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Process Technology

Use of Process Analytical Technology (PAT) as on-line measurement technique for pipe erosion due to particle impact

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(Chandana Ratnayake, Maths Halstensen)

Summary:

Solid particle impact is getting enormous attention due to rapid progress and development in coal conversion plant, where flows of solid particles are sky-scraping at various equipments of plant. Such particles flow can lead to severe erosion in plant for example valve constrictions, blades, pipe joints and other surfaces. The main aim of the thesis is on-line measurement technique of pipe erosion due to particle impact by using Process Analytical Technology (PAT). Three different methods have been introduced to find the thickness of the material. In 1st method, center is made rough and thickness is measure at various rough places by using ultrasonic sensor. Similarly in 2nd and 3rd method, rough edges of material and bending pipe thickness are measured respectively. Thickness of material can be calculated from the sinusoidal graph given by distance between 2 successive reflection (echo time) i.e. $T = V * t/2$. Result from three different experiment shows, erosion on the material can be measured precisely by the application of ultrasonic method. During ultrasonic testing of specimen, Amplitude vs Time graph appears to be higher oscillations at the beginning and almost negligible at the end. Several factors influence the graph for example sample delay, ON and OFF of high gain, high pass filter and low pass filter.

Preface

First and foremost, I would like to express my sincere gratitude to my supervisors Chandana Ratnayake and Maths Halstensen for their supervision and support while conducting this thesis work. I consider myself luckiest to work under their supervision. Their guidance and suggestions encouraged me to work and perform better.

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Porsgrunn, 15 May 2018

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Abbreviation

AoA	Analysis of Alternatives
FDA	Food and Drug Administration
HP	High Pass
KHz	Kilohertz
LP	Low Pass
MHz	Megahertz
MPa	Mega Pascal
MVA	Multivariate Analysis
MVDA	Multivariate Data Analysis
NDT	Nondestructive Testing
PA	Process Analysis
PAT	Process Analytical Technology
PC	Personal Computer
PCA	Principle Component Analysis
R&D	Research and Development
UTM	Ultrasonic Thickness Measurement
2D	Two Dimensions
3D	Three Dimensions
μs	Microsecond

1 Introduction

Erosion of materials due to the impact of particles can be life-limiting occurrence for the operation in erosive environment. Solid particle impact is getting more attention in recent year because of research and development in coal conversion plants, where flow of the solid particles is more in various equipment of the plant. This flow can cause severe erosion in different section of pipes like valve constrictions, blades, pipe joints and other surfaces [1]. Surface impact due to material is one of the methods of material degradation which can also classify as wear. This process consists of several complicated phenomenon like simulation and interacting processes with the numbers of other chemical process. Erosion of metal surfaces due to solid particles involves long time of exposure under the same condition (steady state condition) [2].

1.1 Background

Erosion is the result of interaction between solid surface and flow containing abrasive particles with a certain velocity [3]. There are 3 main reason to concern about erosion i.e. safety, economics and conservation. Failure of bridge or damage in pipe of oil and gas industry can result in human injury or even loss of life. It is a complicated process which arises due to the simultaneous and interaction processes, typically involve mechanical, chemical and material parameters. Considerable research investigated for the factors which cause erosion such as particle velocity, angle of impact, shape of particle, size of particle[4]. Figure1.1 shows the nature of erosion in 2 different materials.

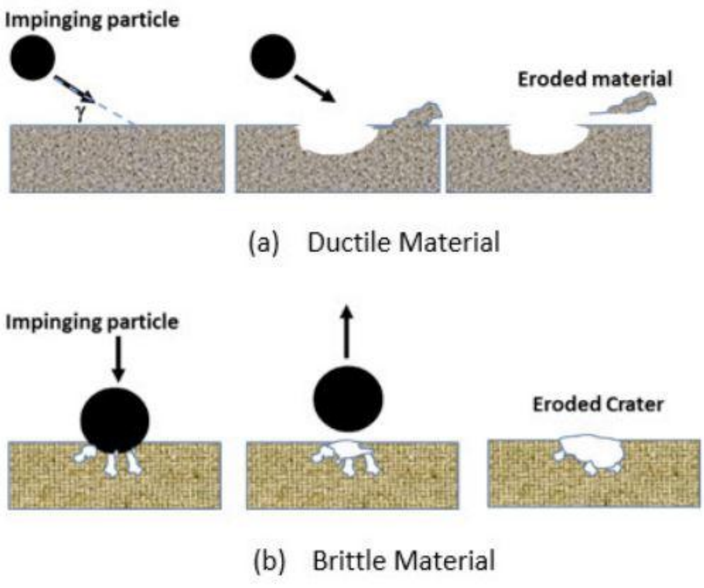

Figure 1.1: Erosion due to particle impact a) in ductile material b) brittle material [5]

Erosion in any surface of material is dependent of number of particles impact on it. Additionally physical quantities linked with it for example velocity of the particle, direction of the strike. These conditions can be determined by the flow pattern. Any small deviation in the flow condition can highly change the system. For example, if there is minor change in the viscous regime or temperature then it might largely vary erosion rate [3].

Many experiments were conducted to explain the erosion process but experiments are time and money consuming and also fail to provide the sufficient information about dynamic process of erosion. High speed camera is used to capture the impact on material. This process involved sophisticated instruments and expensive, which was not so friendly. However, numerical model such as computational fluid dynamic can explain stress, strain, interaction forces and deformation about information of particle and target material. Since it is reasonable in many ways also provides enough information to measure erosion [5]. For this thesis, we are going to use of Process Analytical Technology (PAT) as on-line measurement technique for pipe erosion due to particle impact. The result is compared with the standard methods.

1.2 Objectives of Thesis

The objective of thesis is to study feasibility of process analytical technology to measure erosion test in the pipes or bend section. Ultrasonic test machine has been used in order to appraise at dissimilar parts of the test specimen. Basically, the thesis has been divided into 3 phases.

- Phase – I: Use of Ultrasonic sensor to measure various edges of solid material.
- Phase – II: Use of Ultrasonic sensor to measure various part of irregular center surface of test material.
- Phase – III: Use of Ultrasonic sensor to measure various part of bend pipe and design clamp to hold the sensor.

1.3 Organization of the Report

The thesis is divided into 5 main topics. First topic explains about brief introduction with background and objective of the thesis. Second topic represents literature review of the erosion, test method and its industrial applications. Topic 3 is the main body of thesis where materials and methods are discussed. This topic involves testing of material thickness in 3 different phases, where two phases includes in plane surface and third involves in bending pipe. Similarly, topic 4 interprets results and discussion, where results of 3 different phases are briefly discussed. Topic 5 is conclusion of the work and also recommendation for future work. Images of the master’s thesis task description, apparatus used and ultramonit lab installation are attached at Appendix A, Appendix B and Appendix C respectively.

2 Literature review

Process analysis is getting well known across the various fields by the current acceptance in pharmaceutical industry as the element of Process Analytical Technology (PAT). This method is mostly based on real time analytics to the production problems [6]. In the recent days, it has been framework for innovative process in manufacturing field and in the quality assurance. The concept of PAT is to design, examine and production through measurement of identified critical control which oversee product variability [7]. However, our main aim of the thesis is to use of PAT as on-line measurement technique in pipe erosion due to particle impact.

2.1 Erosion

Erosion is the process in which the material gradually degraded solid particles or reduces in thickness of material through abrasion. There are many reasons which cause erosion. Mostly erosion take place at the bending where maximum stress is applied or where the particle impact is more as compared to other places. While considering the pipe, which carry liquid erosion mostly takes place at the bends of pipe. Similarly, if the material carries solid materials then maximum strike place is eroded more. Erosion can occur both inside and outside of the materials [8].

2.1.1 Erosion Mechanism

According to literature, there are number of ways to explain erosion mechanism based on different authors. Hence, it is difficult to explain by only one source. Based on our topic, erosion mechanism is explained as follows [9]:

Most commonly used metals are unstable expect gold and platinum which are already in metal state. Unstable metals are produces by the artificial process called reducing; therefore they tend to return to their original state when exposed to atmosphere. By the definition of corrosion, it is a process of material to return to its thermodynamic state [10].

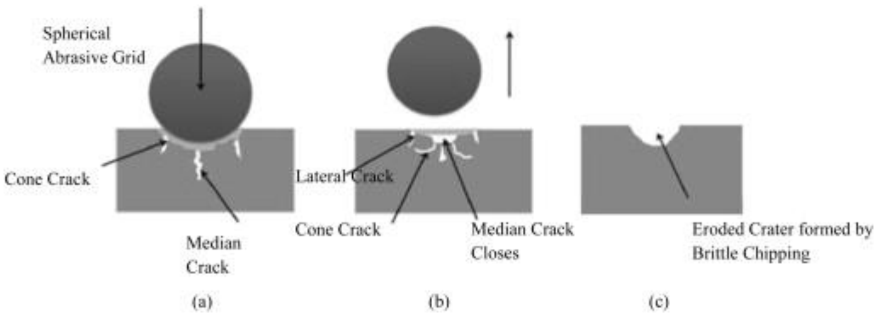

Figure 2.1: Erosion due to particle impact [12]

When particle impacts with certain speed, it scars the surface. Shape and size of scars on the surface depends on various parameters such as material surface, size of particles, and angle of impact. Based on the ductility of material, erosion mechanism gets changes [11]. Erosion in the ductile materials is the consequences of micro cutting. Particle impact to the surface with the low impact angle, there is a formation of crater. When other particle continuously impact then crater becomes larger also pile up around the crater. According to micro geometry model, the rate of erosion gets decrease if the surface of material is hard [12].

2.2 On-line measurement

The first step of measurement would be at-line testing comparing to off-line testing. This measurement steps lead to provide rapid results. There is also one advantage where, elimination of sample takes time delay. Besides traditional testing like dissolution, friability, hardness and thickness, one method of process analytical technology is on-line testing. In on-line testing, the sample either draws or monitors periodically. Process analytical technologies are the systems which can provide quality parameters and performance characteristics information of raw materials when it is on-line, in-line, at-line and off-line [13]. In on-line measurement, the sample is abstracted from the process then it is analyzed well and if it is appropriate then returned. On-line measurement process is shown in figure 2.2 [14].

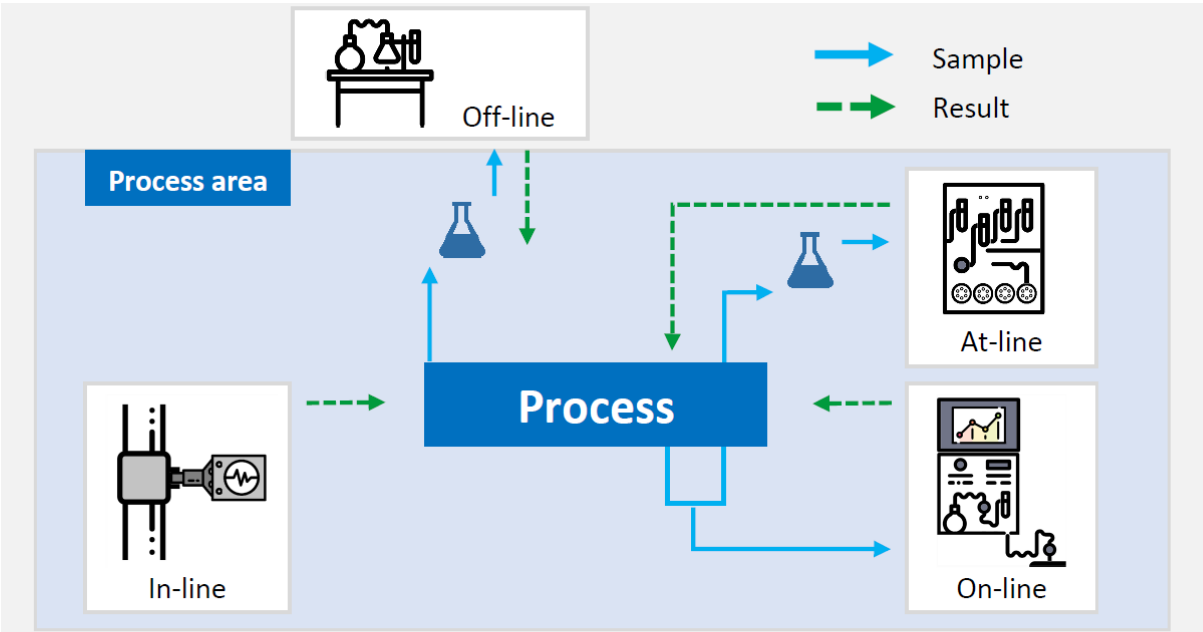

Figure 2.2: On-line measurement [15]

Operation of PATs includes application of the analytical chemistry, sensors, feedback process and information related to the operation. Additionally, the most fundamental of implementation involves scientific understanding of the manufacturing process and the effects on the physiochemical characteristics of the related product. In the on-line measurement process the probe is just on the line which passes information to the monitor [13].

2.3 Ultrasonic Method

Ultrasonic thickness measurement (UTM) is the non destructive testing process, in which the thickness of the material is measured by time taken by the ultrasonic wave to return to the surface (initial position) [15].

2.3.1 Working Principle

Ultrasound is the sound which is higher than the human hearing i.e. 20 KHz. In the ultrasonic testing, the sound pulse has to be travelled inside the test material from the initial position to inside surface or wall then reflect back to initial position. The refection occurs generally from different material. In this method, the transducer contains a piezoelectric element which is energized by the short electric impulse to generate the ultrasonic wave. Thus, the generated wave travels in the test material and return back to transducer which converts sound energy into electrical energy. This can be illustrated by the mathematical formula and graphical representation [16]:

Mathematically,

$T = V * t/2$

Where,

T = Thickness of the test material or specimen

V= Velocity of the test material or specimen

t= To and fro time taken in test material or specimen

Figure 2.3 shows the working principle of ultrasonic testing.

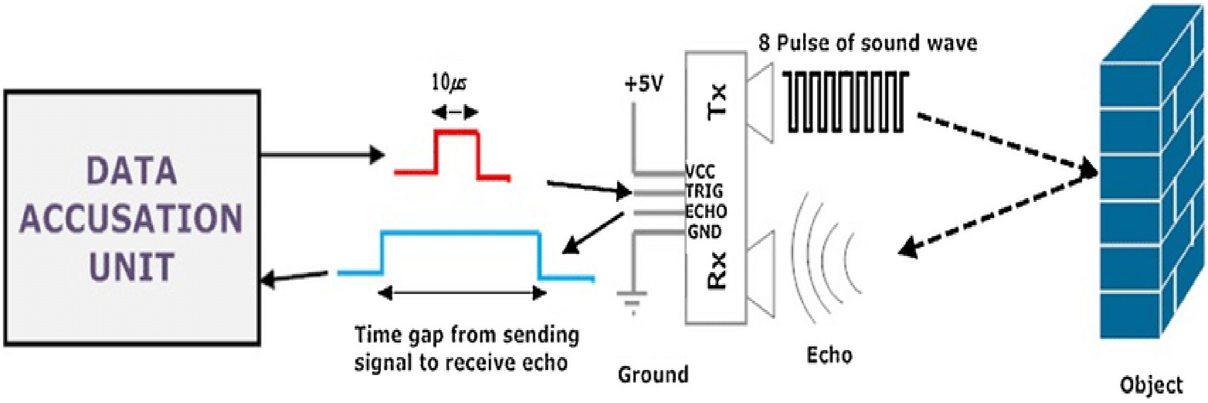

Figure 2.3: Working principle of Ultrasonic sensor [17]

2.3.2 Measurement Modes

There are commonly 3 measurement modes to measure the sound travel in the test specimen.

- Mode 1

This method of measurement is most common way of approach, in which time measurement is done between the excitation pulses which generates the sound wave and the initial returning echo. This is subtracted by a small zero value which is fixes for the instruments. Accuracy limit of this mode is more than the rest 2 modes [16].

- Mode 2

This is the type of measurement in which echo plays a crucial role. Here time is measured between echo returning from surface of test specimen to first backwall echo. This gives better accuracy than mode 1 [16].

- Mode 3

This mode involves measurement of time interval between 2 successive backwall echoes. This is the most accurate method of measurement. Following figure describes the details about waveform, transducer, range of thickness and accuracy limits [16].

