ZIBELINE INTERNATIONAL PUBLISHING

Frontiers in Manufacturing Engineering (FME)

DOI : http://doi.org/10.26480/fme.01.2017.11.18

ISSN: 2329-8227 (Print)
ISSN: 2329-8219 (Online)
CODEN : FMERA8

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PREVENTIVE MAINTENANCE FOR OVER-HEADED PIPELINES WITH AUTOMATED ULTRASONIC THICKNESS MONITORING

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ARTICLE DETAILS

Article History:

Received 12 July 2017
Accepted 12 August 2017
Available online 1 September 2017

ABSTRACT

This paper focused on pipe burst, one of the major disasters occurring in oil industry. At present, the small diameter steel pipelines with thin boundary has been commonly used in transportation especially aerospace, military, petrochemical plants, nuclear industry and pipeline industries etc. In order to guarantee or monitoring of steel pipeline without leakage/shutdown in service, it is required to inspect the defect or faults accurately. Many experts, scientist, research scholars and industrialist have done several researches on this subject. As we know, ultrasonic in-service testing is frequently used to detect a defect in work-piece before, during processing and after testing. To monitor the pipe conditions such as thickness, corrosion, erosion, corrosion rate and material deterioration, automated crawler with probe remotely operable system architecture design for in-service preventive monitoring has been developed and presented in this paper.

KEYWORDS

NDT (Non Destructive Testing), SPT (Signal Processing Testing), transducer, Continuous Wavelet Transform (CWT), Discrete Wavelet Transform (DWT), Ultrasonic Testing (UT).

1. INTRODUCTION

High precision, thin and high strength steel pipeline, often working underground or upper ground in the presence of varying temperature and pressure depends on situation and workload assign to a pipe, play an extremely important role in the growth of national economy, and it is commonly used in aviation, warships, petrochemical plants, missiles, atomic energy, space technology, aerospace industry, pipeline industry and other fields [1]. But in most of the processing units, some material deterioration take place and gave a birth to cracks and debris due to fluid flaw inside pipeline or some other conditions like chemical reactions results will appear in the outside and internal surface of the steel pipeline, and this problem is mostly caused by the slag/debris in the raw material or material deterioration. Usually most of the defects are related to method by which steel pipelines are produced, for i.e., the common defects in the seamless steel pipes are cracks, skin inclusions, debris; the welded steel pipe are cracks, inside slag, porosities, undercut, under cracks, lack of fusion; the rolled steel pipes are cracks and cold-lap. In order to guarantee the in-service safety to overcome pipe burst cases, loss of production and smooth working of plant and reliability of the steel pipelines in service, so it is essential to examine the inside flaws of pipes before it was used in process unit [2,3]. As we know, Non-Destructive Testing (NDTs) is a technique by which we can detect the flaws without doing any harm to work-piece. Many other flaws or cracks detects inspection techniques have been practically applied into most of industries, such as the Ultrasonic in-service inspection, Radiographic inspection, Magnetic Flux Leakage, Magnetic particle inspection, Remote Field Eddy Current Testing, Penetrate inspection, Eddy current inspection, Laser Testing and so on [4-6].

Figure 1 represent the types of non destructive testing with further sub classifications.

The principle aim for ultrasonic in-service inspection of engineering materials like pipeline is the detection of corrosion, erosion, material deterioration, and location of leaks, cracks, also the classification of internal flaws, geometry, and defects as quickleqy with accurate readings. The ultrasonic in-service testing uses pulse-echo method to find flaws or leaks in pipes has become widespread in pipeline industry manufacturers [7,8]. Ultrasonic in- service Testing is one of the most competent and effective ways to detect outer or inner surface defects. There are some kinds of ultrasonic waves generated by transducer to a work-piece such as longitudinal wave, transversal wave, guided waves, surface wave, lamb wave, railey waves, plate wave, and different wave is used according to the test piece or system requirements [9]. This research work focused on the ultrasonic in-service inspection technology for small diameter and thin walled pipes, including some mathematical theories of ultrasonic testing, algorithms for microprocessors used in this subject along with the main components of testing such as control unit, communication unit. The new development in the present trends of ultrasonic testing and some suggestion are also discussed in this paper.

