit that drives it. It should be connected to make it functional (to generate and receive an ultrasound wave). The Industrially made ultrasonic transducer has a built-in circuit of the same kind. So it does not require an external circuit unlike the piezoelectric transducers. Based on this idea, the receiver and transmitter circuit were made ready in the Tuotantostudio laboratory.

The main goal is not just generating, transmitting and detecting an ultrasound wave, rather to study its property while being propagated through metallic media. Like any other wave, a sound wave needs a medium (media) to travel from one end to another. Even though the purchased low frequency piezoelectric transducers are intended by the manufacturer for devices using air as a medium, I used different types of metals instead. The already available metals in the laboratory and the purchased ones were used as metallic media.

Counter checking of equipment used as a measuring and displaying tool is the core for the reliability of the data collected. This was done with the available equivalent equipment. It is also too tiresome trying to identify the faulty electronic components used in the already developed circuit. Preliminary testing and checking of the components save time and energy.

All the mentioned set up were like a platform for the piezoelectric transducer, which is the core of this study.

2.1 Piezo Electronic Transducers

A transducer is any device that transforms some form of energy to another form of energy. Likewise, a piezoelectric transmitter as a transducer transforms electrical energy to mechanical energy, which generates ultrasound, while the receiver transforms the perceived sound energy to a mechanical energy before ending as an electrical energy. On the other hand, the transceiver combines both duties. Therefore, it can act in place of either of them. Generally, Ultrasound transmitter, Ultrasound receiver and Ultrasound transceiver are the main transducers of this study. The conversion of electrical pulses to mechanical vibrations and the transformation of returned mechanical vibrations back into an electrical energy is the back bone in this testing process. The following listed piezoelectric were used as a study sample.

TABLE 1. List of piezoelectric transducers used in the study

Part number	**Type of transducer**	**Acoustic media matching material**
MCUSD18A40S09RS-30C	Transceiver	Aluminium
MCUSD13A300B09RS	Transceiver	Ceramic
MCUSR18A40B12RS	Receiver	Aluminium
MCUSD14A48S09RS-30C	Transceiver	Aluminium
MCUSD14A40S09RS-30C	Transceiver	Aluminium
MCUSD14A58S9RS-30C	Transceiver	Aluminium

2.2 Soldering and Curie-point

In order to solder electrical wires with the electrodes on the piezoelectric, one needs to bear in mind the Curie point (temperature) of the material. Exceeding the limit will cause the ceramic lattice structure to be more symmetric than the initiate depolarisation of a piezoelectric phase. Care should be taken of making sure the soldering temperature is below the curie point of the material. For the low power applications like the one in this thesis the usage temperature is the same as the ambient temperature, Otherwise the temperature dissipated in the ceramic is considered. As wiring was needed as the pins of some of the transducers used are shorter, the soldering temperature was used accordingly not to end up in spoiling them. (The Morgan Crucible Company 2009, Date of retrieval 22.05.2014).

TABLE 2. Curie temperature of materials (Wikipedia 2014b, Date of retrieval 22.05.2014)

Material	**Curie temperature** (k)
Cobalt (Co)	1400
CrO_2	386
$CuOFe_2O_3$	728
Dysprosium (Dy)	88
EuO	69
Gadolinium (Gd)	292
Iron (Fe)	1043
Iron(II,III) oxide ($FeOFe_2O_3$)	858
Iron(III) oxide (Fe_2O_3)	948
$MgOFe_2O_3$	713
MnAs	318
MnBi	630
$MnOFe_2O_3$	573
MnSb	587

2.3 Equipment

An Oscilloscope and a Multimeter were the mainly used equipment to mention other than the function generator which is used as source. The two were used interchangeably in some aspects. In this testing, the oscilloscope was mainly used as both displaying and measuring the signals. While the multimeter is used in measuring the values of the components used in an electrical circuit. The basic features in which most oscilloscopes share are listed below as follows

- A screen, displays a signal in a voltage time versus a time graph
- Vertical part controllers, related to a vertical part of the display.
- Horizontal part controllers, related to a horizontal part of the display.
- Trigger, used to synchronize the input signal to the horizontal display.

On the other hand a Multimeter combines various measurement functions. A typical one can measure voltage, current and resistor values. In addition to the basic features, it can incorporate other measurements like capacitance, conductance, inductance, frequency and the like. In this experiment it is used as a counterchecking value of electric circuit components, identifying faulty components and wiring. (Pengra D. 2007, Date of retrieval 22.05.2014).

2.4 Transmitting and Receiving Circuits for a Low Frequency Piezoelectric

Transmitting circuit is mostly built around the integrated circuit (IC) 555 or complementary metal-oxide semiconductor (CMOS) devices. In this particular case the 555 IC is used as an oscillator. It can also be used as a timer for time delays and a flip-flop element. The signal generated by the IC 555 is treated by the inverting buffer in 4049B CMOS, which provides six inverting buffers, before handing it to the NAND gate of 4011B IC that determines the reaching time of the signal. After all these, the signal is delivered to the ultrasonic sensor to be transmitted.