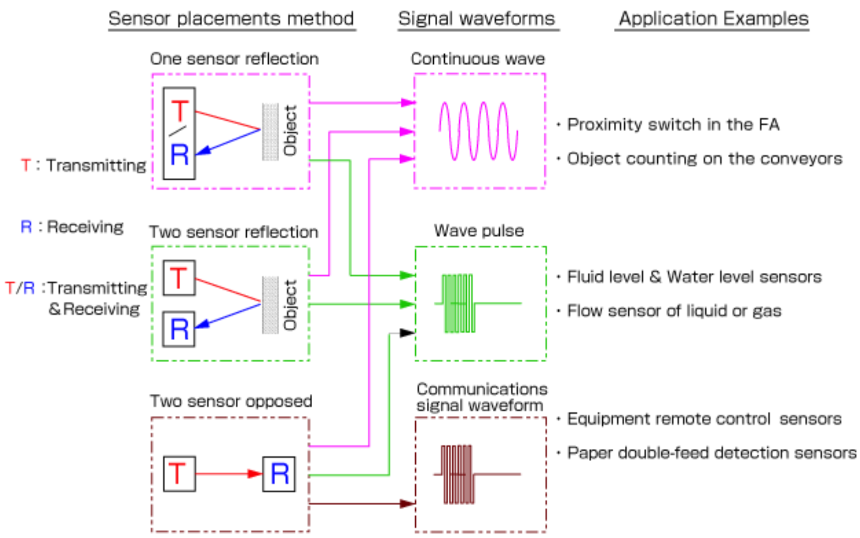

Figure 2.4: Three different modes of waveform [17]

2.3.3 Transducer Types

Based on the type of test specimen and the material properties, different types of transducer are used. Here are 4 types of transducer which are commonly used based on their application [16].

- Contract transducers:

In this type of transducer as the name suggest, there is the direct contact between transducer and test specimen. These types of transducers are the simplest and most commonly approach one. These are the first choice for the thickness measurement [17].

- Delay line transducers:

In delay line transducers some materials which are thermal insulated and heat sensitive element like cylinder of plastic, epoxy or fused silica is used between transducers and test specimen in order to make some delay. The main reason for this is to separate excitation pulse recovery from backwall echo [18].

- Immersion transducers:

This process involves use of line or bath of water to connect sound energy into the test specimen. This is highly effective for the on-line or in-process measurement of moving product [19].

- Dual element transducers:

These types of transducers are mostly use for measurement of rough, corroded surfaces with corrosion gages. In this case, the transmitting and receiving elements are mounted on a delay line at a minute angle to focus energy. Dual measurement is not as accurate as other process but it is significantly better for the corrosion process applications [20].

2.4 Multivariate Data Analysis

Multivariate analysis (MVA) is the process in which each missing value is replaced by the observed mean for that variable [21]. This process can be more complicated if physical based quantity included calculating hierarchical "system-of-system". Study has revealed MVA has struggled with dimensionality. This problem has overcome by the use of surrogate models which provide precise result by using physics based code. Surrogate model takes the process in the form of equation, hence it can be evaluated very fast [22].

2.4.1 Principle Component Analysis (PCA)

Principle component analysis (PCA) is a MVA technique in which data are analyzed and observed, which are described by interrelated quantitative dependent variables. Main objective of this process is to extract important information from the data and arrange it to the orthogonal variables called as principle components. After this it is to exhibit the similar pattern of the observation and keep the variables as point in the map. The quality of PCA can be measured by using technique called cross validation such as bootstrap and jackknife [23]. PCA is very useful for 3 or higher dimensional data. For instance, the image below shows the application of PCA i.e. higher dimensional data (3D) is converted to lower dimension data (2D) [24].

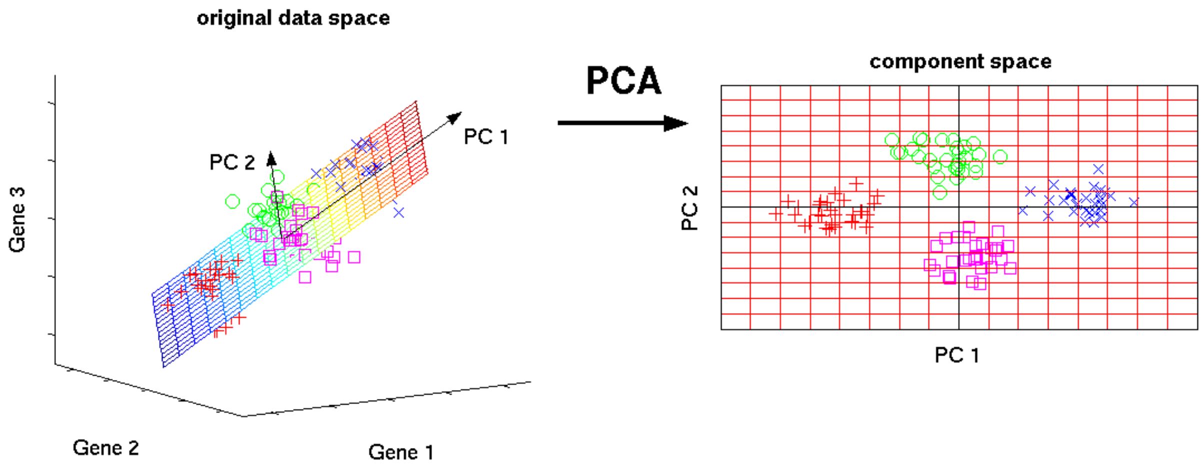

Figure 2.5: CPA conversion from 3D to 2D [24]

The result of procedure depends on scaling of matrix, so it must be defined. Here each variable is scaled to unit variance, which can be recommended for the general use [25].

Multivariate analysis can be use for following process [26]:

- Use for capacity based design
- Use for inverse design (variables are treated as independent variables)
- Use for Analysis of Alternatives (AoA)
- Analysis of concept based on change of situation
- Identification of important factors

2.5 Industrial Application

Process Analytical Technology (PAT) is a system which is use for design, analyze, control the manufacturing process based on scientific and engineering principle involved. PAT initiative is based on US Food and Drug Administration (FDA) whose main ambition is "quality cannot be tested into products: it should be built-in or should be by design" [27].

Initial goal of the PAT is to generate predetermined quality of product. Effectiveness of the PAT implementation can be found if detail study of science as well as chemical and mechanical properties of the all elements [27]. PAT has application in daily use or in industry sector. Some of them are listed below:

2.5.1 Spectroscopic tools and implementation

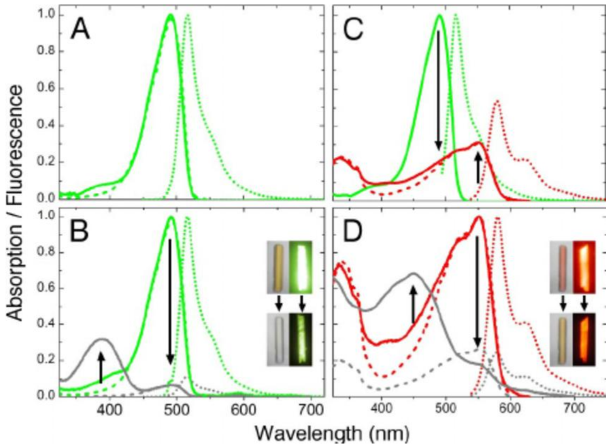

Figure 2.6: Spectroscopic analysis [28]

PAT may be specially designed for probe based instruments or online measurement. It also able to work for spectroscopic technology such as Mild Infrared, UV-Vis and NIR, where this process provides continuous monitoring so that researcher can understand to optimize process design and quality [6].

2.5.2 Measurement of crystal size distribution

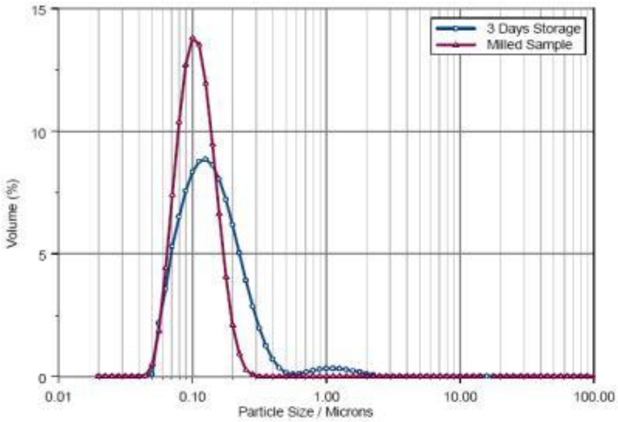

Figure 2.7: Particle size distribution [28]

In the process industry, probe based technique are used to track particle shape and size. These things can be deflected by the presence of dilution or not. By observing the rate and change in angle to the particles with the crystals in actual (real) time, correct parameters for crystallization can be optimized [27].

2.5.3 Lab and R&D

Figure 2.8: Research and development process [28]

PAT in research and development allows timely measurement which also reveal previously unknown process component and kind of relationship. A collection of data can provide depth mechanistic approaching to formulation, reaction process and fermentation/crystallization. PAT can also provide proof of process understanding regulatory document submission [27].

2.5.4 Scale up from lap to manufacturing

Figure 2.9: Manufacturing Industry [28]

When the process is scale up from lab to pilot plant, Process analytical technology takes as step as projected. At the time manpower apply PAT to generate signature or fingerprint to monitor reproducibility during machinery/equipment transfer. This method helps in rapid troubleshooting, optimization and defect identification. If there is any kind of deviation occurs in the process, PAT helps to identify the root cause. Also, it improves safety in exothermic reaction and explosive environment [27].

2.5.5 Inline particle characterization

Figure 2.10: Inline particle characterization [28]

Inline particle size measurement provides direct measurement of size, shape and counts them at full concentration without the help of direct sample. By understanding these things, researcher can detect the endpoints also ensure batch to batch stability and product excellence [27].

3 Materials and Methods

The experiment is about erosion test by using ultrasonic sensor. Here, transducer is kept contact over the test material which sends ultrasonic wavelength. This wavelength travel from one end of the pipe to another end, based on the time of echo. Thickness of the pipe is determined by using T = V * t/2. Here we are going to check 3 different profile of the test specimen which are explained below:

3.1 Working

Once all the equipments are connected well, then application is ready to run. Figure 3.1 shows the working principle of ultrasonic sensor. Similarly, experimental setup is shown in figure 3.2.

From the figure 3.2 power has given to ultramonit lab kit, which is connected to PC. Transducer is connected to ultramonit lab kit. When the transducer is made in contact with test specimen (pipe), it send the ultrasonic signal to the material. Transmitted signal moves with the velocity of 5920 m/s towards another end of the material. When it reaches to another end (can be detected by means of another medium like air or wood) it gets reflection towards the source. Again it reaches to the source position, now it’s the first reflection. Same process continues until the experiment is stop. In this case, adjusting the sample delay is crucial, improper sample delay can cause reflection of sound through the half way or any point between the materials. By the help of time taken by 2 successive oscillations thickness of the material can be calculated. In other word, erosion can be estimated.

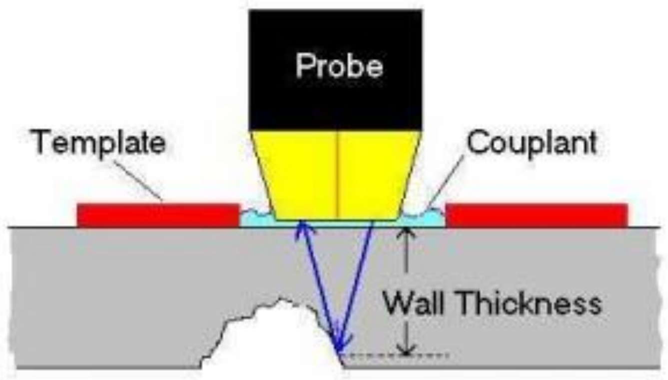

Figure 3.1: Working process [28]

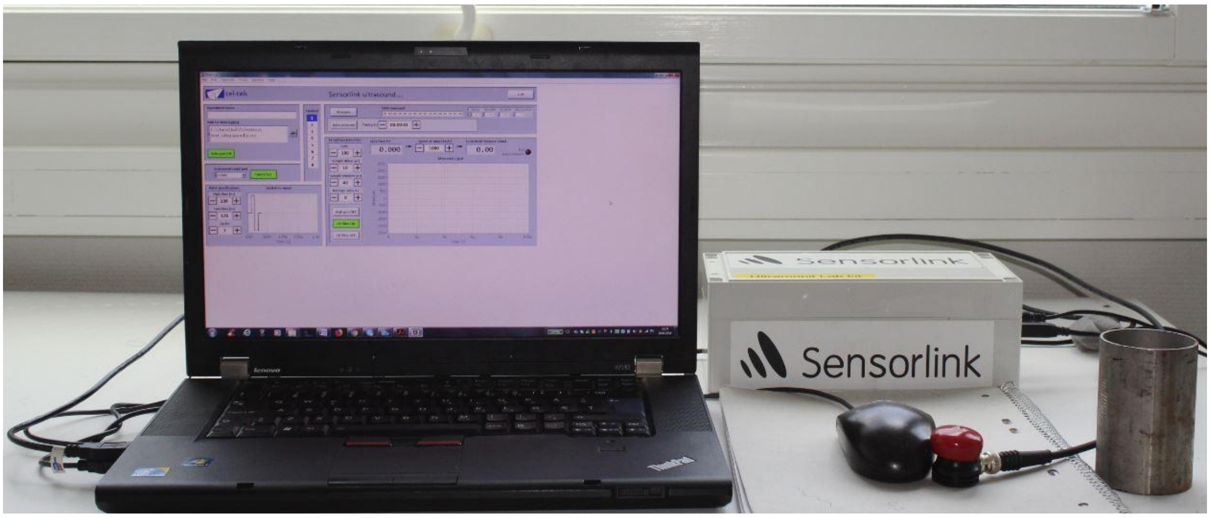

Figure 3.2: Experimental setup

Figure 3.2 is software of sensorlink ultrasound. This is used to measure the thickness of the test specimen by the means of echo. Speed of sound is varies from material to material, first we are going to measure 3 different rectangular material of thickness 2mm, 3mm and 5mm. Result are noted and compare with the standard dimension. The pattern of echo is displayed in the form of waveform, which is represented as amplitude and time (seconds). Since the test specimen is not brought to contact with transducer to measure amplitude and time, there is no any fluctuation in graph as shown in figure 3.3.

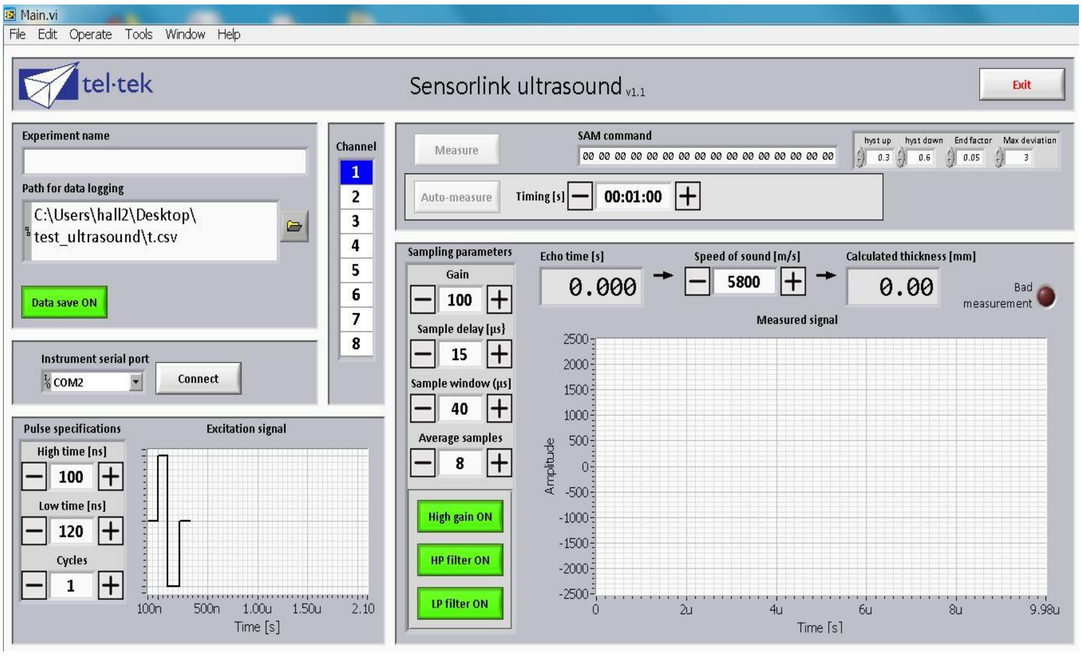

Figure 3.3: Pattern of software

3.2 Phase I – Use of Ultrasonic sensor around the rough centre of rectangular plate.

In this method, the surface of mild steel around the centre is made irregular by the help of grinder as shown in figure 3.4. Different test at various length and depth is measured by the help of ultrasonic sensor. Sensor is mounting on the rough surface by the help of clamp. By the help of echo travelled, the thickness of the test material is measured through the software. In this case, red marked area is the tested place.