2. EXISTING PROBLEMS IN CONVENTIONAL ULTRASONIC TESTING

1) In a research work authored by Z G Yang, some existing problems of conventional ultrasonic testing methods were proposed [10]. Conventional ultrasonic testing methods are generally not suitable for small diameter pipelines and the region behind this described below:

Diffusion of sonic energy takes place when ultrasonic beam transmits with the help of transducer from the outer wall of pipeline to the inner wall of pipeline refraction wave production diffusion phenomena (inci dent wave c1 having velocity 2720 m/s, refraction wa-

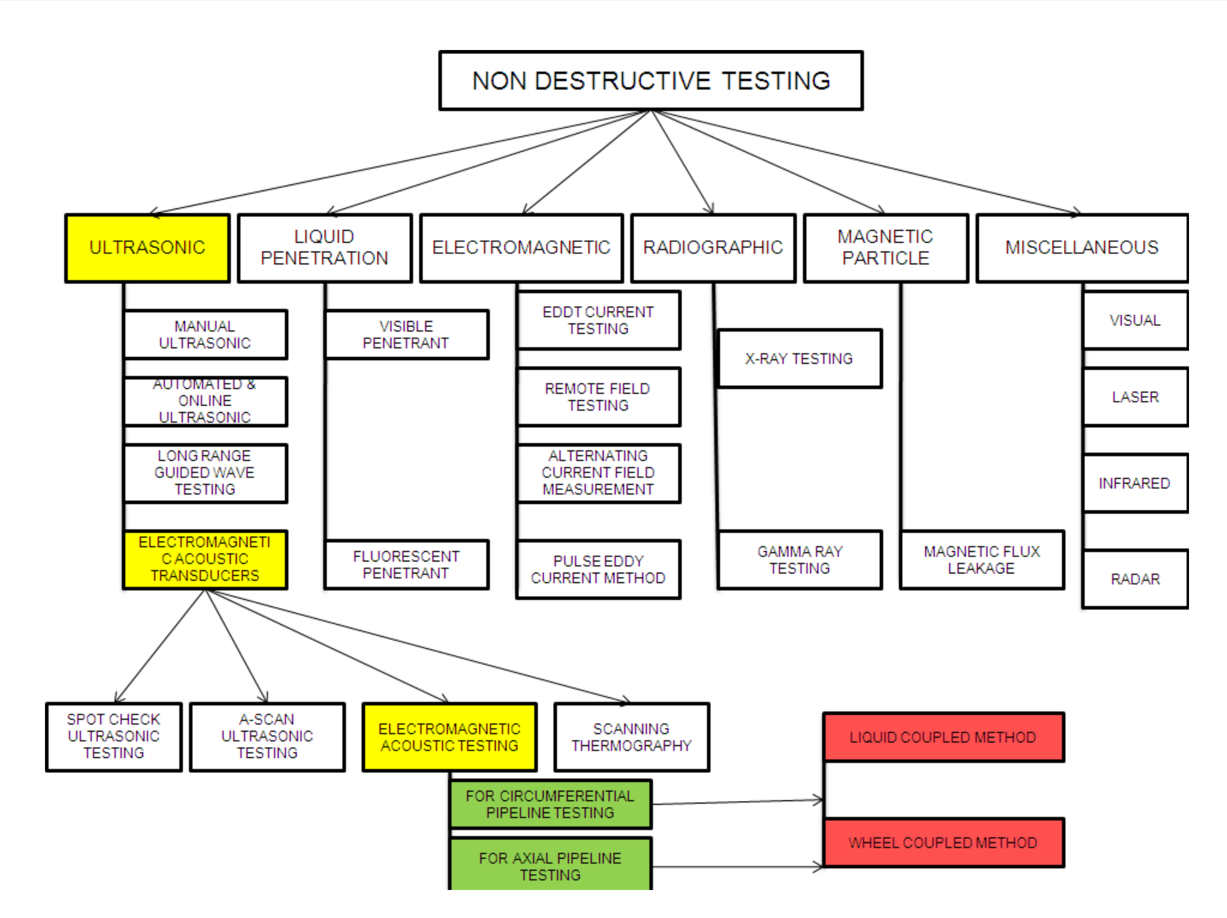

Figure 1: Types of NDT

-ve c2=3100 m/sec) because of the small radius pipeline having a small curvature. Diffusion phenomena also take place due to properties of reflection wave to be more severe in case of small pipeline diameters, as shown in Figure 2. These factors "small curvature and severe" directly influence the sensitivity of ultrasonic testing [11].