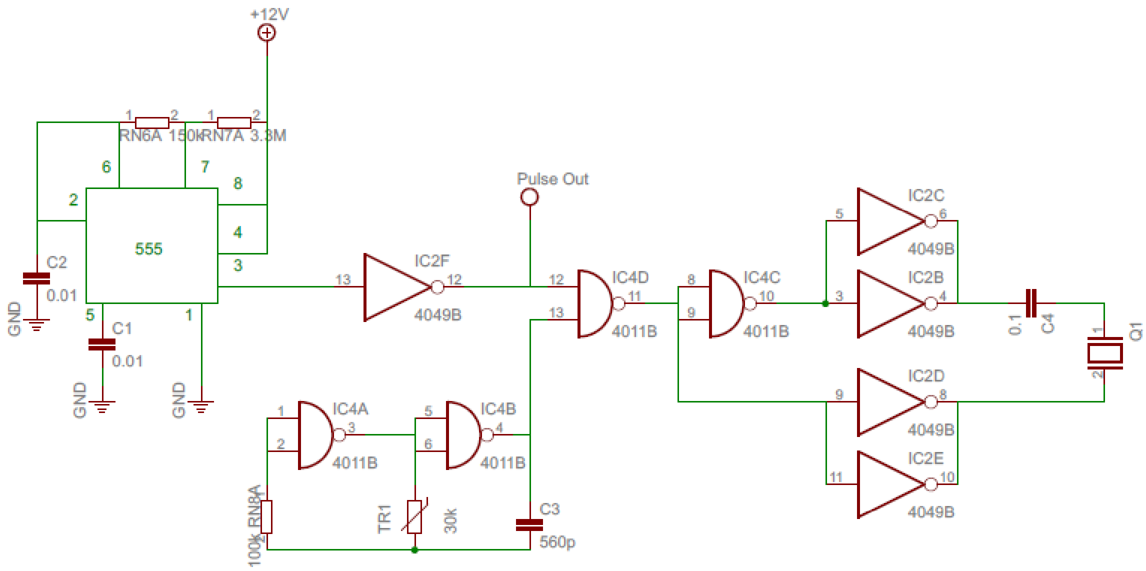

FIGURE 3. Transmitting circuit block schematic diagram (Murata 2008)

Receiving block is the one responsible for detecting the transmitted signal from the transmitting block. This block is mainly constituted of an operational amplifier (In particular CA3140 BiMOS) and common electronic components (resistors and capacitors). The CA3140 provides a very high input impedance, a very low input current and a high speed performance. It is internally phase compensated to provide a very stable operation.

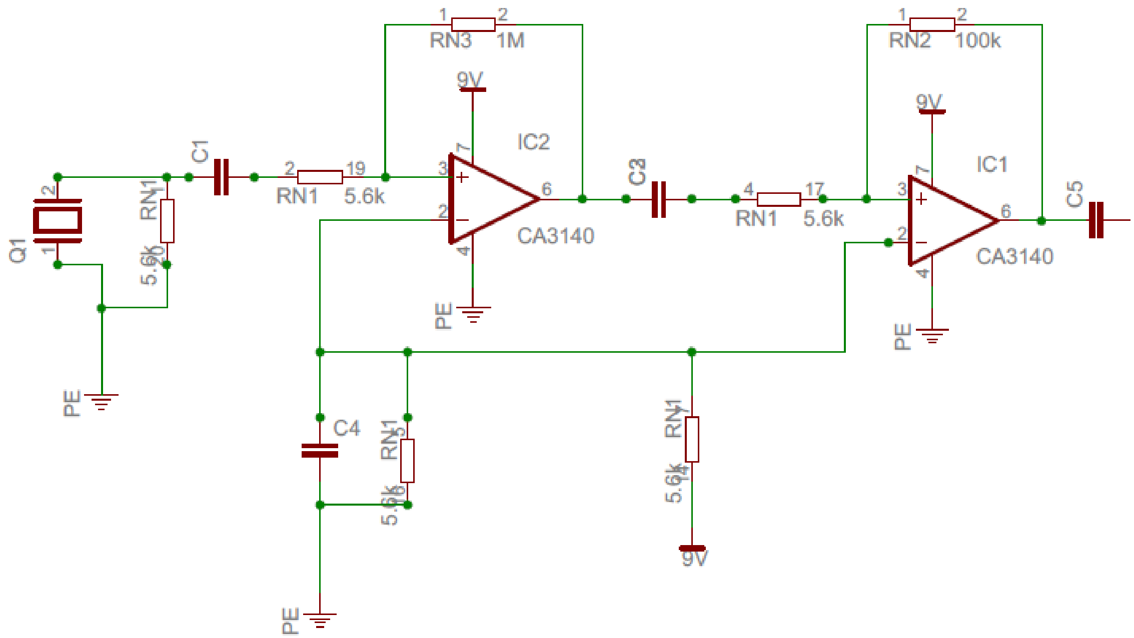

FIGURE 4. Receiver circuit block schematic diagram (Renesas 2004, Date of retrieval 22.05.2014)

3 DEFINITION

Matter is consisting of particles named atoms and molecules, which are bonded together in a certain fashion. These atoms are vibrating consistently in their equilibrium position without being noticeable to bare eyes. When matter is stressed or pressured under its plastic limit, the law of inertia applies in order to restore its natural state known as electrostatic force. This will cause the medium embracing it to go through an oscillatory motion to initiate a sound wave.

3.1 Crystals

The embedded active element is the heart of all the transducers as it converts the electrical energy to an acoustic energy and also the vice versa. It is made of a piece of polarized material, Some of the molecules are positively charged while the others are negatively charged. The electrodes are attached to two of its opposite faces. When an electric field is applied across the material, the polarized molecules will align themselves with the electric field, resulting in induced dipoles within the molecular or crystal structure of the material. This alignment of molecules will cause the material to change dimensions. This phenomenon is known as electrostriction. A standard dielectric in a capacitor can be taken as a good analogy to show the overall idea of how it functions. (Wikipedia 2014, Date of retrieval 22.05.2014).

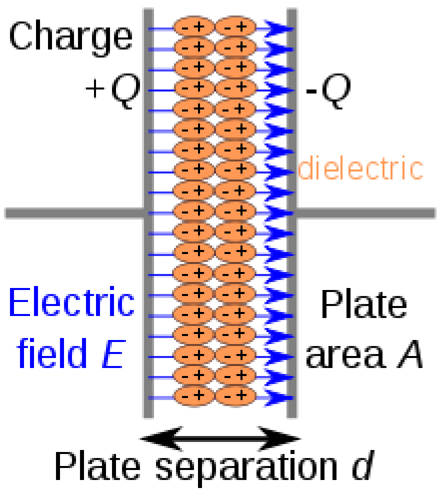

FIGURE 5. Dielectric in a capacitor (Wikipedia 2008, Date of retrieval 22.05.2014)

Electric field is developed whenever opposite charges are separated spatially, and that shows the existence of electric potential. The same principle is working in the case of piezoelectric materials but instead of the direct external applied voltage, electro mechanical stress is the cause of separation of charges. When this kind of material is made to change its dimension due to external mechanical force it will develop electric field which is the cause of electric potential. This phenomenon is called the piezoelectric effect. (Wikipedia. 2014, Date of retrieval 22.05.2014).