Figure 3.4: Rectangular plate rough around center

3.3 Phase II – Use of Ultrasonic sensor around the rough edges of rectangular plate.

This method is quite similar to phase-I. In this method same mild steel is used as test specimen. The measurement is done around the edges of the rectangular plate. Edges are made irregular by the help of grinder. Transducer is kept in slightly different length in order to measure vary thickness. Red marked symbols are the tested area as shown in figure 3.5. Result is more or less similar because of the negligible chance in length.

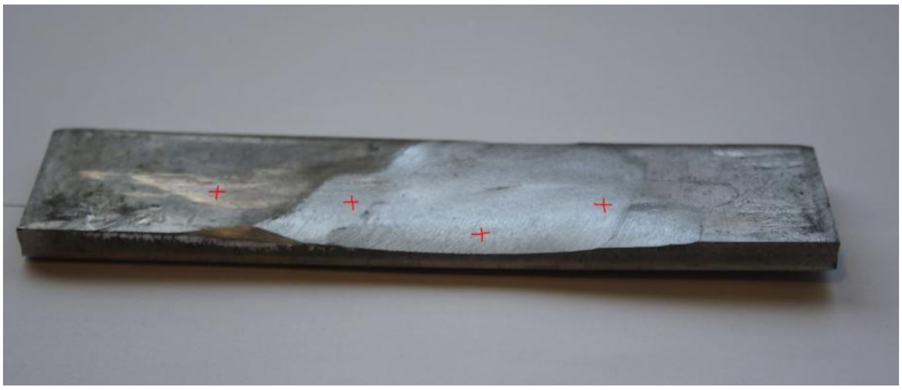

Figure 3.5: Rectangular plate rough around edges

3.4 Phase III – Use of Ultrasonic sensor around the bending pipe.

Figure 3.6 represents the ultrasonic sensor around the bending of pipe. It is important to understand keeping transducer fix around the pipe is not an easy task rigid material should hold it. A special designed clamp has introduced to fix the sensor around the pipe which is shown in figure 3.9. In this case, ultrasonic sensor is kept around the bending of pipe, which send wave to find the thickness. Various tests are done at dissimilar part of pipe marked as red in the figure 3.6. Which are recorded for the result analysis.

Figure 3.6: Test specimen (pipe)

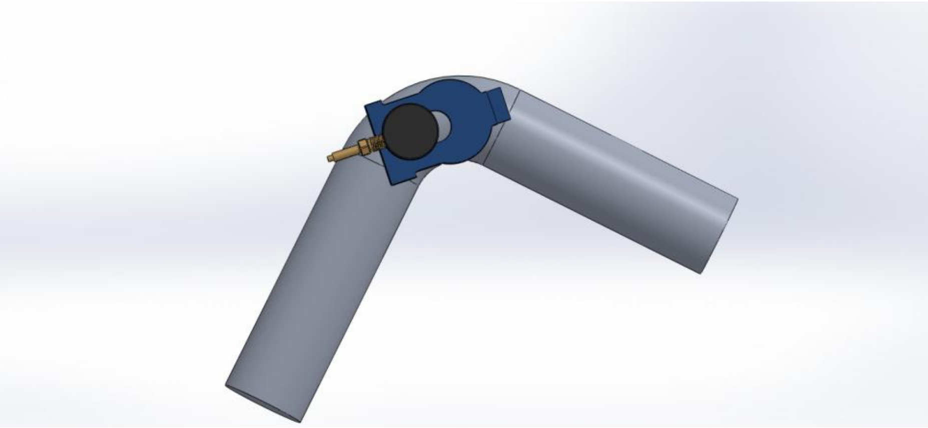

Figure 3.7: Ultrasonic sensor around the bending pipe (top view)

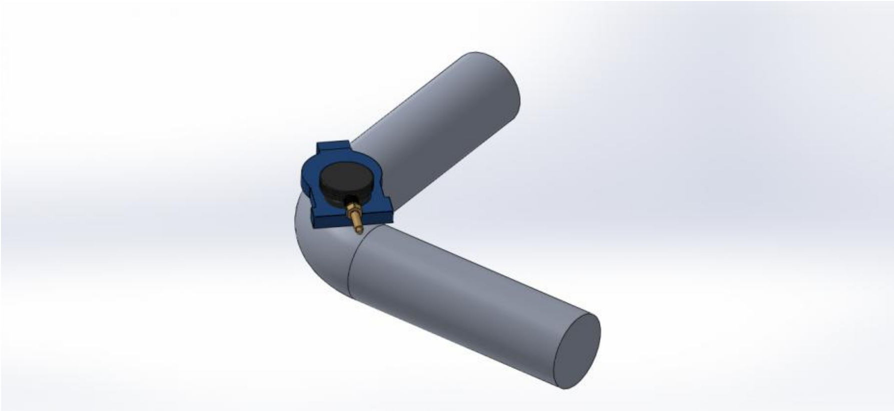

Figure 3.8: Ultrasonic sensor around the bending pipe (side view)

Figure 3.9: Sensor holding Clamp

4 Results and Discussion

4.1 Initial test on some regular pattern

In this method, test is done on 2mm, 3mm and 5mm thick material by keeping gain as 100, sample delay by 10µs, sample window by 40 µs and taken for 100 average sample. Results were taken for 3 different types:

1. When High gain ON, HP filter ON and LP filter ON
2. When High gain OFF, HP filter ON and LP filter ON
3. When High gain OFF, HP filter ON and LP filter OFF

Based on the requirement (ON/OFF) of gain and filters the results get deflected. Echo time and thickness are noted and compared with the standard measurement (Vernier Scale).

4.1.1 Test on 2mm material

Figure 4.1 represents the measurements when it is at High gain ON, HP filter ON and LP filter ON. Amplitude vs Time graph should appear the way it has appeared in the figure 4.1. There are number of waveform because we have taken average sample as 100. Since it is right way of measurement so there is no red blink in bad measurement. Time travelled from one end to disturbance is 674.4 nanoseconds for 2mm specimen. As the material is mild steel, velocity of sound is taken as 5920 m/s.

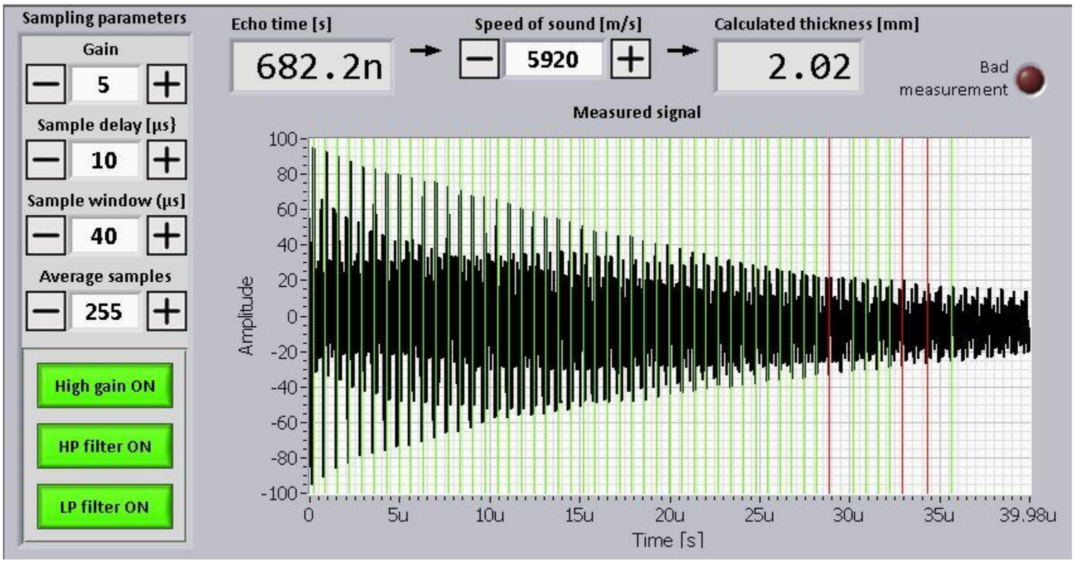

Figure 4.1: High gain ON, HP filter ON and LP filter ON

Figure 4.1 represent sample test when gain and both filters are on. As the gain is given as 5, amplitude is increased by 5 times. The graph represents the reduction of sound wave with time. Thickness of material can be calculated when echo time and speed of sound are known.

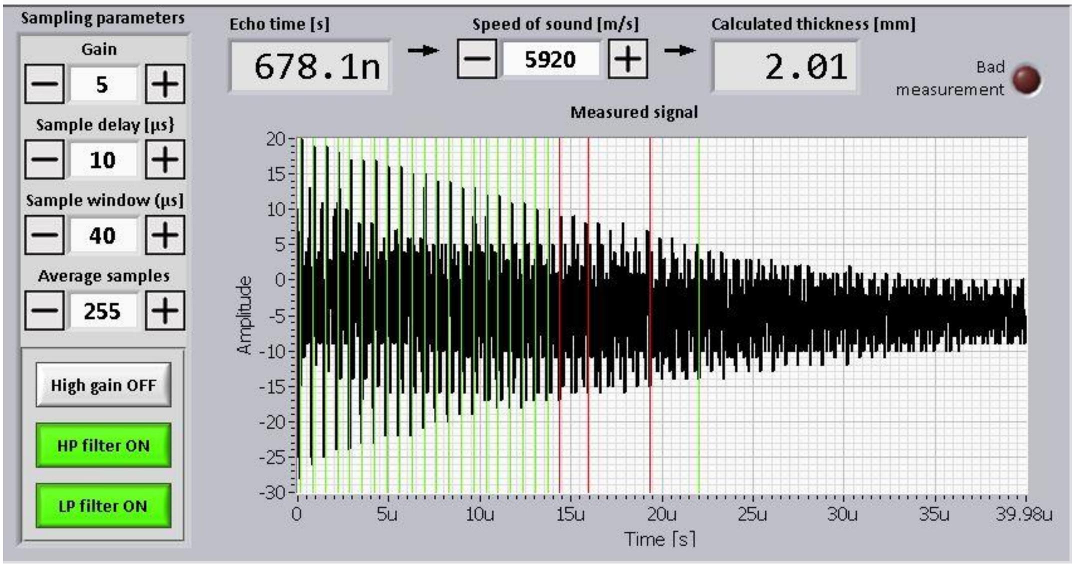

Figure 4.2: High gain OFF, HP filter ON and LP filter ON

Figure 4.2 show sample test when gain is off and both filters are on. As the gain 5 is off, amplitude is reduced by 5 times i.e. 20.

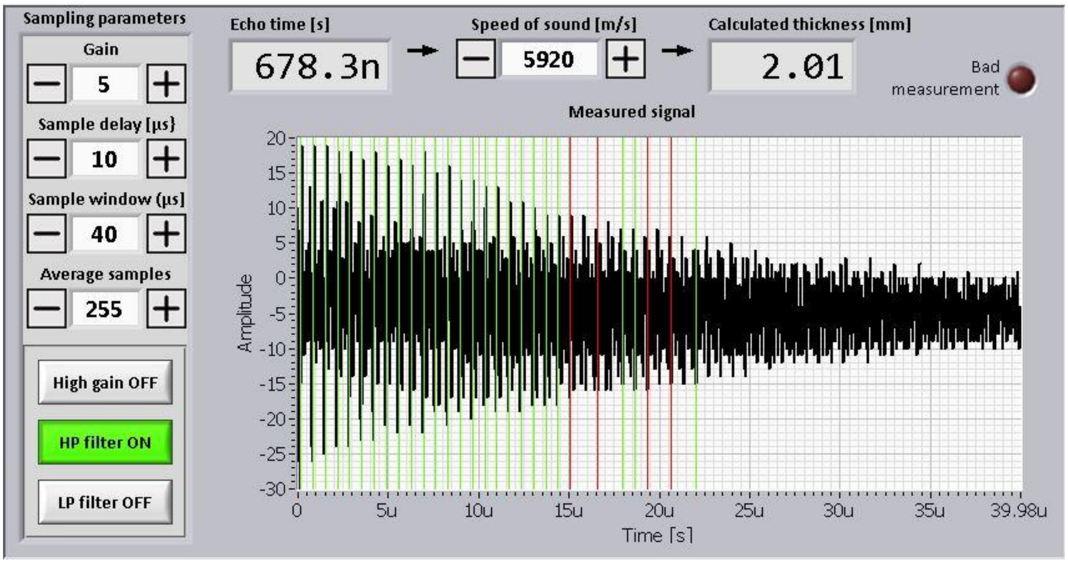

Figure 4.3: High gain OFF, HP filter ON and LP filter OFF

Figure 4.3 illustrates sample test when gain and LP filter are off and HP filter is on. As the gain 5 is off, amplitude is reduced by 5 times i.e. 20 and absence of LP filter causes disturbance in the graph.

4.1.2 Test on 3mm material

Three different results found for 3mm test specimen. Which are displayed in figure 4.4, figure 4.5 and figure 4.6.

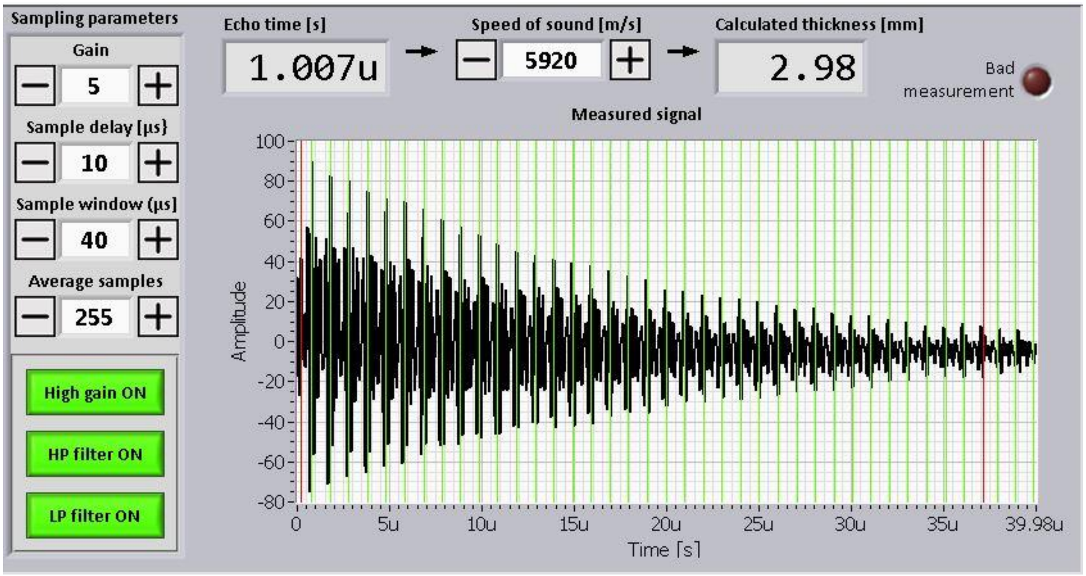

Figure 4.4: High gain ON, HP filter ON and LP filter ON

Figure 4.4 represent sample test when gain and both filters are on. As the gain is given as 5, amplitude is increased by 5 times and reached to 90 as shown in figure. The graph represents the reduction of sound and ultimately it reaches to zero.

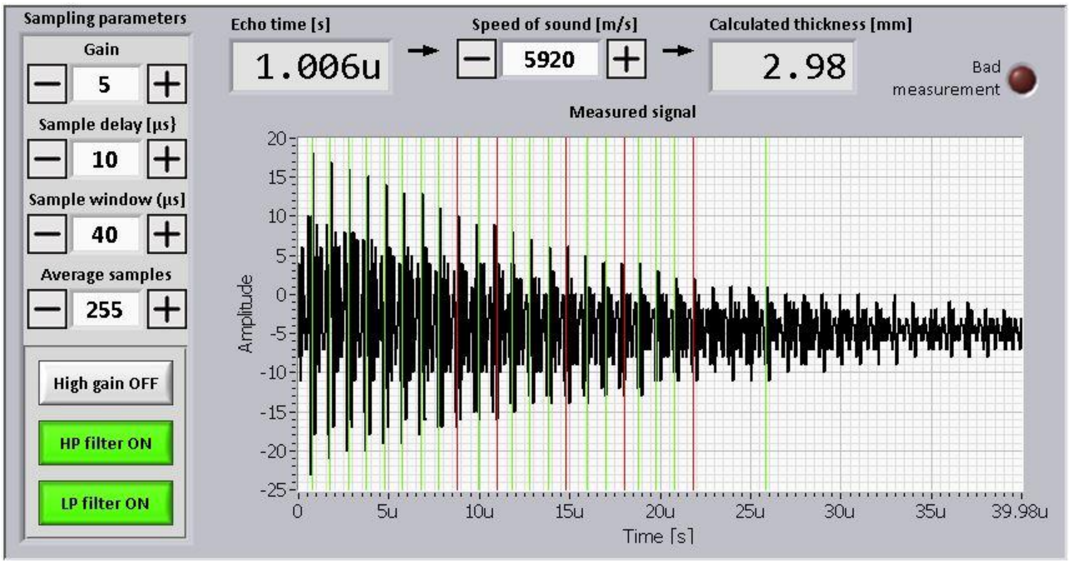

Figure 4.5: High gain OFF, HP filter ON and LP filter ON

Figure 4.5 show sample test when gain is off and both filters are on. As the gain 5 is off, amplitude is reduced by 5 times i.e. 17.5 as shown in graph.