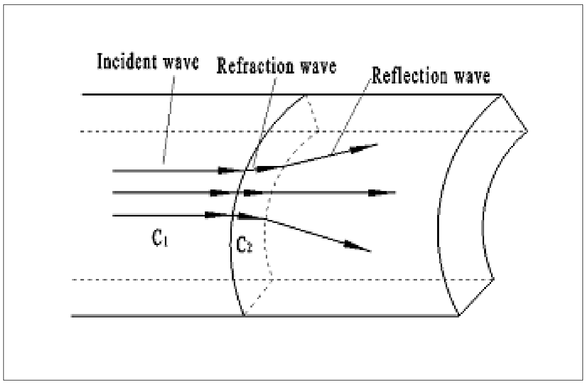

Figure 2: Loss of sonic energy through pipeline

2) An outcome of a thin pipeline wall (inner/outer radius) is to avoid the severe diffusion by locating an inspection zone in the first half of near field zone in small diameter pipelines. This near field zone reduces the sensitivity of ultrasonic in-service testing.

3) Ultrasonic testing of small diameter pipelines is not able to detect gas pockets or slag at but joints or welded materials due to sonic diffusion and near field zone effect.

4) Conventional probes base does not fit properly on small diameter pipelines, which affect the accuracy of measurement.

3. WORKING PRINCIPLES AND BACKGROUND OF ULTRASONIC WAVES

Based on a study, principle of the in-service ultrasonic water immersion method with highlighting transducer probe was proposed by the author, some important theoretical information was introduced [12]. In ultrasonic testing, the amplitude of defected pulse echo is directly proportional to the force of ultrasonic wave's reflection sound. If the defect size in the form of crack or leak is larger, the reflection sound force is higher than the defect (leak or crack) pulse echo higher. The force of reflected sound wave pressure calculated by attenuation, acoustic impedance of probe and material, reflection coefficient, transformation coefficient of wave and reflection coefficient. The ratio of reflected wave amplitude to incident wave amplitude is called coefficient pointed by JL Rose [13]. The factor value directly depends on angle of incidence, interfacing, frequency and velocity of wave. The interface between same medium and different medium was dealt by boundary condition method for e.g. solid to solid, solid to liquid and liquid to solid mostly this type of interface are used in above system. The reflection/refraction coefficient of solid to solid, liquid to solid, solid to liquid could be calculated. Ultrasonic flooding method is mainly used in case of interface between two semi infinite medium for e.g. steel-water, water steel and steel to air. Now in present situation, direct contact ultrasonic methods are replaced by water immersion method especially in case of small thickness pipeline, because direct contact ultrasonic methods produce a big curvature. In pulse echo mode sending and receiving of pulsed wave (sound) is performed by