There are many polarized crystalline materials that exhibits piezoelectricity. Naturally occurring crystals like Quartz (sio_2), Table sugar and Rochelle salt are some of them among the many. The family of synthetic ceramics Barium titanate ($BaTiO_3$), Lead titanate ($PbTiO_3$) and Zinc oxide (ZnO) also exhibits this property.

From biological materials Tendon, Silk, Enamel and others can be mentioned in this category. (Wikipedia. 2014, Date of retrieval 22.05.2014).

3.2 Piezoelectric Sound Components

They consist of a ceramic plate which has electrodes on both sides and a metal plate. They are glued on each other. Whenever an external dc source is applied to the electrodes cause a change in a radial direction of the piezoelectric ceramic depending on the direction of the terminal connection. It will expand in one case and shrink in the other. Despite this, the metal plate glued to it does not go through any significant change, it makes the deformation radial. As In the case of AC, a source voltage connected to the electrodes causes the diaphragm (substrate) move up and down consistently. This vibration of the diaphragm generates a sound wave that is needed. (Murata 2012, Date of retrieval 22.05.2014).

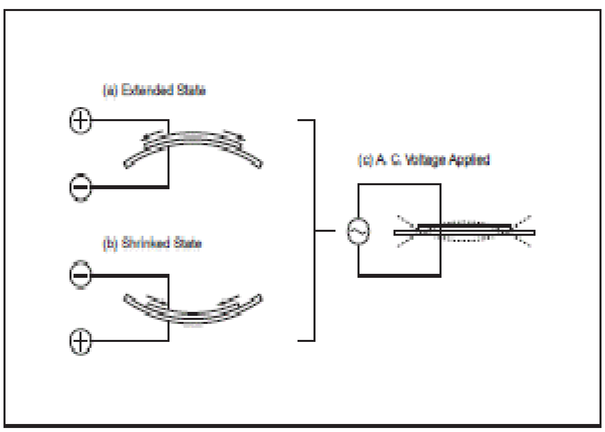

FIGURE 6. Distortion of piezoelectric element causes diaphragm bend up and down (Murata 2012, Date of retrieval 22.05.2014)

A Piezoelectric cased in a cap can be categorized as a self-drive type and an external-drive type. The Self-drive type incorporates a built in oscillator; Therefore just an external DC source makes it work properly. The External-drive type one needs an external circuit in addition to the voltage source, as the built-in oscillator is missing in it. The case (cap) for the piezoelectric can be plastic, ceramic, or metal depending on the objective it is needed for. (Murata 2012, Date of retrieval 22.05.2014).

3.3 Periodic Wave Properties

Wave is an oscillation or disturbance of matter that propagates through a medium from one point to another in space/matter. It generally has basic and derived characteristics that help to differentiate one from the other.

- Amplitude (A) - a measure of change of periodic variable in a single period. It is possible to measure either a peak-to-peak or peak amplitude of the wave.
- Wavelength (λ) - it is a distance between corresponding points where the wave repeats.
- Speed (c) – This tells the time rate of change of position of a wave form.
- Phase Constant (Δφ) – Position shift in a peridic wave.

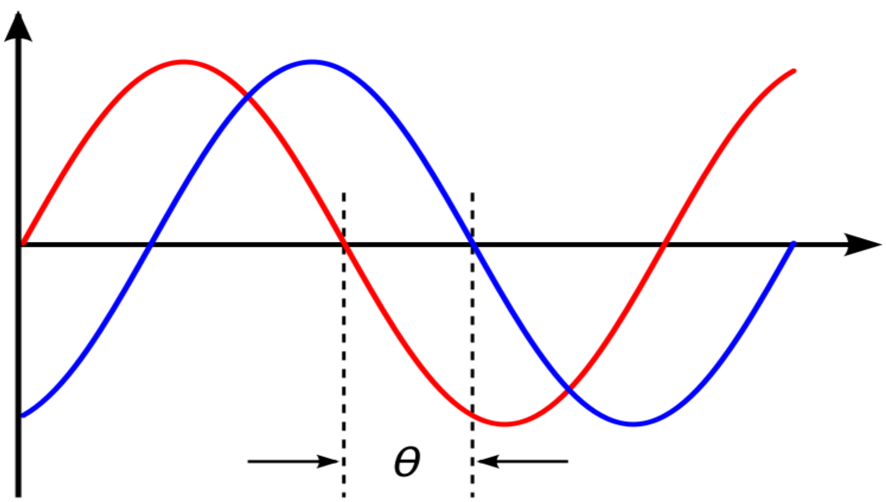

FIGURE 7. Phase constant (difference) between periodic waves
(All About Circuits 2003-2012, Date of retrieval 22.05.2014)

On the other hand the derived ones are listed as Period (*T*), Frequency (*f*), Angular Frequency (*ω*), and Wavenumber (*k*). (HyperPhysics 2006, Date of retrieval 22.05.2014).

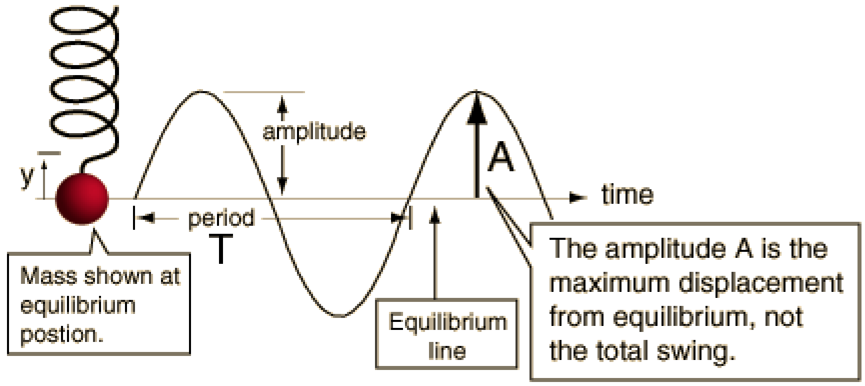

FIGURE 8. Derived characteristics of periodic wave (Rod N. 2000, HyperPhysics Date of retrieval 22.05.2014)