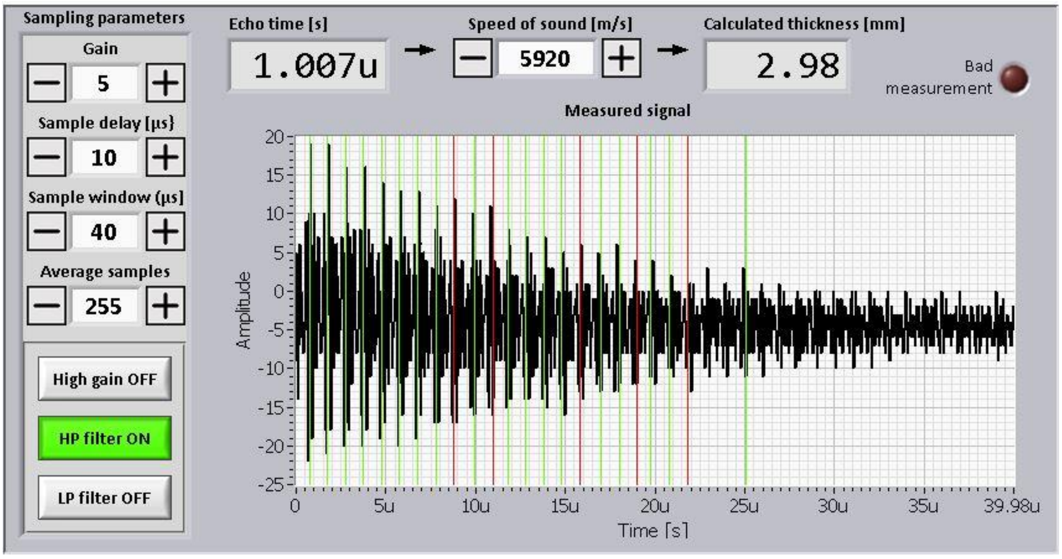

Figure 4.6: High gain OFF, HP filter ON and LP filter OFF

Figure 4.6 illustrates sample test when gain and LP filter are off and HP filter is on. As the gain 5 is off, amplitude is reduced by 5 times i.e. 19 and absence of LP filter causes disturbance (noise) in the graph.

4.1.3 Test on 5mm material

Similarly 2mm and 3mm process, measurements were taken for 5mm test specimen and results are shown in figure 4.7, figure 4.8 and figure 4.9.

- When High gain ON, HP filter ON and LP filter ON

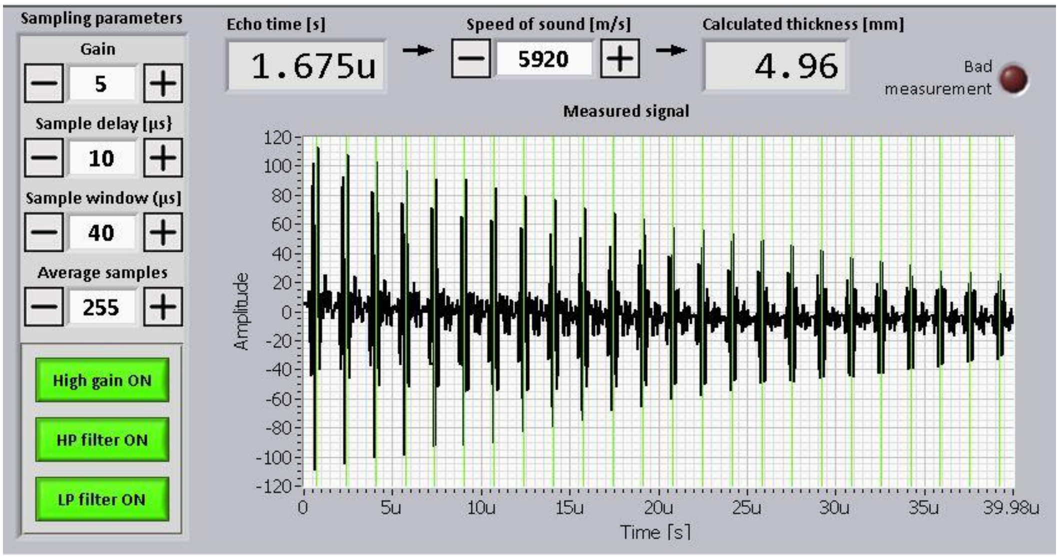

Figure 4.7: High gain ON, HP filter ON and LP filter ON

Figure 4.7 represent sample test when gain and both filters are on. As the gain is given as 5, amplitude is amplified by 5 times and reached to 115 as shown in figure. First signal is transmitted signal, all others expect first are reflections.

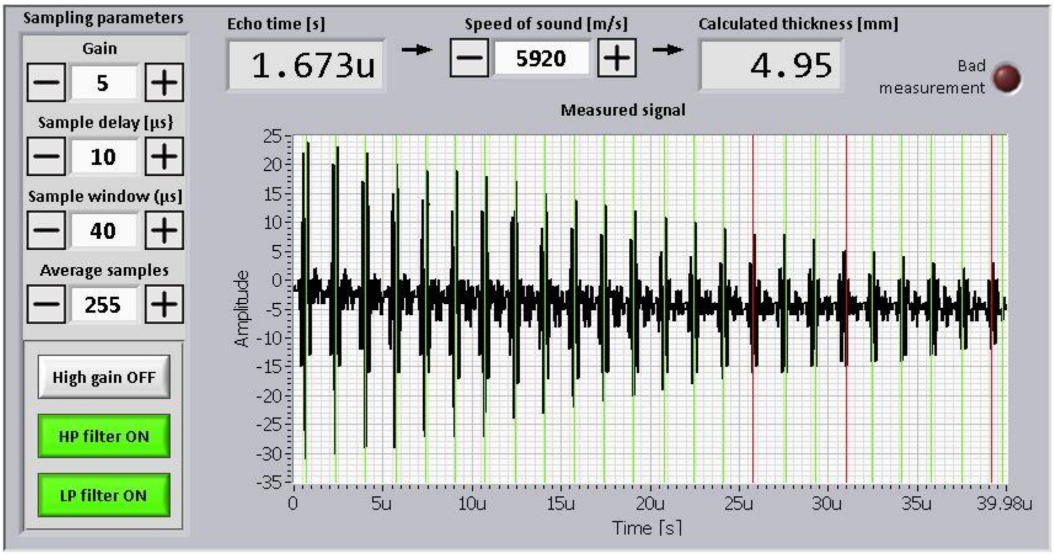

Figure 4.8: High gain OFF, HP filter ON and LP filter ON

Figure 4.8 explains sample test when gain is off and both filters are on. As the gain 5 is off, amplitude is reduced by 5 times i.e. 24 as shown in graph. Thickness and echo are measured.

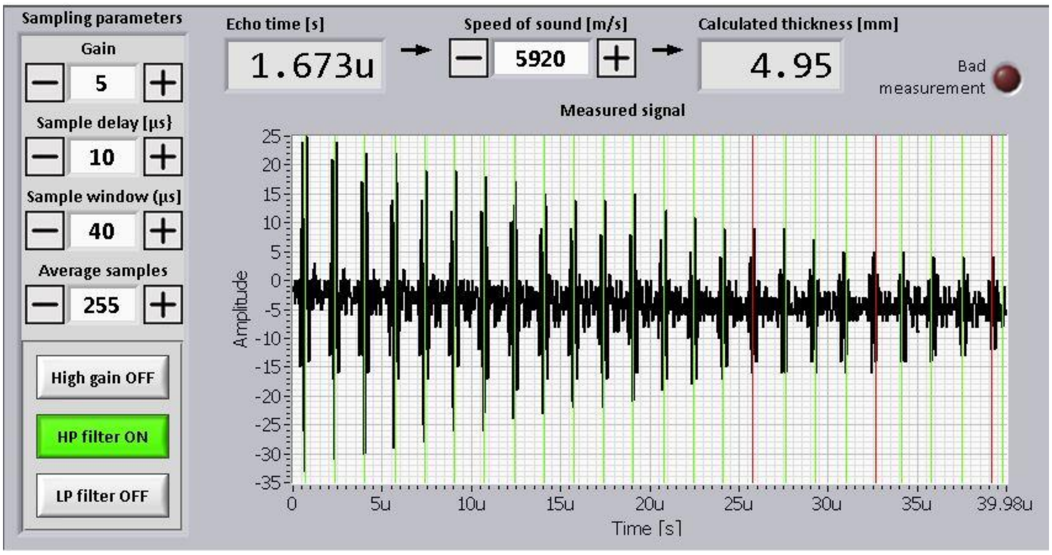

Figure 4.9: High gain OFF, HP filter ON and LP filter OFF

Figure 4.9 illustrates sample test when gain and LP filter are off and HP filter is on. In this case, sample delay is 10µs, the sample window shows result for 40 numbers of waveform and average sample is taken as maximum i.e. 255.

4.1.4 Summary of Initial test

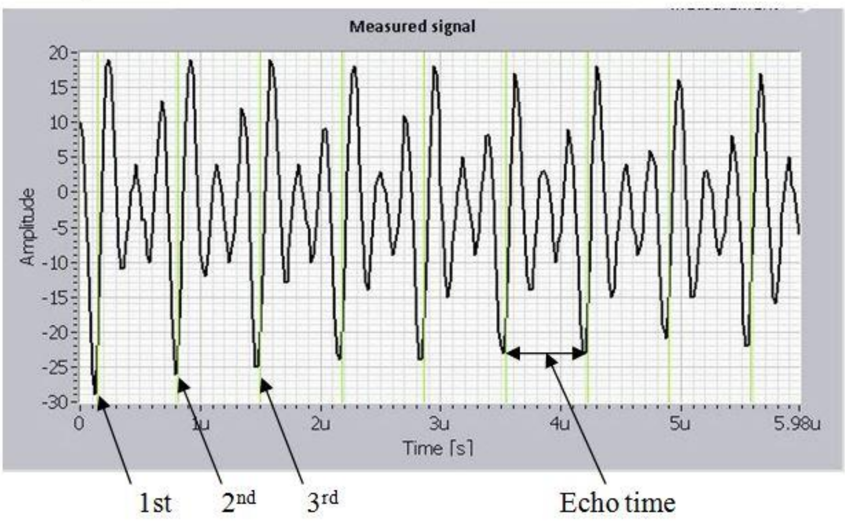

Figure 4.10: Discussion of wave geometry

Figure 4.10 shows the Amplitude vs Time graph For the window sample 6. 1st wave in the graph is transmitted signal whereas 2nd, 3rd and all other signal are the first reflection, second reflection and so on. From one big amplitude to another amplitude is time taken by the sound to reach from 1 end to another end called as echo. General trend of graph shows, reduction in size of amplitude and at last reach to zero this is because sound energy. Sound energy get decreases with time. From different test on 2mm, 3mm and 5mm material we can see the effect of gain, sample parameters, sample delay and average samples.

Gain amplifies the amplitude, let us suppose if the gain given as 10 then the amplitude fluctuates from 10 to 100. It is crucial to understand the sample delay, if the sample delay is given earlier than the sound travel from one end to another then before reaching to another end it gets reflected. Hence below threshold time, sample delay should not be given. In order to understand the graph, minimum sample window helps. In this case sample delay is taken as 6 and required information is noticed well. Likewise, average sample takes the information of average information of that sample. Less the average more accurate information can be gained.

Thickness can be calculated from the graph as:

$T = V * t/2$

$= 5920 * 6.8*10^{-6}/2$

$= 0.0201m = 2.01mm$

Where $t = 6.8*10^{-6}$ seconds is the distance between to successive high pick from the graph.

Test on 2mm, 3mm and 5mm can be summarized in table 4.1. Analysis from the result wave, thickness and echo is measured.

Table 4.1: Results of test 1

Test material	Type of material	Thickness in mm (ultrasonic sensor)	Thickness in mm (vernier scale)	Echo (nano second)	Velocity of sound(m/s)
Specimen 1	Mild steel	2.01	2.00	674.4	5920
Specimen 2	Mild steel	2.98	3.00	1005	5920
Specimen 3	Mild steel	4.95	5.00	1675	5920

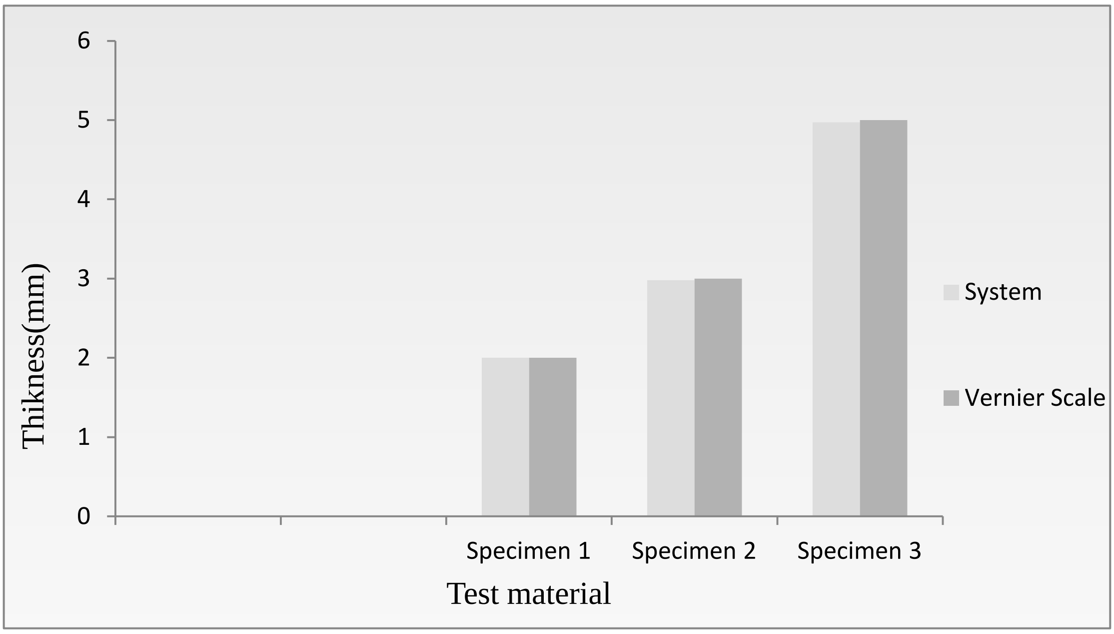

Figure 4.11: Thickness of test specimen measured in system and vernier scale

4.2 Phase I – Use of Ultrasonic sensor around the rough centre of rectangular plate.

4.2.1 Test 1

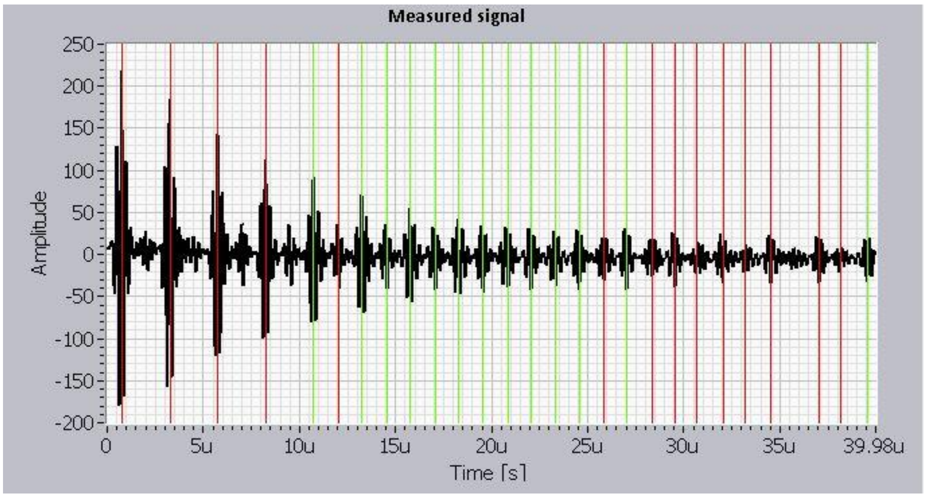

Figure 4.12: High gain ON, HP filter ON and LP filter ON

Figure 4.12 represent sample test when gain and both filters are on. In this case gain is on so amplitude is increased by 5 times. The graph represents the reduction of sound wave with time. All large waveform from transmitted to reflection ends all are almost same because there is negligible change in surface. Between 2 big oscillations we can see small oscillation which arises due to disturbance.