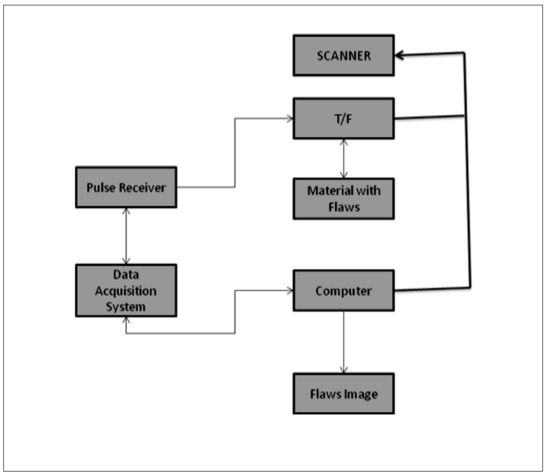

Figure 3: Pulse Echo Mode

Table 1: Comparative study of transducers with their special features

Transducer	Application	Advantages
contact	1. For straight test piece/beam flaw detection. 2. For Detection and sizing of de-laminations. 3. For knowing Material characteristics. 4. For velocity measurements. 5. Used for both metallic and non metallic materials. 6. Suitable for temperature up to (50 ℃).	1. High durability and wearing resistance capacity. 2. For rugged industrial environments. 3. Close acoustic impedance matching. 4. Can be used for a wide variety of materials.
Dual Element	1. Pipeline thickness measurement. 2. In-service Corrosion/erosion monitoring. 3. for measurement of Weld overlay. 4. Detection of cladding in pipeline. 5. Detection of porosity, debris, leaks and cracks. 6. Crack detection at but joints. 7. Temperature capability is (425 ℃)for 5.0 MHz, 1750C for 7.5 MHz and 4250C for 10MHz.	1. To improves surface resolution. 2. To eliminates delay. 3. Good responses at rough or curved surfaces. 4. Reduces back echo noise. 5. Capable of using both lower frequency single element transducer and Higher frequency single element transducer.
Angle Beam	1. for flaw detection. 2. For time-of-flight diffraction transducers. 3. In-service inspection of pipes, turbines, boilers, welded components and machine components. 4. for size detection.	1. Easily wedges are used. 2. Wedges customized according to need. 3. signal to noise characteristics improves with the help of wedges. 4. High temperature wedges are easily available for hot materials. 5. Wedges available in integral design. 6. Contouring available.
Delay Line	1. used in case of limited clearance gap. 2. for flaw detection. 3. for precision thickness measurements.	1. Excellent resolution power. 2. Good ability to measure small elements. 3. Good ability to measure thin materials. 4. Frequency value directly proportional to surface resolution. 5. Find small defects.
Protected Face	1. for flaw detection in straight beam. 2. for Thickness measurement. 3. Work proper under high temperature in-service inspection of components or elements. 4. In-service inspection of tube wall, bars and plates.	1. Provide removable delay line. 2. Having protective membrane. 3. Provides versatility in case of protective wear cap. 4. Wear face also provide good impedance matching in case of low impedance materials. 5.threaten in case of easy attachment to following: a)delay line b)protective membrane c)wear cap
Immersion	1. Through transmission testing. 2. used for material characteristics analysis. 3. Sound velocity measurements in test pieces. 4. High speed detection. 5. In-service thickness measurements. 6. Automated scanning capabilities.	1. Uniform coupling. 2. Output sound energy level increased by quarter wavelength matching layer.
High Frequency	1. High resolution power used in micro-cracks inspection. 2. Data represented in C-scan imaging. 3. Minimum thickness measurements up to (0.0004”). 4. for ceramics examination. 5. For advanced engineering of materials. 6. Materials analysis with high reliability.	1. Focusing on small diameters components. 2. Frequencies range (20 MHz to 225 MHz).

transducer. The reflected wave comes from interface, such as imperfection (defect, corrosion) and the wall of sample. These reflected signals are captured by device and comparative results displays by diagnostic machine. Pulse echo mode results in the form of amplitude (intensity ofreflection) and strength of signal. Amplitude and signal strength indicate distance and wall thickness of sample. Figure 3 represents main blocks of pulse echo mode trans- receiver.

In attenuation we use two transducers, one for sending signals and second for receiving signal. Both transducers are laced opposite of sample object. These reflected signals are captured by device and comparative results displays by diagnostic machine. Pulse echo mode results in the form of amplitude (intensity of reflection) and strength of signal. Amplitude and signal strength shows distance and wall thickness of sample. Table 1 focused on transducer applications with advantages. In Figure 4 various types of transducer and its characteristics are shown for the purpose of comparative analysis