- $T = \lambda / v$
- $f = 1 / T$
- $\omega = 2\pi \quad f = 2\pi / T$ 1
- $k = 2\pi / \lambda$

(HyperPhysics 2006, Date of retrieval 22.05.2014)

3.4 Reflection and Refraction of Sound Wave

As the particles in the elastic medium are exposed to a disturbance by an external pressure or vibration; they move in a certain fashion out of the pre-existed one. It is this motion that transfers sound energy from one end of the medium to another which is known as a propagation. As it crosses the interface between media of different type, a part of it is refracted while the rest is reflected back to the original medium. The percentage of energy reflected back to the source medium can be calculated by multiplying the coefficient of reflection by 100.

$R = Z_2 - Z_1 / (Z_2 + Z_1)$ 2

Where R is Coefficient of reflection

Z_2 acoustic impedance of media 2

Z_1 acoustic impedance of media 1

For the refracted part of the wave that crossed the interface, Snell's Law can be applied. (Michael B. 2000, Date of retrieval 22.05.2014).

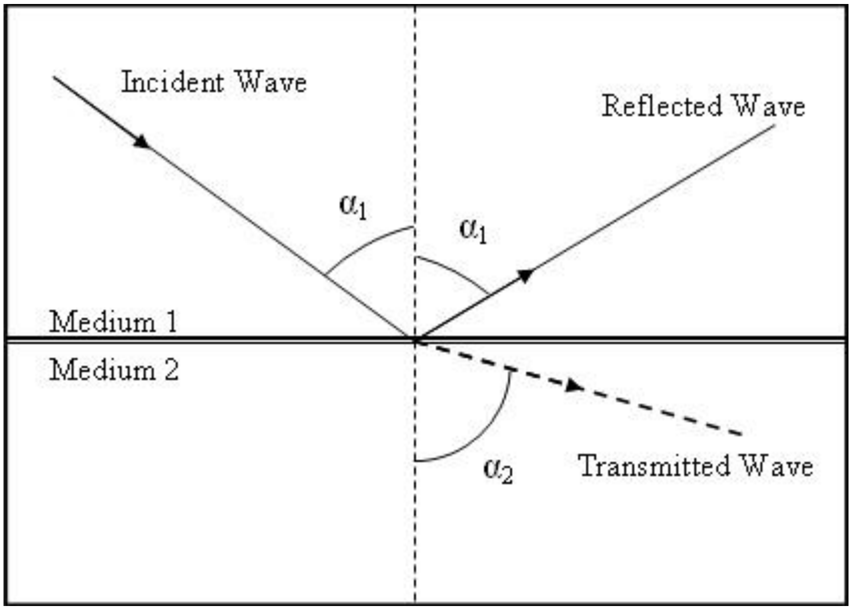

FIGURE 9. Transmitted and Reflected waves across the boundary medium (Tangient LLC 2014, Date of retrieval 22.05.2014)

$$Sin\alpha_1 / c_1 = Sin\alpha_2 / c_2 \qquad 3$$

Where α_1 angle of incident wave

α_2 angle of transmitted wave

c_1 velocity in media 1

c_2 velocity in media 2

3.5 Sound Wave Modes

The motion of particles in a medium caused by a sound wave is grouped into four basic categories relative to the direction of the propagation of wave. The four basic modes of sound wave modes are listed as follows

- Longitudinal (Compressional)
- Shear (Transverse)
- Surface (Rayleigh)
- Plate (Lamb)

All the modes are an extension of a Longitudinal Wave in one or another way. When the wave is refracted from its initial path due to a change of speed caused by the difference in an acoustic impedance of a media, it causes the particles to vibrate in a perpendicular direction to that of the wave. This motion of the particles is known as a Shear Wave. The Surface and Plate waves are the result of combination of Longitudinal and Transverse waves.

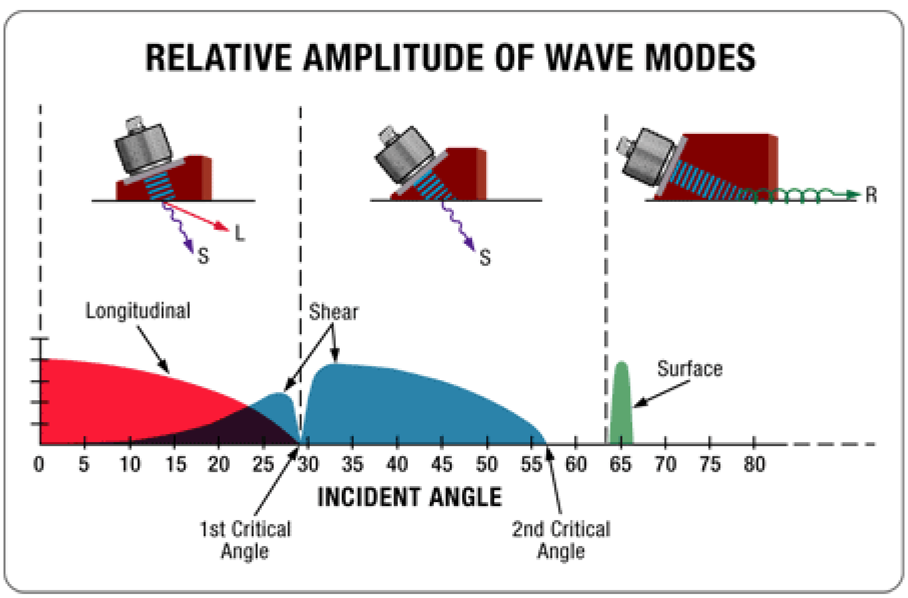

FIGURE 10. Longitudinal Shear and Surface wave (Olympus b, Date of retrieval 22.05.2014).