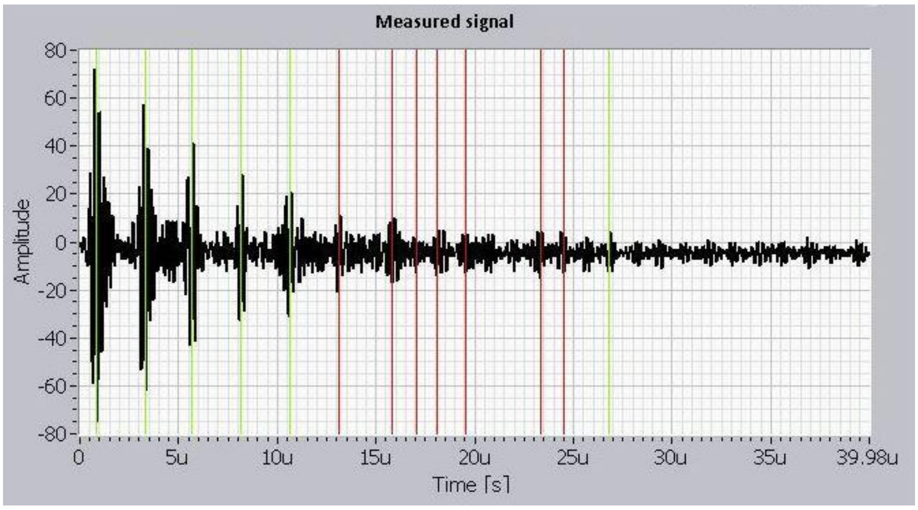

Figure 4.13: High gain ON, HP filter ON and LP filter OFF

Figure 4.13 illustrates sample test when gain is off and both filters are on. As the gain 5 is off, amplitude is reduced by 5 times. Numbers of oscillations are less because of thicker material.

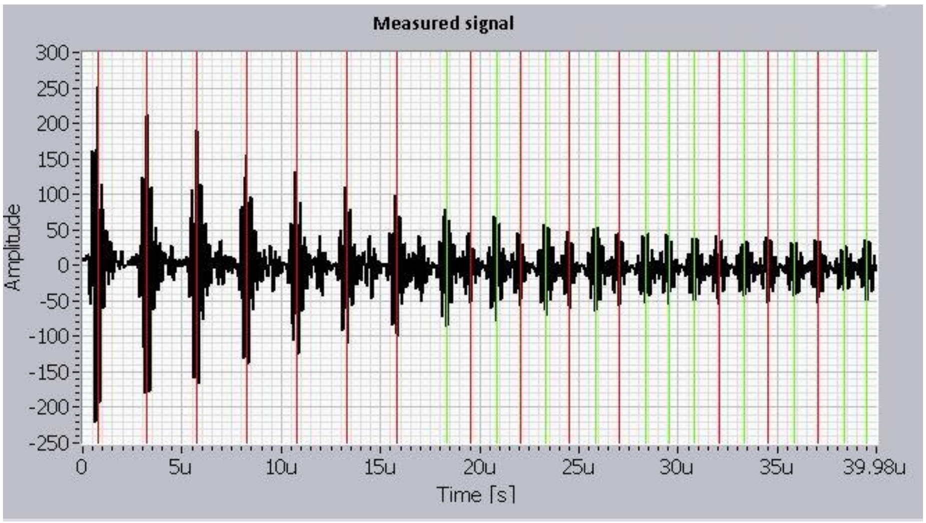

Figure 4.14: High gain OFF, HP filter ON and LP filter OFF

Figure 4.14 illustrates sample test when gain and LP filter are off and HP filter is on. In this case, top and bottom oscillations are not equal because the input pulse is given different. Since the low impulse is high bottom oscillations are bigger.

4.2.2 Test 2

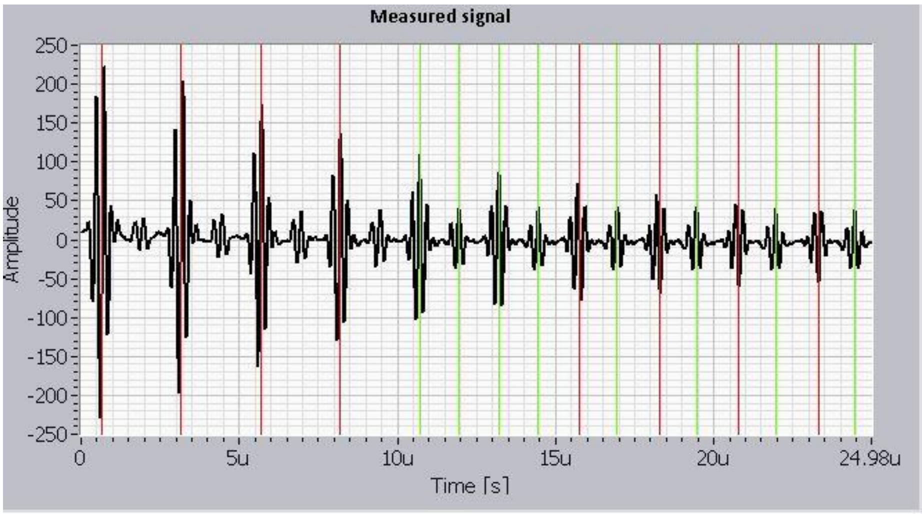

Figure 4.15: High gain ON, HP filter ON and LP filter ON

Figure 4.15 represent sample test when gain and both filters are on. From the graph we can see the clear result because of less number of sample window. Time taken to travel from one end to another end is 5µs as shown in graph.

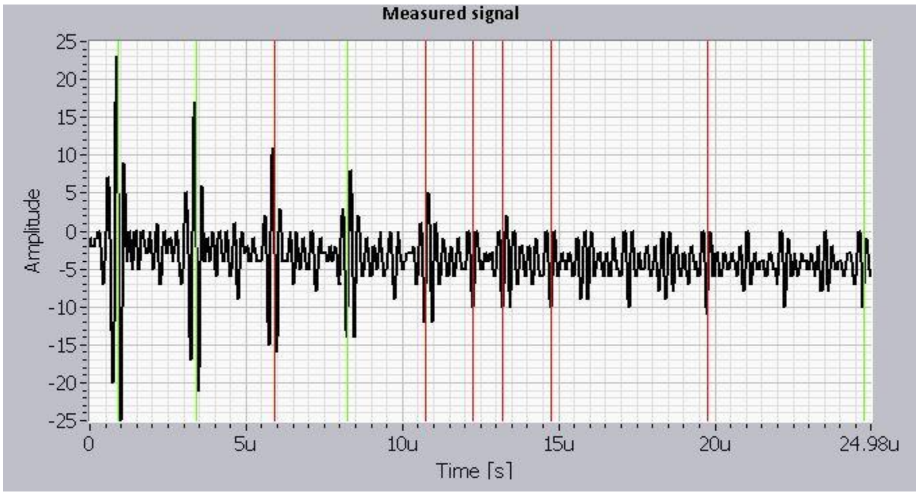

Figure 4.16: High gain ON, HP filter ON and LP filter OFF

Figure 4.16 represents amplitude vs time oscillation when gain and HP filter is on and LP filter is off. Due to the LP filter off, nose formation occurred between the 2 consecutive reflections.

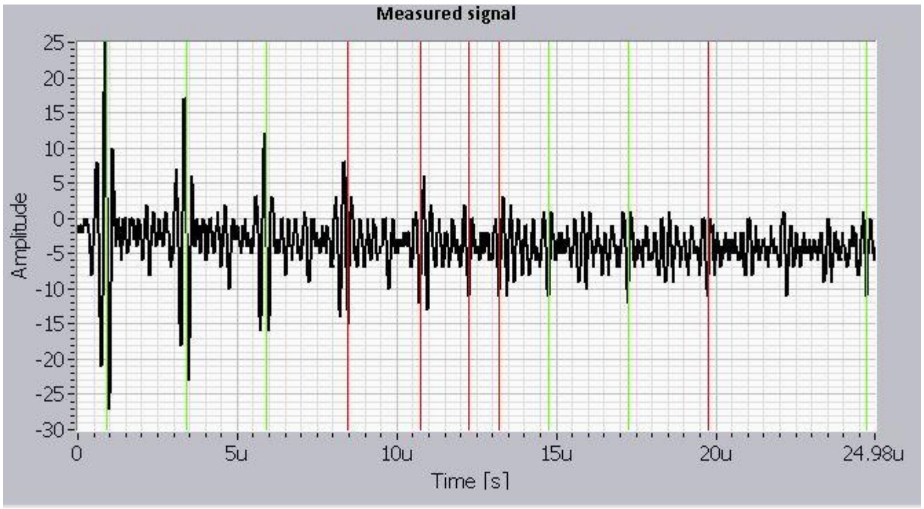

Figure 4.17: High gain OFF, HP filter ON and LP filter OFF

Figure 4.17 represents amplitude vs time graph when high gain and LP are off and HP filter is on. Since low pass filter is off, there is disturbance between reflections.

4.2.3 Test 3

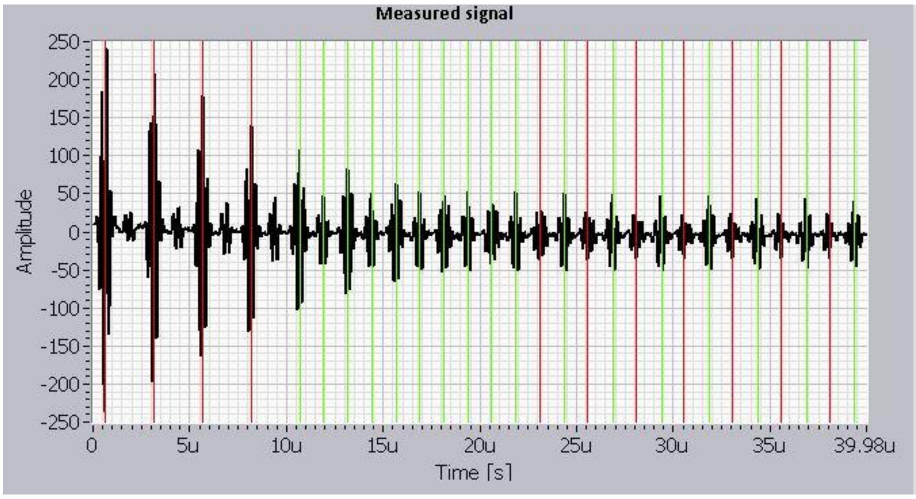

Figure 4.18: High gain ON, HP filter ON and LP filter ON

Figure 4.18 represents graph between time and amplitude, where in y-axis amplitude and in x-axis time is plotted. Since Gain and all filters are on, amplitude is amplified and there is no disturbance.

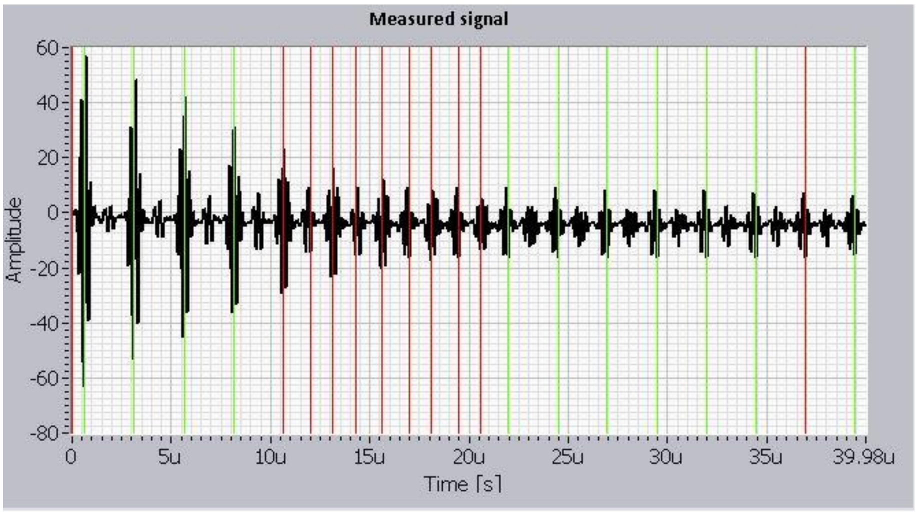

Figure 4.19: High gain ON, HP filter ON and LP filter OFF

Figure 4.19 represents when only low pass filter is off. In this case, There is appearance of disturbance (noise). Since the sample window is taken as 40, numbers of oscillations are visible in the graph.

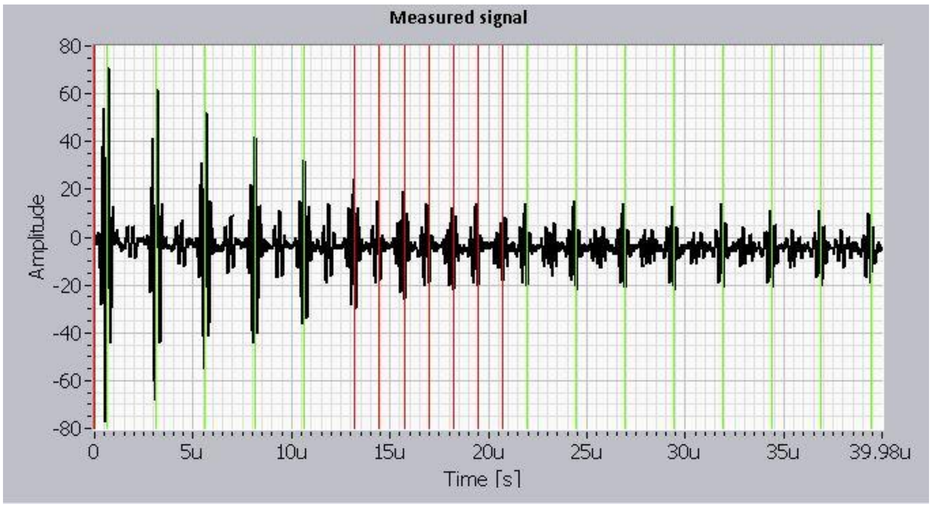

Figure 4.20: High gain OFF, HP filter ON and LP filter OFF

Figure 4.20 represents the graph when only high pass filter is on. In this case, there is not smooth oscillation because of disturbance.

4.2.4 Summary of phase-I

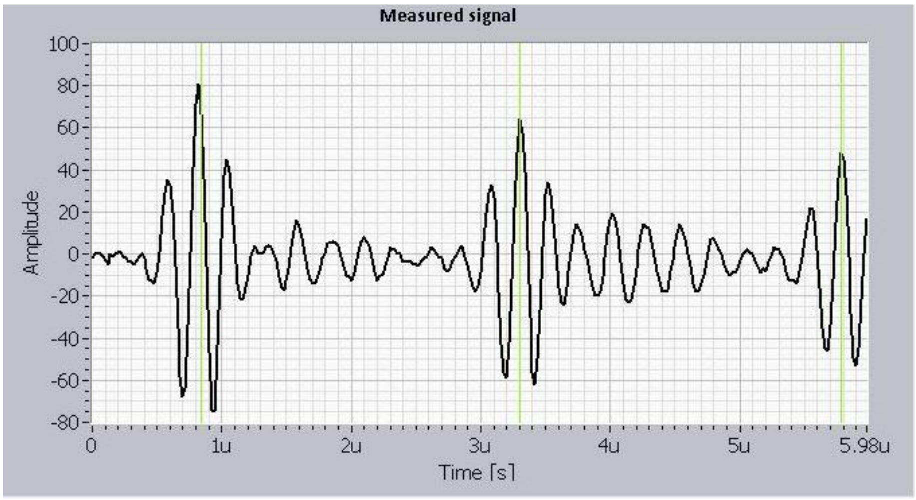

Figure 4.21: Waveform description of phase-I

Figure 4.21 represents the general waveform of phase-I i.e. around the rough centre material. Since the test material is quite bigger in size, there are only 3 waveform when the sample window was given 6. From this we can understand, bigger the size of material, less waveform can be displayed on the software. From the graph time is around 2.5µs. Thickness of material can be calculated as:

$T = V * t/2$

$= 5920 * 2.5 * 10^{-6}/2$

$= 0.074m$

$= 7.4mm$

Ultrasonic test around the center of irregular rectangular plate is observed for phase-I. Data was collected for 3 different places of the plate which is shown in table 4.2.