Transducer	No. of Elements	Generated Wave	Working Temperature	Contact Angle	Working Frequency	Special Featue
Contact Transducer	Single Element	Longitudinal	Normal	No Angle	20MHz-200MHz	Direct Contact to Test Piece
Dual Element Transducer	Two Element	Longitudinal	High	Slightly Angle	20MHz-200MHz	Use in Heavily Corrode Part
Angle Beam Transducer	Single Element	Shear/Longitudinal	Normal	Selected Angle	20MHz-200MHz	Working Based On Snell's Law
Delay Line Transducer	Single Element	Longitudinal	High	No Angle	20MHz-200MHz	Improve resolution/Accurate Thickness
Protected Face Transducer	Single Element	Longitudinal	Normal	No Angle	20MHz-200MHz	also used In Low Impedance Materials e.g rubber
Immersion Transducer	Single Element	Longitudinal	Normal	No Angle	20MHz-200MHz	Scanning Applications
High Frequency Transducer	Single Element	Longitudinal	Normal	No Angle	20MHz-225MHz	High Resolution Image

Figure 4: Comparative chart of transducers

4. COMPARATIVE STUDY OF ULTRASONIC WAVES WITH THEIR CHARACTERISTICS

Generally wave exists in four different modes: L-mode (Longitudinal or S0), T-mode (Torsional), F-mode (Flexural or A0), SH0 (Shear Horizontal Mode). In A0 mode attenuation is very high if plate loaded with liquid, which makes it's unsuitable for many applications. The S0 mode is having low frequencies and the SH0 mode have not significantly attenuated by liquid loading therefore the use of S0 and SH0 modes was considered. According to a research, guided wave inspection range lies between 10~100 meters in case of pipes and more than 10 m in bare plate [14]. Within the inspection range, the open cross-sectional area of detectable defect size in pipes by using magnetostartistic sensor MsS System is typically 3 to 4 percent of the open cross sectional area [15]. Because of the convenience, optimal solution and better performance, MsS System operates in the T wave mode for steel pipe inspection and in the SH wave mode for plate inspection.

It is well understood in Figure 5 wave and particle movements are perpendicular to each other.

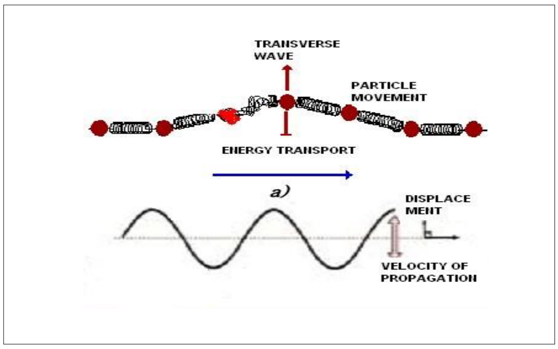

Figure 5: Traverse wave

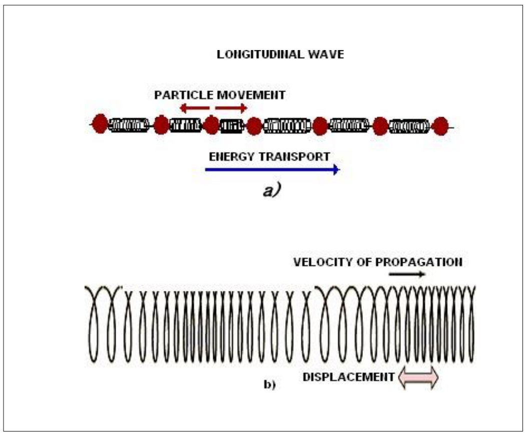

Figure 6: Longitudinal wave

In Figure 6 it is clear longitudinal wave and particle movement is parallel to each other.

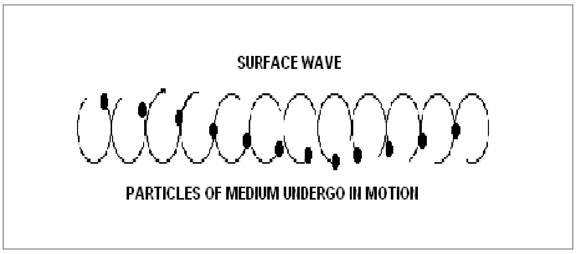

Figure 7: Surface Wave

In surface wave particle movement undergoes circumferential direction. Figure 8 focused on types of guided wave with further sub classifications.