The Longitudinal wave makes the particle vibrate in the same direction (parallel) as the wave, while the shear wave is relatively perpendicular to the direction of motion of the particles. In the two states of matter, air and liquid, sound propagates as a longitudinal wave by compressing the particles in the same direction as of its motion due to a lower value of elasticity. Depending on the angle of incidence (which is the angle between the wave and the perpendicular line with the interface) in solid media, it propagates also in a shear wave mode. The higher the angle means, the higher the shear wave. Beyond the critical angle of incidence (which is when the wave is parallel with the interface), the wave mode turns to a surface wave mode. The Surface and Plate wave modes have the same property. As the propagation media is thicker, the wave type is surface; while it gets thinner like plate, the wave type is Plate wave. There are also other extended wave modes than the mentioned basic four modes.
(Iowa State University 2001-2014, Date of retrieval 22.05.2014).

TABLE 3. Wave modes in solid media (Iowa State University 2001-2014, Date of retrieval 22.05.2014)

Wave Types in Solids	**Particle Vibrations**
Longitudinal	Parallel to wave direction
Transverse (Shear)	Perpendicular to wave direction
Surface – Rayleigh	Elliptical orbit - symmetrical mode
Plate Wave – Lamb	Component perpendicular to surface (extensional wave)
Plate Wave – Love	Parallel to plane layer, perpendicular to wave direction
Stoneley (Leaky Rayleigh Waves)	Wave guided along interface
Sezawa	Ant symmetric mode

“- - With Lamb waves, a number of modes of particle vibration are possible, but the two most common are symmetrical and asymmetrical. The complex motion of the particles is similar to the elliptical orbits for surface waves. Symmetrical Lamb

waves move in a symmetrical fashion about the median plane of the plate. This is sometimes called the extensional mode because the wave is “stretching and compressing” the plate in the wave motion direction. Wave motion in the symmetrical mode is most efficiently produced when the exciting force is parallel to the plate. The asymmetrical Lamb wave mode is often called the flexural mode because a large portion of the motion moves in a normal direction to the plate, and a little motion occurs in the direction parallel to the plate. In this mode, the body of the plate bends as the two surfaces move in the same direction. - -”
(Iowa State University 2001-2014, Date of retrieval 22.05.2014).

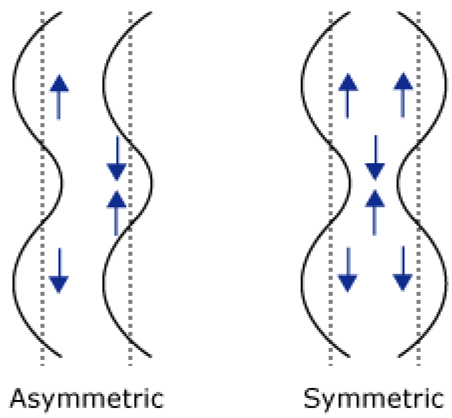

FIGURE 11. Modes of particle vibration (Iowa State University 2001-2014, Date of retrieval 22.05.2014)

3.6 Speed of Sound and Properties of a Medium

The speed of sound is dependent on the properties of the media through which it is being transported. In solid media the speed of transverse wave depends on the shear modulus and its density. On the other hand longitudinal waves in solid media depend on compressibility in addition to the two mentioned ones. The Elasticity of solid materials can simply be elaborated using a number of balls interconnected together using springs. The balls are an analogy for the particles of a medium and the spring for the bond that holds the particle together. As sound travels through the model by compressing and expanding the springs, transmitting energy to a ball will cause the springs attached to it to vibrate; so do the neighboring balls attached to the springs. (Tom H. 1996-2014, Date of retrieval 22.05.2014).

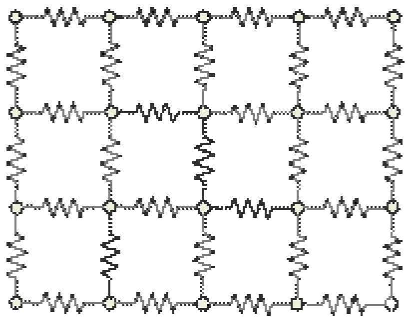

FIGURE 12. Balls interconnected using springs (Iowa State University 2001-2014, Date of retrieval 22.05.2014)

Elasticity of a material is the ability of a material to return back to its equilibrium position. The resonant frequency of each ball is directly related to the spring constant (k) and its mass (m). According to Hooke's law the restoring force (F) is directly proportional to the length of the spring (x) that is stretched within the elastic limit.

This is mathematically stated using Hook's law

$$F = -kx \qquad 4$$

Newton's second law states the force applied to a mass (m) is balanced by the particle's mass and its acceleration (a).

$$F = ma \qquad 5$$

Relating the two forces together shows only x and m are the variables as m and k are constant.

$$ma = -kx \qquad 6$$

The same principle holds when it comes to a sound wave too. A difference in the mass of the media determines the speed of sound. The spring constant is related to the elasticity of materials and the mass of the ball to its density. The speed of the sound is related to the density and elasticity using the equation below.

$$V = \sqrt{(C_{ij} / \rho)} \qquad 7$$

Where V is the speed of the sound, C is elasticity (elastic constant) and ρ the material density. The subscript ij under C shows the directionality of the elastic constant with respect to the wave type and its direction of motion.
(Iowa State University 2001-2014, Date of retrieval 22.05.2014).

TABLE 4. Ultrasound velocities in common solid materials (Olympus a, Date of retrieval 22.05.2014)

Material	**V** (in/μs)	**V** (m/sec)
Aluminum	0.2490	6320
Beryllium	0.5080	12900
Brass	0.1740	4430
Composite, graphite/epoxy	0.1200	3070
Copper	0.1830	4660
Diamond	0.7090	18000
Fiberglass	0.1080	2740
Glycerin	0.0760	1920
Inconel®	0.2290	5820
Iron, Cast (soft)	0.1380	3500
Iron, Cast (hard)	0.2200	5600
Iron oxide (magnetite)	0.2320	5890

3.7 Acoustic Impedance

The acoustic impedance (*Z*) of a material is defined as the opposition (reluctance) to the displacement of particles to the by sound wave. It is the product of the material density (ρ) and acoustic velocity (*c*).

$$Z = pc \qquad 8$$

Acoustic impedance is important in the determination of an acoustic transmission and reflection at the boundary of two materials having different acoustic impedances. When a sound wave hits the acoustic interface, which is the boundary between two different acoustic materials, at normal incidence, some of the waves transmit across the interface while the rest is reflected back to the original medium. This process is called dB loss.

$$dB\ loss = 10\ log_{10}(4Z_1Z_2 / (Z_1 + Z_2)) \qquad 9$$

Where, Z_1 and Z_2 is the acoustic impedance of the first and second material respectively. (Olympus NDT 2006, Date of retrieval 22.05.2014).