Table 4.2: Summary of phase-I

Test	**Thickness in mm (system)**	**Thickness in mm (vernier scale)**
Test 1	7.17	7.50
Test 2	6.93	7.10
Test 3	6.23	6.70

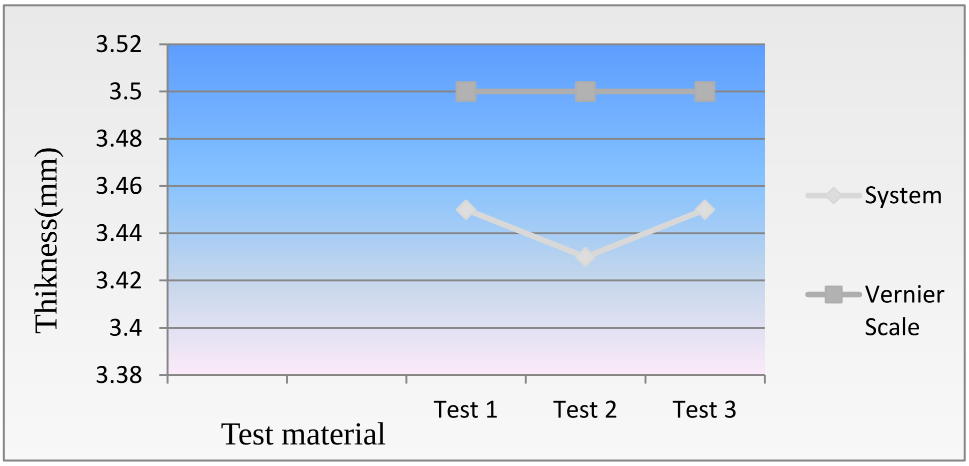

Figure 4.22: Three different tests for phase-I

4.3 Phase II – Use of Ultrasonic sensor around the rough edges of rectangular plate.

4.3.1 Test 1

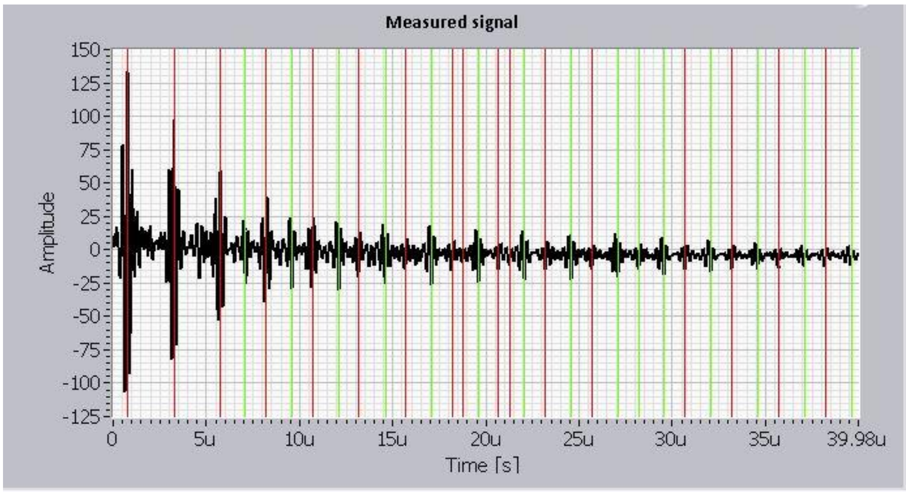

Figure 4.23: High gain ON, HP filter ON and LP filter ON

Figure 4.23 shows the condition of graph gain and both filters are on. From this figure we can see that due to the gain, the amplitude has jumped from 25 to 125. Between the equal interval there is formation of pick oscillation and at the end of the graph it is about to reach to zero.

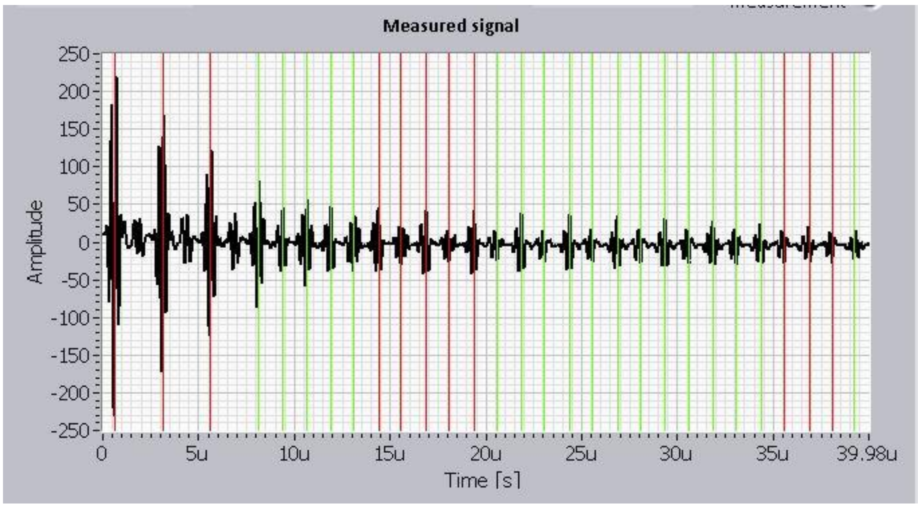

Figure 4.24: High gain ON, HP filter ON and LP filter OFF

Figure 4.24 represents when low pass filter is off, in the absence of LP filter, there can arise of disturbance.

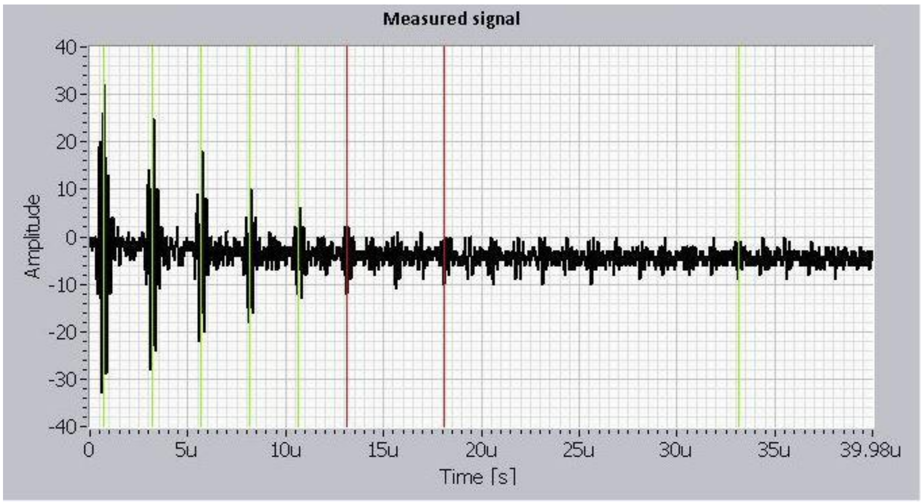

Figure 4.25: High gain OFF, HP filter ON and LP filter OFF

Figure 4.25 shows the graph between amplitude and time when gain and LP filter is off. In this graph we can clearly see lots of disturbance.

4.3.2 Test 2

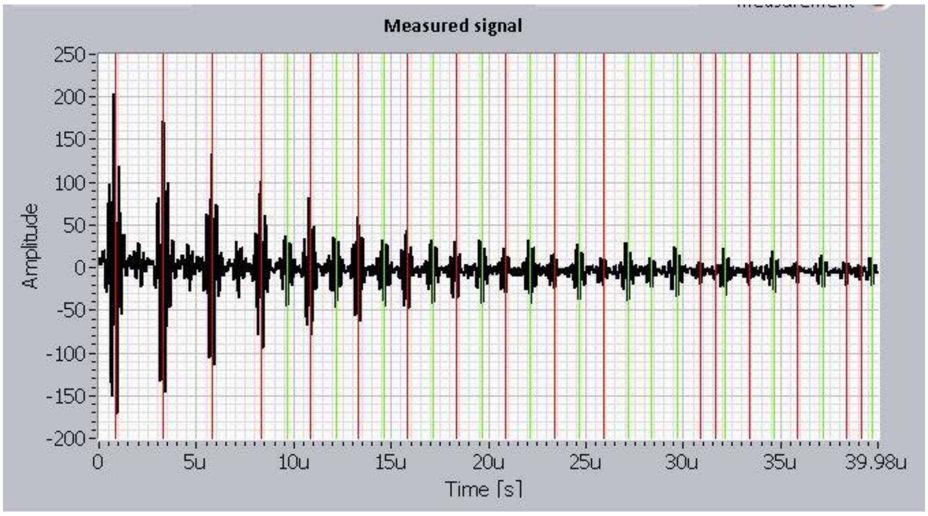

Figure 4.26: High gain ON, HP filter ON and LP filter ON

Figure 4.26 signifies the graph when high gain and both filters are on. In this case the amplitude is increased by 5 times as the gain is given as 5. There is less disturbance because both filters are on.

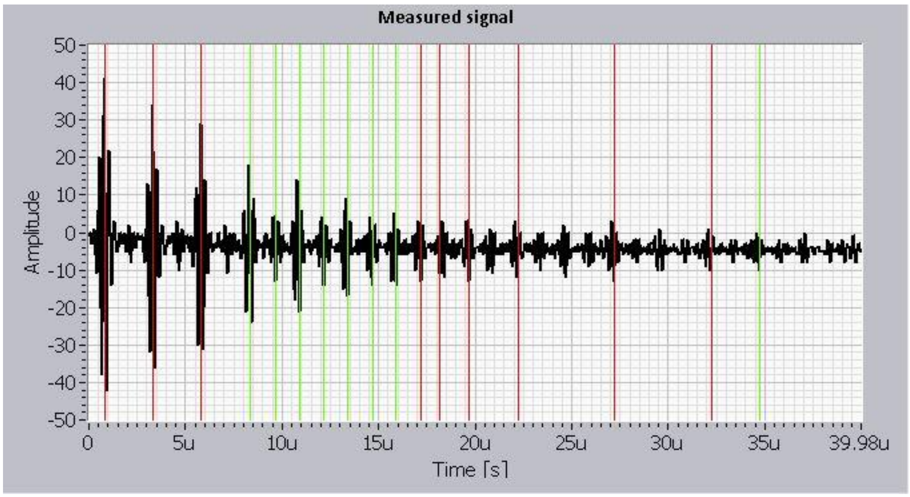

Figure 4.27: High gain ON, HP filter ON and LP filter OFF

Figure 4.27 shows graph when low pass filter is off, in the absence of low pass filter. From the graph number of disturbance is visible between the reflections.

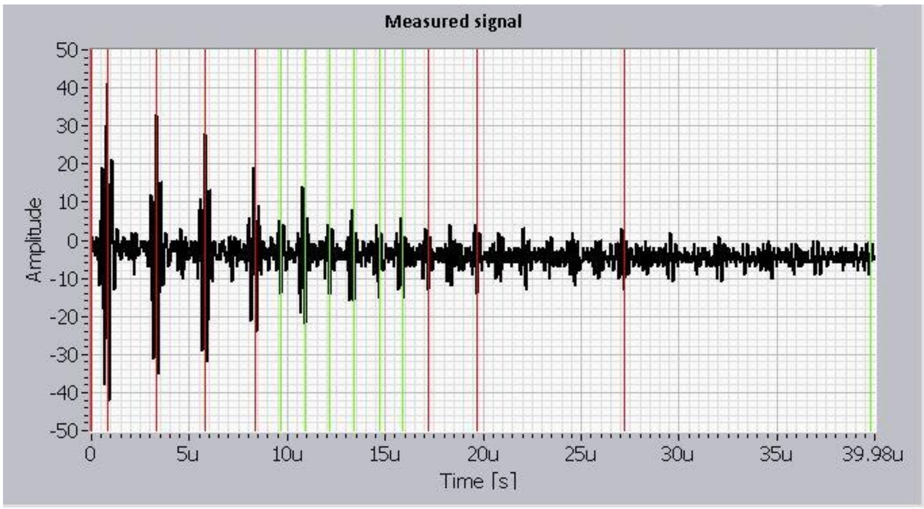

Figure 4.28: High gain OFF, HP filter ON and LP filter OFF

Figure 4.25 represents the graph between amplitude and time when gain and LP filter is off. Since the gain is off, there is reduction in amplitude size and turing off of LP filter leads to disturbance.

4.3.3 Test 3

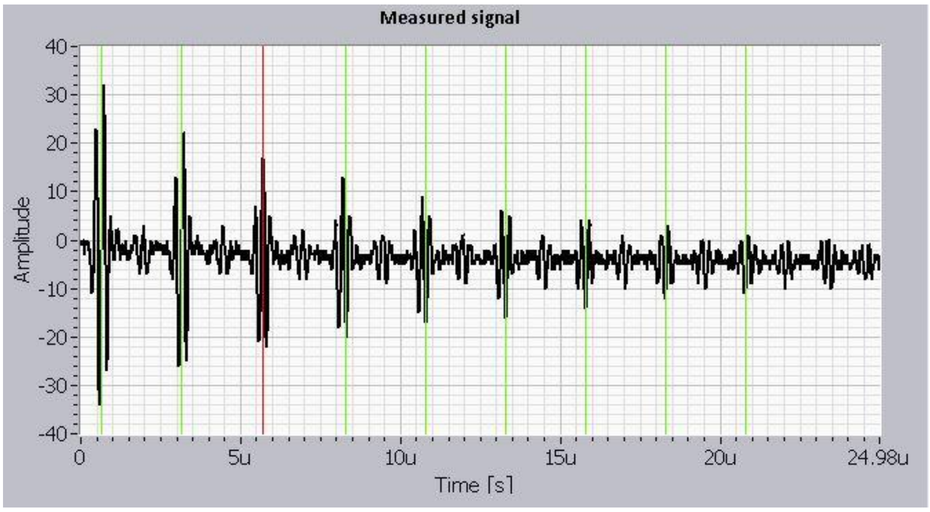

Figure 4.29: High gain ON, HP filter ON and LP filter ON

Figure 4.29 signifies the graph when high gain, High pass and low pass filters are on. Amplitudes are less in number and clear this is due to the less number of sample window.

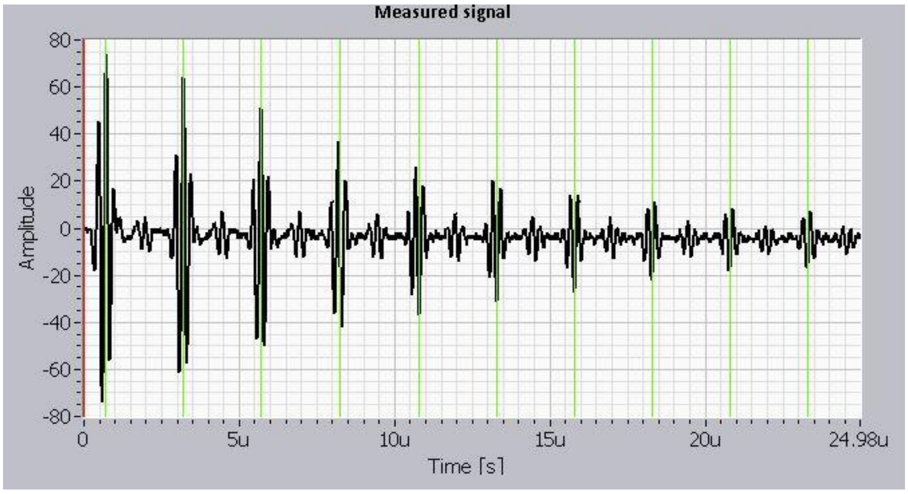

Figure 4.30: High gain ON, HP filter ON and LP filter OFF

Figure 4.30 represent graph when low pass filter is off and other 2 parameters are on. From the graph number of disturbance is visible between the reflections because of turned off LP filter.

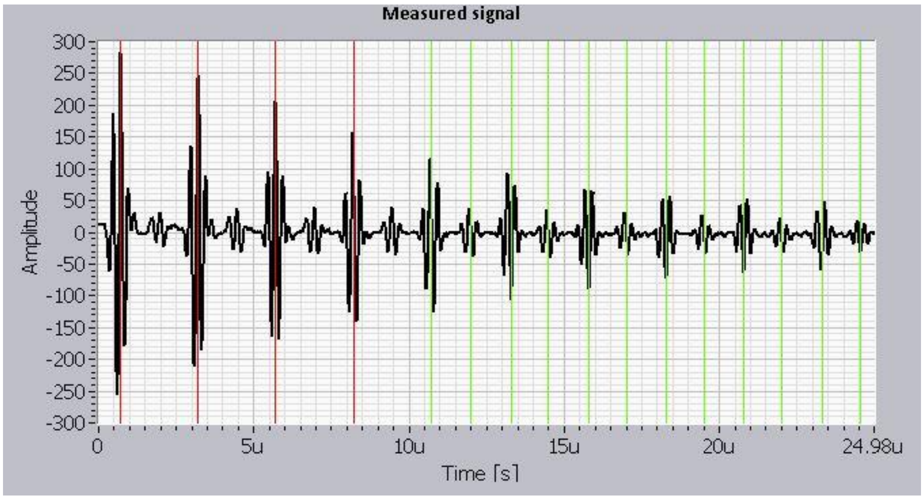

Figure 4.31: High gain OFF, HP filter ON and LP filter OFF

Figure 4.31 shows the graph between amplitude and time when only high pass filter is on. From the graph we can measure echo time as 5µs (echo).

4.3.4 Summary of phase-II

Figure 4.32: Waveform description of phase-II

Figure 4.32 demonstrate the graph between amplitude and time. Here we can observe amplitude fluctuate from 205 to 220 because of the pulse variation. In this case high time is given as 100 and low time as 120. When both times are equal, symmetric graph can be obtain. Time taken for single echo from the graph can be seen as 2.5µs. We can calculate thickness of material as:

$T = V * t/2$

$= 5920* 2.5*10^{-6}/2$

$= 0.074m = 7.4mm$

Measurement on 3 different test with their results are tabulated in table 4.3.

Table 4.3: Summary of phase-II

Test	Thickness in mm (system)	Thickness in mm (vernier scale)
Test 1	7.23	7.50
Test 2	5.71	6.00
Test 3	3.57	3.80

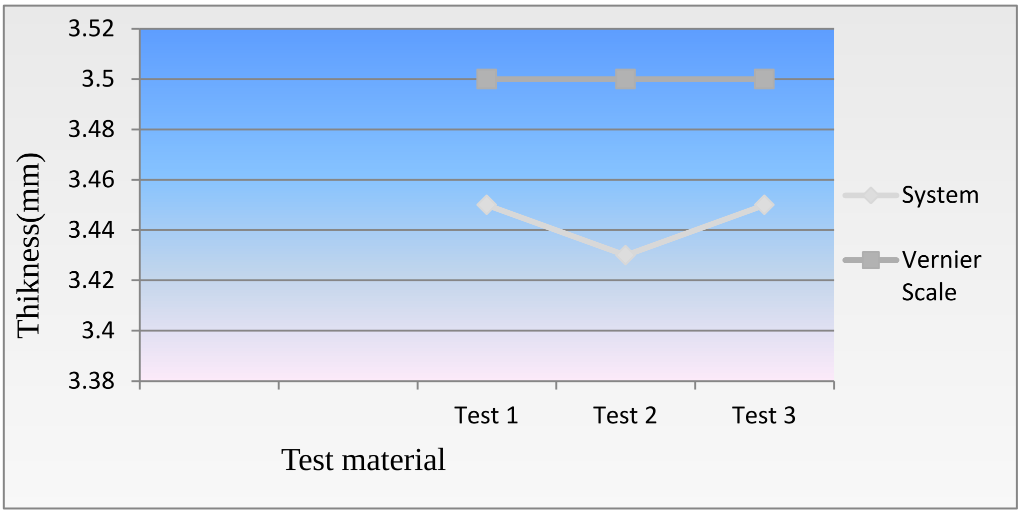

Figure 4.33: Three different tests for phase-II

4.4 Phase III – Use of Ultrasonic sensor around the bending pipe.

4.4.1 Test 1

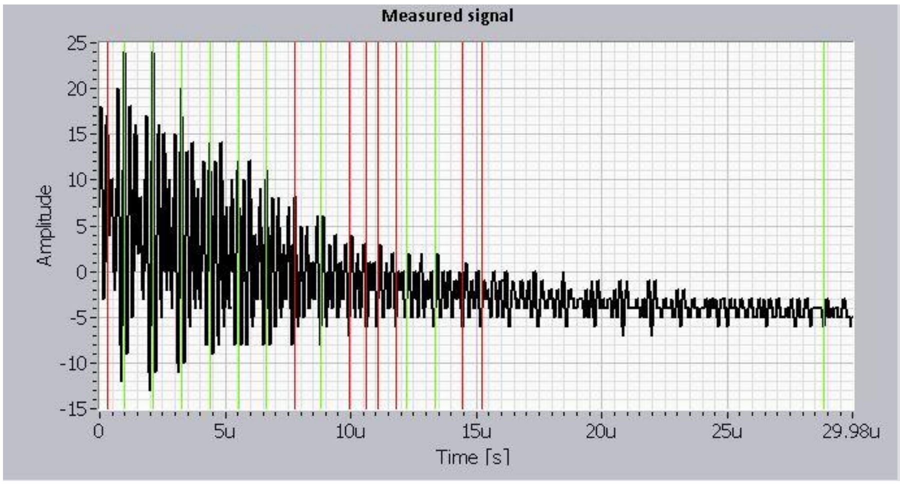

Figure 4.34: High gain ON, HP filter ON and LP filter ON

Figure 4.34 signifies the graph between amplitude vs time when high gain, High pass and low pass filters are on. Amplitudes are high it is due to the multiplication of gain factor. There are numbers of oscillation because the material is thick in size.

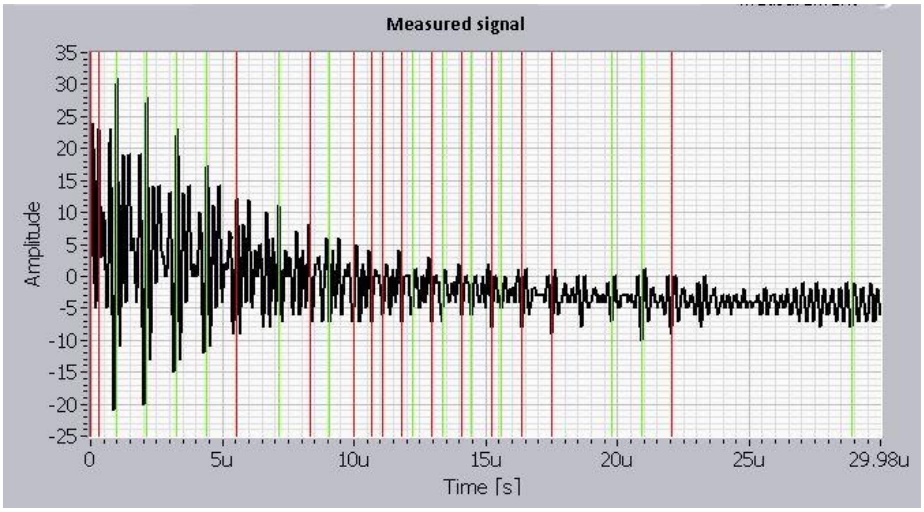

Figure 4.35: High gain ON, HP filter ON and LP filter OFF

Figure 4.35 represent graph when LP filter is off. From the graph number of disturbance is visible more between the reflections since there is absence of LP filter.

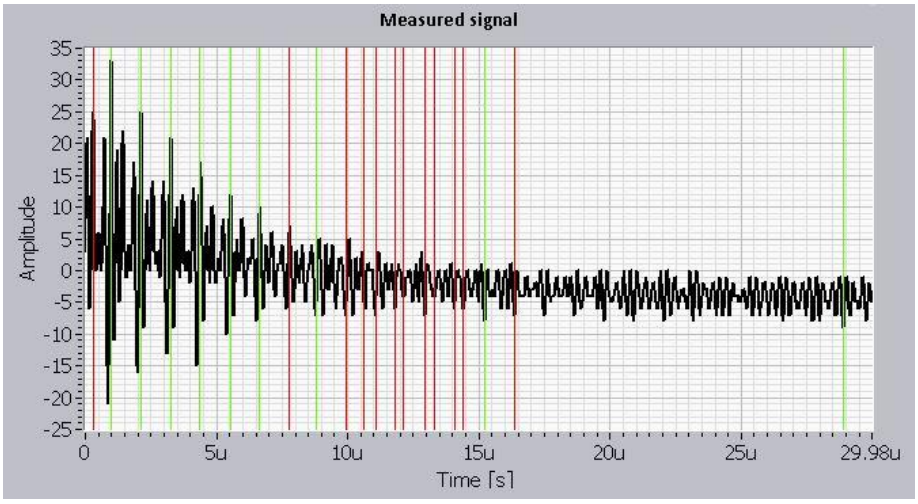

Figure 4.36: High gain OFF, HP filter ON and LP filter OFF

Figure 4.36 represents the graph between amplitude and time when high gain and LP filter are off. From the graph number of sample can be observe more it is due to the higher sample window and thin material surface.

4.4.2 Test 2

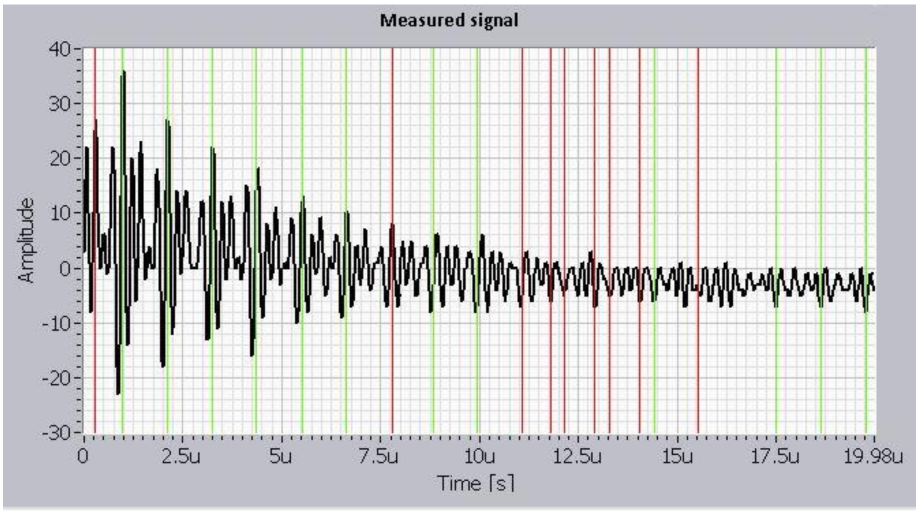

Figure 4.37: High gain ON, HP filter ON and LP filter ON

Figure 4.37 shows the graph between amplitude vs time when all the parameters are on. There are numbers of oscillation because the material is thin in size. Oscillations are reducing from one end to another that is the general trend.

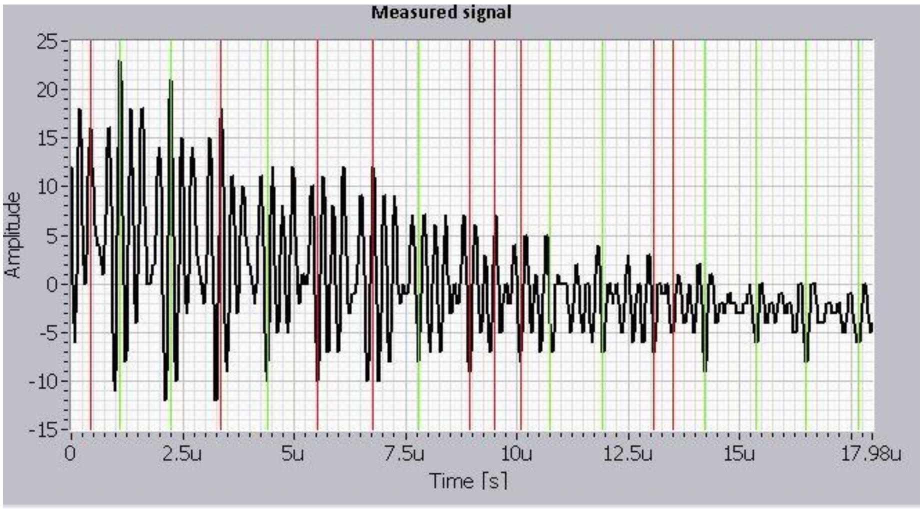

Figure 4.38: High gain ON, HP filter ON and LP filter OFF

Figure 4.38 represent graph when high gain and HP filters are on but LP filter is off. From the graph number of disturbance is significantly high between the reflections because of the absence of LP filter.

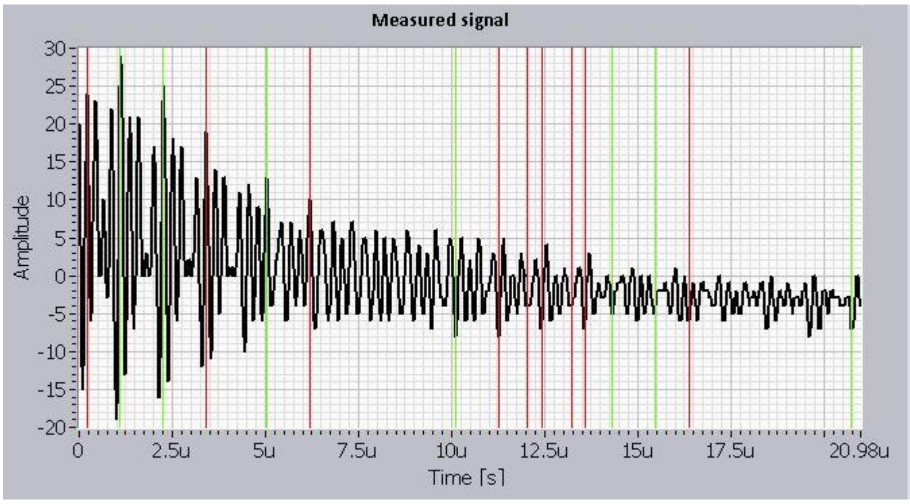

Figure 4.39: High gain OFF, HP filter ON and LP filter OFF

Figure 4.39 represents the graph between amplitude and time when 2 parameters are kept off and only HP filter is on. Oscillations are reducing with time, because sound energy propagation reduces with time.

4.4.3 Test 3

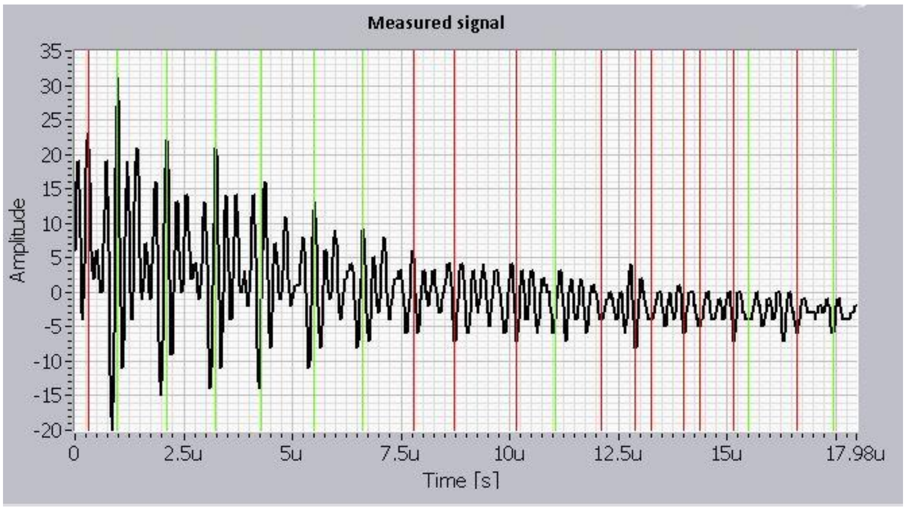

Figure 4.40: High gain ON, HP filter ON and LP filter ON

Figure 4.40 signifies the graph when all the parameters are on. Amplitudes are more in number when window sample is kept small is due to the small size of test material.