3.8 Near Field

A sound filed is generally divided into two zones, the Near Field and the Far Field. The near field in particular is the place close to the contact surface. In this region the echoed wave goes a noticeable amplitude difference due to the fact that it is very difficult to analyse the flaw of using an amplitude based technique

The near field distance (*N*) of the transducer frequency is calculated using the element diameter (*D*) and the sound velocity (*c*) of the test material.

$$N = D^2/4c \qquad 10$$

(Olympus NDT 2006, Date of retrieval 22.05.2014).

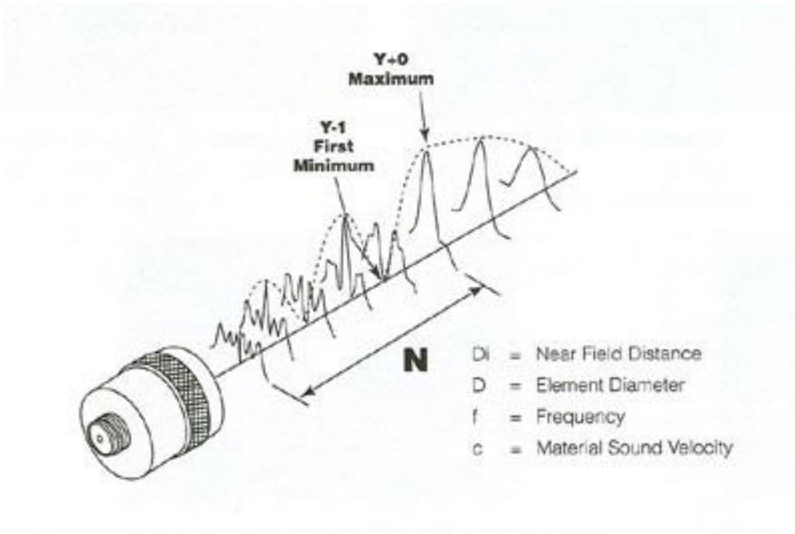

FIGURE 13. Near and Far field effect of a Transducer (Boston Piezo-Optics Inc. (No year of publication), Date of retrieval 22.05.2014)

4. MEASUREMENT

The measurement was done using the industrially made high frequency ultrasonic transducer which is a self-drive type and a low frequency piezoelectric transducer external-drive type driven by an external circuit which was developed in the lab. The industrially made ultrasonic transducer was needed as a bench mark to analyse the extent and possibility of using a low frequency piezoelectric in place of it. As a non-destructive testing (NDT), it introduces high frequency sound waves into the sample media needed to be measured or tested without causing any effect. The goal was achieved by measuring two basic quantities.

- Time of flight – It is the amount of time needed to travel through the sample.
- Amplitude of received signal – The displacement from the equilibrium position.

The samples which had been taken for this purpose were chosen based on the type and kind of metal.

TABLE 5, Sample types

Type	Shape	Kind	Relative size
Steel	Quadrilateral	Homogenous	Medium
Steel	Quadrilateral	Homogenous	Smaller
Steel	Rod	Seamed	Longer
Aluminium	Rod	Homogenous	Shorter

4.1 Ultrasonic Transducer

The four major transducers incorporated in the Olympus made ultrasonic transducers are listed as Dual Element Transducers, Angle Beam Transducers, Delay Line Transducers, Immersion Transducers and Normal Incidence Shear Wave Transducers. As mentioned earlier, time-flight and amplitude are the two basic quantities measured using these transducers as a non-destructive testing device. Based on the round trip time flight through the sample material, thickness or length can be calculated using the mathematical relation below. (Olympus NDT 2006, Date of retrieval 22.05.2014).

$$T = ct / 2 \qquad (11)$$

Where T is Material Thickness

c is Sound Velocity in a Sample Material

t is Time of Flight

(Olympus NDT 2006, Date of retrieval 22.05.2014).

Measuring amplitude on the other hand helps to determine the sizing flaws or attenuation of a sample material. It is usually measured in decibels (dB) which is the logarithmic value of the ratio the amplitude of two signals.

$$dB = 20 \log_{10} (A_1 / A_2) \qquad 12$$

Where *dB* is Decibels

A_1 is Amplitude of Signal 1

A_2 is Amplitude of Signal 2

(Olympus NDT 2006, Date of retrieval 22.05.2014).

For this particular study only the Normal Incidence Shear Wave Transducer is used as a bench mark in measuring the length and thickness of the sample materials. It was almost precisely able to meet the intended goal in every sample in which the measurement was done. Initially the measurement test was done on the calibrated steel plate to counter check the result. This assures the reliability of the measurement made by this Shear Wave Transducer.

FIGURE 14. Normal Incidence Shear Wave Transducer from Olympus (Olympus c, Date of retrieval 22.05.2014)

As a standalone transducer it has its own advantages

- It generates a shear wave type which is perpendicular to the sample surface
- Ease of alignment
- The ratio of the longitudinal to a shear wave component is generally below -30dB

4.2 Piezoelectric Transducers

Bearing in mind the low frequency piezoelectric transducers have used in different applications for various purposes using air as a transporting medium, the study was done to examine the possibility of using it in solid materials particularly in metallic objects. As they are an external-drive type transducer, it was needed to connect them with an external source generator as an oscillator while on the other time with the laboratory developed oscillator circuit.

Even though this study is limited to detecting the propagated signal through a metallic medium from the transmitter, the aim is far sighted from just simply it. This is the initial step to go ahead and meet the goal of using it in place of the very expensive ultrasonic transducers. It prevails hope for further develop the possibility of using it not only in air but also through metallic media. The piezoelectric which are used in this study are either a Transmitter, a Receiver (which is a separate component) or a Dual Functional Transceiver, which can be used alternatively.

TABLE 6. List of Piezoelectric and their signal propagation strength through steel

List of piezoelectric	**Frequency** (kHz)	**Steel Plate**	**Input Voltage** (V_{pp})	**Output Voltage**	
				Max (V_{pp})	Min (V_{pp})
MCUSD18A40S09RS-30C	40	Seam	10	9.44	9.36
		Seamless	10	9.44	9.36
MCUSD13A300B09RS	300	Seam	10	0.58	0.53
		Seamless	10	–	–
MCUSR18A40B12RS	39	Seam	10	9.02	6.02
		Seamless	10	8.44	6.02
MCUSD14A48S09RS-30C	48	Seam	10	6.36	6.24
		Seamless	10	6.36	6.40
MCUSD14A40S09RS-30C	40	Seam	10	1.24	1.08
		Seamless	10	1.42	1.36
MCUSD14A58S9RS-30C	58	Seam	10	9.44	9.36
		Seamless	10	9.52	9.36

The signal generated from the MCUSD13A300B09RS was relatively weaker through the metallic sample media on the receiver side but the rest, except MCUSD14A58S94S - 30C, the signal was comparably stronger and stable. The analysis of the signal will be detailed in the conclusion part.

5 POSSIBILITIES of FUTURE DEVELOPEMENT

One of the major aims of this thesis was to assess the possibility of using the piezoelectric as a non-destructive test device to measure length by using the same technique used by the Normal Incidence Shear Wave Transducer. In the previous title, it was mentioned the two basic quantities which need to be measured to determine the length or thickness of a medium in which the wave is propagated. This basic idea also applies while using a piezoelectric transducer as a measuring device. For this particular case the burst signal was introduced into a steel metal block of about 1.5m. The signal was then reflected back on the end surface of the steel and it reached the initial original spot after a round trip of the block, collected by a receiver.

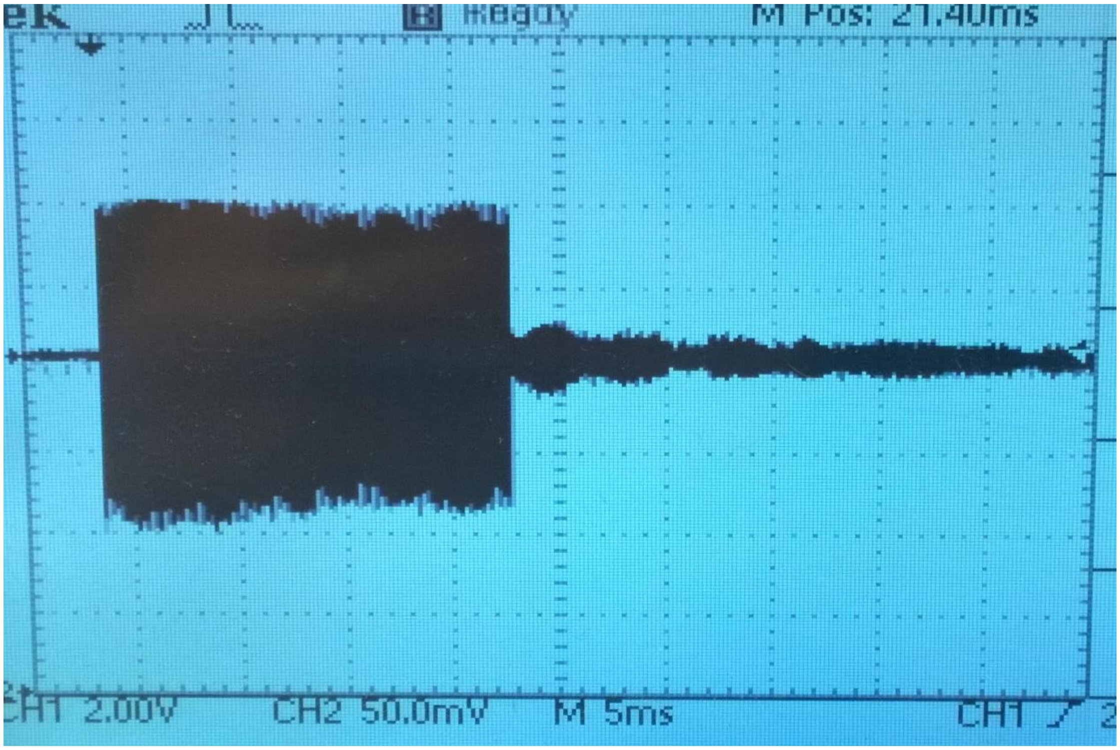

FIGURE 15. Shows the burst signal received after it is reflected back on the surface of a steel block. (Korva R. 2014, Tuotantostudio.)

This reflected back burst signal is comparable to the flight time as in the ultrasonic transducer. Here time can be calculated using basic mathematics of subtraction, the difference between the initial time of the burst signal and the destination time when it is reflected back to the original position. As can be easily noted on the picture the burst has noise. This makes it difficult to use as it is. The possible cause of this noise is the aggregate of the near field effect, unwanted reflected back signals and other reasons. This can be addressed by developing an external circuit that can be used to alleviate the problem of sensitivity, axial and near surface resolution ability.   The method applied on external noise suppression method might solve the problem. As the study is limited, studying the propagation of the wave could not be made any further development. This will make the possibility open for a further study of using the low frequency piezoelectric which is made for air as propagation media, as a non-destructive testing device for measuring the length of metallic objects. The received, reflected back signal, was strong as clearly can be noticed in the figure except the noise.