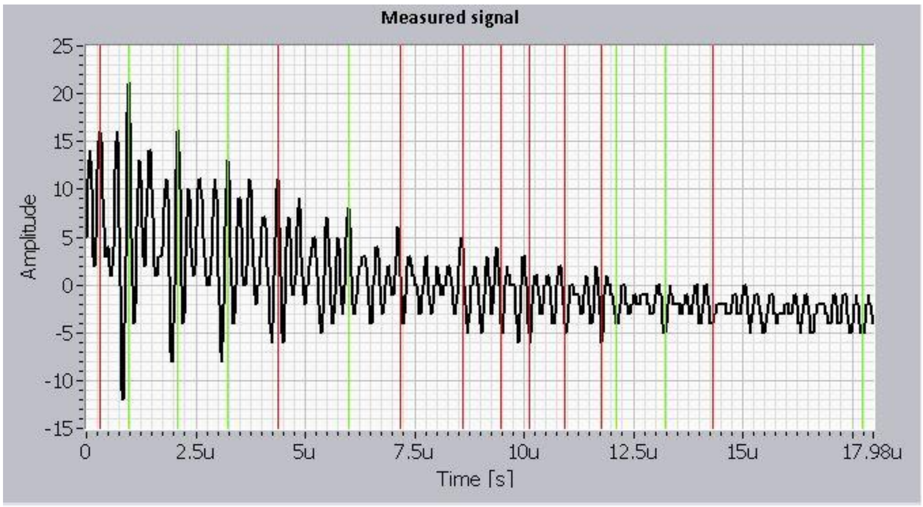

Figure 4.41: High gain ON, HP filter ON and LP filter OFF

Figure 4.41 represent graph when low pass filter is off and high gain and HP filter is on. From the graph number of disturbance is visible between the reflections because LP filter is off.

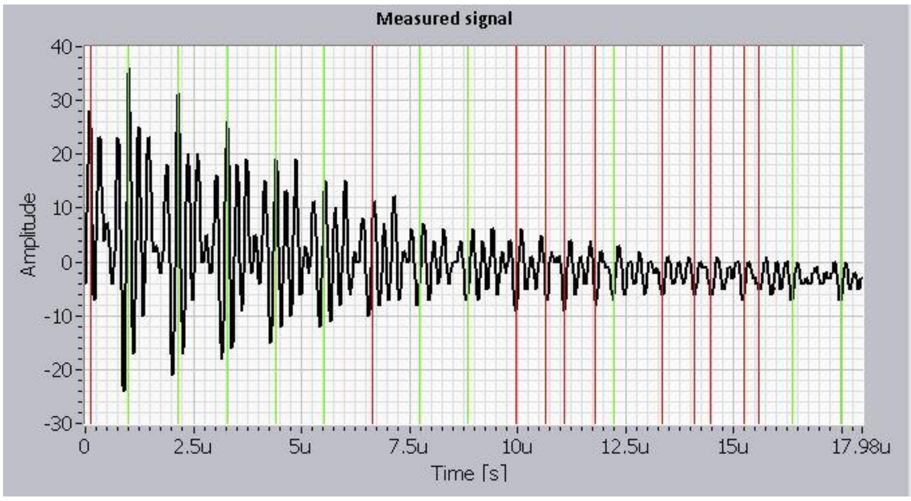

Figure 4.42: High gain OFF, HP filter ON and LP filter OFF

Figure 4.42 shows the graph between amplitude and time when only high pass filter is on. From the graph we can see for first few microsecond there is disturbance until there is visible of first transmitted signal at 1.25 µs.

4.4.4 Summary of phase-III

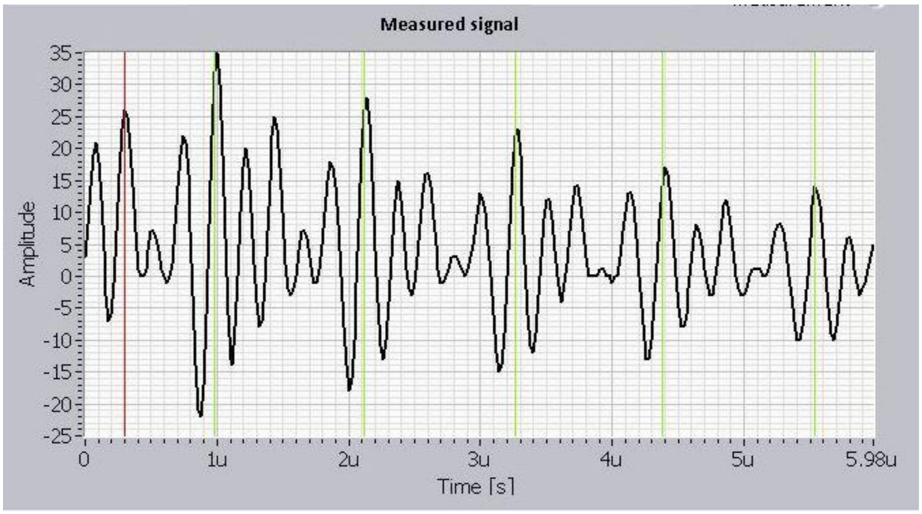

Figure 4.43:Waveform description of phase-III

Figure 4.43 signify the graph between Amplitude vs Time. Where we can see before 0.9µs, There is disturbance which is noise. Graph is zigzag before the transducers send the ultrasonic sound. Once it get transmitted from the 2µs we can see reflection sounds in decreasing order. Waveform decreases with time because energy propagation decreases with respect to time. From the first echo time, thickness of material can be calculated as:

T = V * t/2

= 5920* 1.1*10^{-6}/2

= 0.032m = 3.2mm

Thickness measurement in the bending needs a special design clamp in order to fix the transducer. Three different reason of the same pipe is taken into the measurement consideration. Table 4.4 represents the summery of the phase-III.

Table 4.4: Summary of phase-III

Test	Thickness in mm (system)	Thickness in mm (vernier scale)
Test 1	3.45	3.50
Test 2	3.43	3.50
Test 3	3.45	3.50

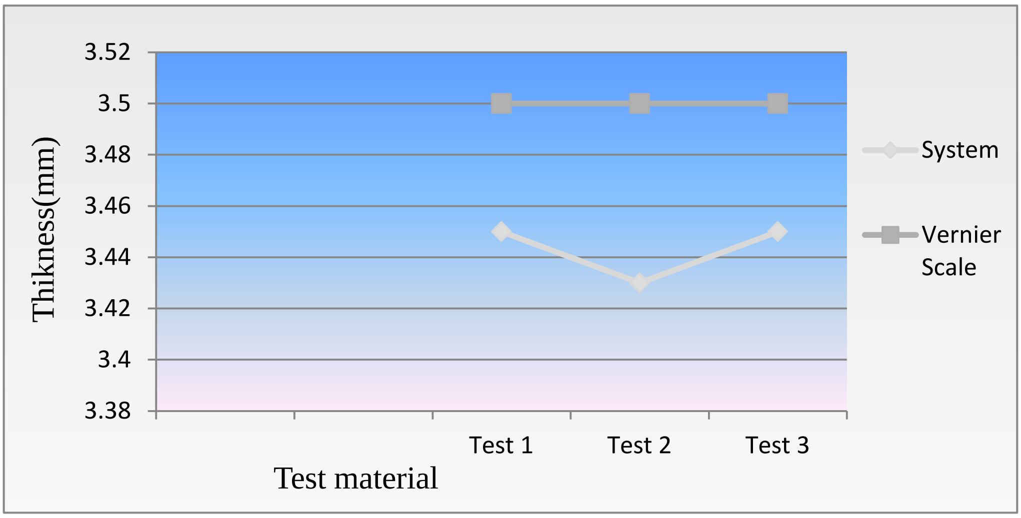

Figure 4.44: Three different tests for phase-III

5 Conclusion and Recommendation for Future Work

5.1 Conclusion

This Master Thesis represents the feasibilities of available PAT methods as on-line impact erosion measurement technique due to the particle bombardment. Basically, 4 different approaches have been introduced to reach the optimal result. Proper clamping of transducer over the test specimen, suitable grease between test specimen and transducer is compulsory to get efficient result. Results in the rough surface observed as accurate as the standard scale measurement. The effect of the gain is just to amplify the amplitude; it does not change the result when it is turned on or off. In order to avoid disturbance in measurement process low pass filter should be turned on. Some of the important information can be concluded as:

- Amplitude vs Time graph represents transmitted and reflection signal. The first signal is transmitted signal and next to this signal is 1st reflection then 2nd reflection and so on.
- Distance between 1st reflection and 2nd reflection is time travel by the sound wave to reach from one end to another end so called echo.
- The pattern of oscillation is decreasing pattern. This is because sound energy loses its energy when it travel (with respect to time).
- Turning on High gain, amplifies the number of times (in amplitude)as it is given in the gain.
- Switching off LP filter causes disturbance (noise) in the process.
- Should be aware minimum sample delay because if it is quick then the time taken to travel back and forth can be less. Then it propagates randomly from any distance of material. This gives bad result.

Since the experiment worked perfectly with precise results it can be implemented in industry for example on metals, ceramics, composites and plastics. However, this is not suitable for wood and paper products.

5.2 Recommendation for Future work

In this master thesis, the experiment was done for very thin material for example about 10mm. Results are significantly accurate when it is compared with standard measurement. But yet to experiment in bulk specimen to observe effectiveness and check echo time mechanism, effect of gain and sample delay.

Similarly, in order to hold the ultrasonic sensor around the pipe or round material, only one method was implemented which worked one direction at once (either horizontal or vertical). In future, clamp can design and fabricate to work in both directions at the same time.

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Appendix A

Master Thesis task description

University College of Southeast Norway

Faculty of Technology, Natural Sciences and Maritime Sciences, Campus Porsgrunn

FMH606 Master's Thesis

Title: Use of Process Analytical Technology (PAT) as on-line measurement technique for pipe erosion due to particle impact

HSN supervisors: Chandana Ratnayake & Maths Halstensen

External partner: Ingrid B Haugland, SINTEF Tel-Tek

Task background:
Handling of particulate materials plays a quite significant role in many industrial sectors, contributing in the base cost of products, energy consumption, environmental and safety issues. Even though pneumatic conveying has been recognised as an efficient powder conveying technique, one major challenge, especially for the abrasive materials, is the erosive wear of the pipe surface, which can lead to unplanned maintenance and equipment repair due to leakage of pipes. The leakage may result in significant discharge of the bulk material to the surroundings with associated occupational hygiene problems. The eroded material from the pipe wall is released into the transport stream, causing undesired or even dangerous contamination.

Process Analytical Technology (PAT) coupled with Multivariate Data Analysis has been used in many processes as effective online monitoring techniques. In recent developments, PAT has been applied in particulate materials handling and processing systems.

Task description:
Modelling and controlling of impact erosion due to solid particles have been studied extensively in past years. However, there is no generalised approach to explain the complex erosion mechanism, due to numerous number of influential parameters involved with the process. The PAT techniques could be used to monitor impact erosion in crucial locations of the plants as on-line detection methods to acquire accurate erosion data and to use them as warning signals avoiding complete openings in pipe sections, bends, etc.

The aim of the present study is to investigate feasibilities of available PAT methods, Ultrasonic Sensors and Acoustic Sensors, as on-line impact erosion measurement techniques. Multivariate and Chemometric data analysis will be used as supportive tools for the purpose. In addition to the offline tests, sensor techniques will be tested as online detection methods coupled with pilot pneumatic conveying test rigs available at SINTEF Tel-Tek's powder testing facilities.
The project will be performed in parallel to an on-going study to investigate impact erosion due to industrial particulate materials; alumina and dolomite.

Student category: PT or EET students

Practical arrangements:
SINTEF Tel-Tek will facilitate the necessary test materials, pilots test rigs, etc. USN will be responsible for other standard facilities (office, library, software, etc.).

Address: Kjølnes ring 56, NO-3918 Porsgrunn, Norway. **Phone:** 35 57 50 00. **Fax:** 35 55 75 47.

Signatures:

Student (date and signature):

Supervisor (date and signature):

Appendix B Ultramonit lab kit Installation

Ultramonit lab kit application is installed from setup file. This application needs USB serial adopter which is installed from internet (www.moxa.com). Based on the system used 64 bit or 32 bit, serial port should be chosen. Proper com port should be choosing carefully, once it is confirmed the same port should be chosen for the result analysis.

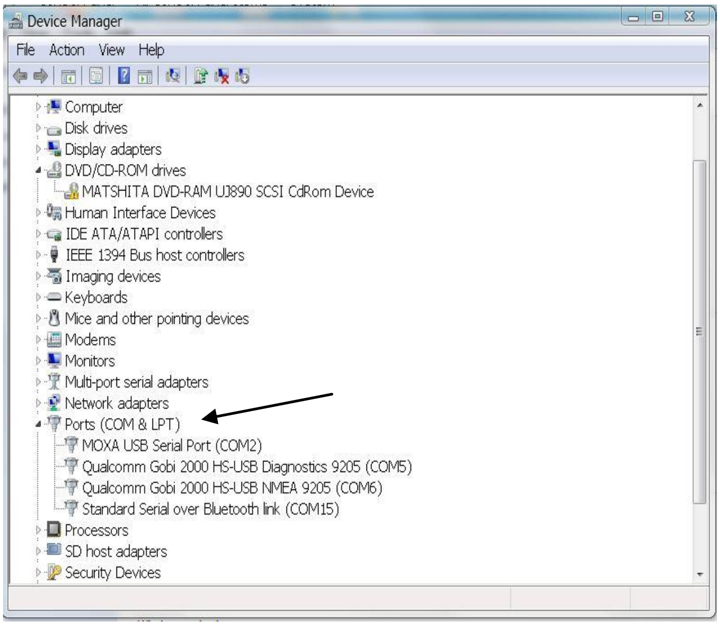

Figure a: Demonstration of ports

It is important to know, the device is working or not. Which can be confirmed from the software properties as displayed is working.

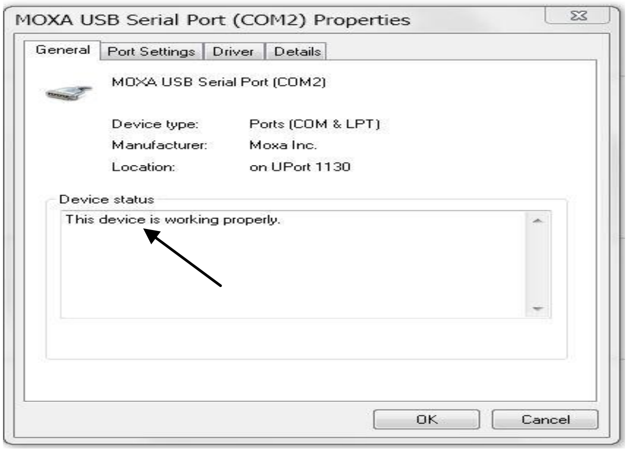

Figure b: Verification of working

From the port setting we can see the properties of device, also on requirement we can make an adjustment on it which is shown in figure c.

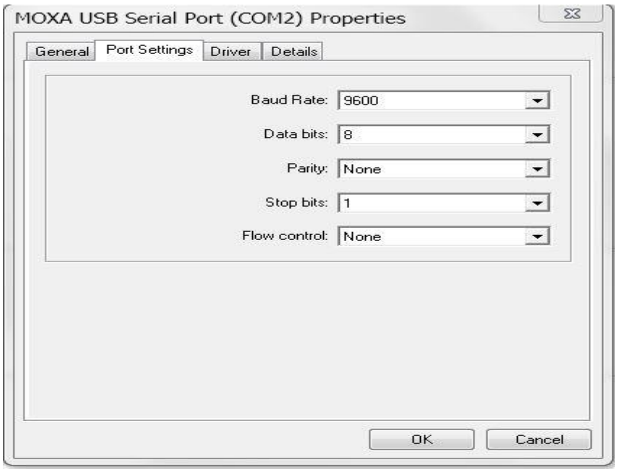

Figure c: Port details

Appendix C Apparatus Used in Experiment

- Ultramonit lab kit

Figure 1: Sensorlink device

- Vernier caliper

Figure 2: Vernier caliper

- Grease

Figure 3: Grease

- Test specimen

Figure 4: Test specimen

- One of the sample from the bundle.

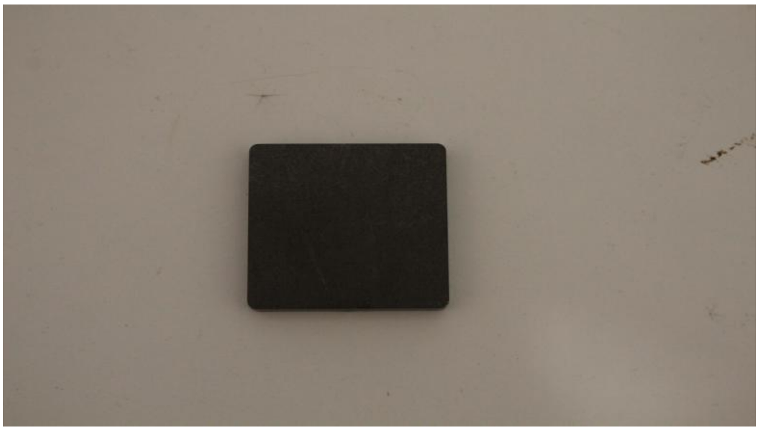

Figure 5: Sample test material

- Transducer

Figure 6: Transducer

- Probe

Figure 7: Probe