As a low frequency signal can travel a longer distance without being reflected back unlike the high frequency signals driven by the ultrasonic transducers, this property favours it over its counter ultrasonic transducers. As frequency and wave length are inversely related implies the higher the frequency, the lower the amplitude.

$$\lambda = v / f \qquad (13)$$

Where v is the phase velocity

f is wave's frequency

λ is wave length

The wave with a lower amplitude cannot make a turn around and proceed its way. Instead is reflected back to the same direction or diverted in some angle from its initial path. This can be illustrated using the figure below.

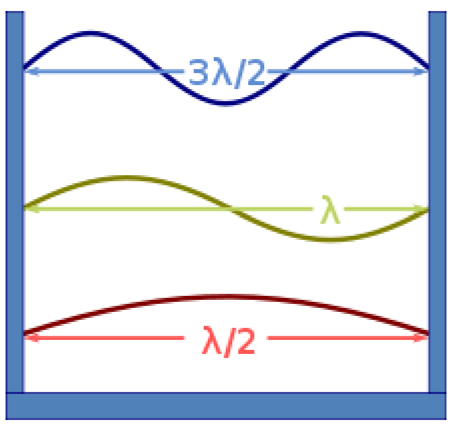

FIGURE 16. Sinusoidal standing waves in a box with different frequencies (Wikipedia 2009, Date of retrieval 22.05.2014)

6. CONCLUSION

In this topic I will go through the potential internal and external bodies that played a role in affecting the result so far what is achieved. Internal potential causes are the ones that are related to the attribute of the piezoelectric intact component from the production line. On the other hand the external potential intruders are the ones that caused noise in the collected data outside of the main piezoelectric body itself. Out of the eight piezoelectric testing samples two of them will be considered to verify the analysis.

TABLE 7. Technical terms for MCUSD13A300B09RS piezoelectric (Farnell 2013, Date of retrieval 22.05.2014)

No	Item	Specification
1	Part Number	MCUSD13A300B09RS
2	Construction	Water Proof
3	Using Method	Dual Use
4	Centre Frequency	300 ± 15kHz
5	Receive Sensitivity Echo (V)	≥800mV (driven signal: 200Vp-p, 300kHz, at 20cm)
6	Capacitance (pF)	300 ± 25% at 1kHz
7	Max. Input Voltage	400Vp-p
8	Directivity (-3dB)	10 ± 2
9	Distance of Detection	0.04m to 1m
10	Protection Class	IP65
11	Material	Aluminium
12	Operating Temperature Range	-20°C to +80°C
13	Storage Temperature Range	-35°C to +85°C

TABLE 8, Technical terms for MCUSD18A40S09RS-30C piezoelectric (Farnell 2013, Date of retrieval 22.05.2014)

No	Item	Specification
1	Part Number	MCUSD18A40S09RS-30C
2	Construction	Water Proof
3	Using Method	Dual Use
4	Centre Frequency	40 ± 1kKz
5	Sound Pressure Level (dB)	≥90 (30cm/10V rms)
6	Sensitivity (dB)	≥-90dB/V/μbar
7	Beam pattern	110 × 50°
8	Capacitance (pF)	2,000 ± 25% at1kHz
9	Operating Temperature Range	-40°C to 85°C
10	Storage Temperature Range	-40°C to 85°C
11	Allowable Input Voltage (Vp-p)	160V
12	Housing Material	Aluminium

6.1 Internal Potential Cause of Distortion

As it is observed closely the engineering of low frequency piezoelectric, the characteristics of the piezoelectric element, which is the core producer of ultrasound, have an impact on the output. This element is made of different kinds of piezoelectric materials characterised by several coefficients. These coefficients are the comparison scale to decide which one is better than the other. The data sheet along with the piezoelectric state the value for each of the listed piezoelectric coefficients.

- Electrical flux density (D)
- Mechanical stress (T)
- Electrical field(E)
- Mechanical strain(S)
- Piezoelectric charge coefficient(d)
- Permittivity(ε^T) for constant T
- Compliance or elasticity coefficient(s^E) for constant E

These can be simplified using the relationship between the electrical and elastic properties as

$$D = d \times T \times \varepsilon^{T} \times E \qquad 14$$

$$S = s^{E} \times T + d \times E \qquad 15$$

As the technical data from the manufacturer does not state any of the mentioned coefficients, it is unfortunate to calculate the parameter D and S, which would have helped to make the analysis about the electromechanical property. But generally speaking, the higher value of these parameters shows the stronger ultrasound generation possibility. The dielectric inside the cap and the media matching surface can be treated as a single total permittivity constant as the generated signal is propagating through a metallic object.

6.2 External Cause of Distortion

There are a number of external causes that can be counted as a possible source of the distortion. The reflected back signals at the contact surface are one of the causes of the distortion. The more vacuum space availability in between the contact surfaces almost makes the propagation impossible, as any form of sound is reflected back. Therefor the receiver detects a very distorted and unstable signal. On the other hand as sound travels through different boundaries causes reflection. Whenever there is a big mismatch, so there is also a recognisable reflection. This can be justified using the coefficient of reflection.

$$R = ((Z_2 - Z_1) / (Z_2 + Z_1))^{2} \qquad 16$$

Where R is Coefficient of Reflection

Z is Acoustic Impedance of The Materials

Multiplying this ratio by 100 gives the percentage of energy that is dissipated at the interference or boundary relative to the original energy. Like any other signals which are generated using a transducer are susceptible to Near Field Effect, it is affected by the effect in around the transducer.

On the other hand, even though the lower frequency of piezoelectric transducers favours it over the ultrasonic transducers; it also has its own disadvantage. As the frequency gets lower to the frequency of a human audible sound; the counted number of interference from the surrounding environment increases. It even makes it difficult to alleviate the interference using the noise reduction circuit as it shares similar characteristics.

Being said all, almost all the sampled piezoelectric except one were able to transmit the generated signal through the sample media. The exceptional one has a big value of coefficient of reflection due to its media matching material type, which is of ceramic unlike the aluminium one for all the rest. As it is stated earlier, the big difference in an acoustic impedance is the cause for signal reflection while transmitting through the media interface. All the rest of the piezoelectric transducers were able to transmit the signal due to the closer value of acoustic impedance with the transmitting media.

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