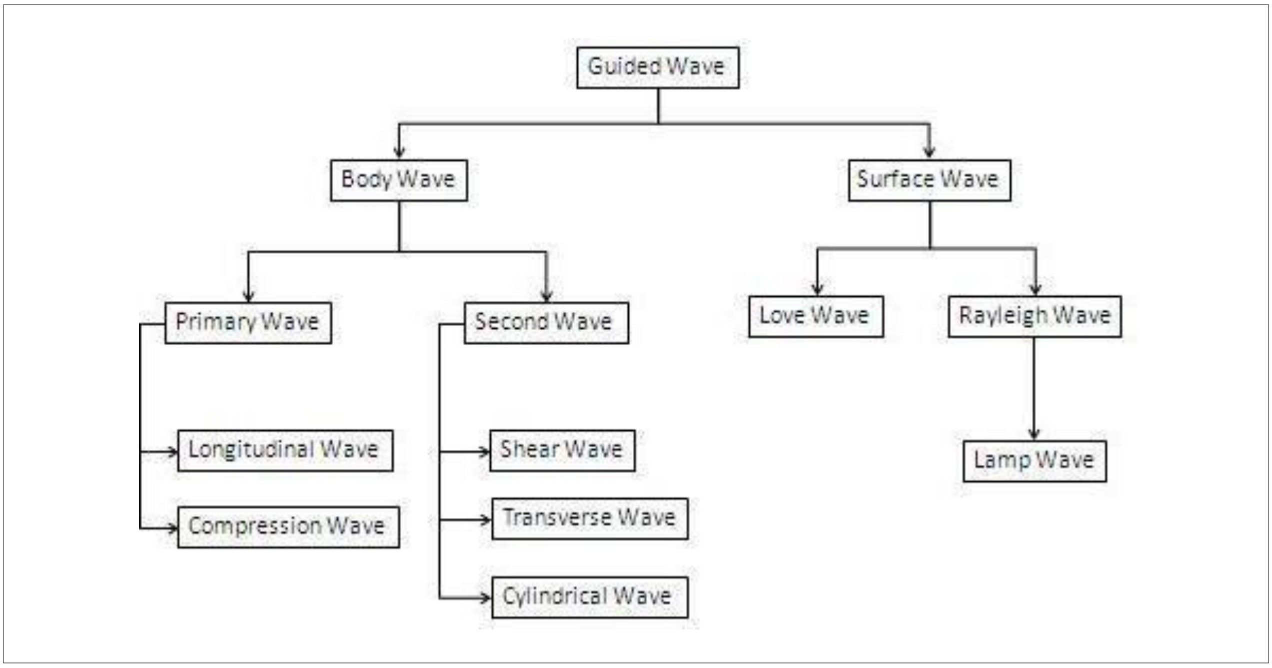

Figure 8: Category wise type of waves

5. ULTRASONIC INSPECTION WITH NEW TRENDS (FOR SMALL DIAMETER PIPELINES)

Steel pipelines especially with small diameter generally used as the safest, reliable and most economical mode of transportation in oil and gas industries (processing units) lying under or upper ground layer. Due to reliability, safety, low product loss, environment friendly, low transportation cost and easy way of transportation, they are being used in others field also or extensively. In order to guaranty the above system advantages, it is necessary to extend life of pipelines, for this case it is necessary to monitor in-service of piping system to overcome any unhappy event before occurring during processing. Ultrasonic in-service defect inspection is the most common technique used to detect immature cracks/leaks likely to be occurring in pipeline. Study showed the performance of an in-service ultrasonic flaw detection method based on or evaluated by the success of pulse waves received after scattered by microstructures [16]. Therefore, the reliability of data directly depends on the signal noise ratio in case of small diameter pipelines. With the development of an automation with the help of microprocessor gave a birth to more and more new in-service ultrasonic inspection techniques with accuracy and reliability, and digital signal processing technologies also play a important role in this field. In sum, the trends of in-service ultrasonic inspection technologies for thin steel pipelines are described as follows:

Ultrasonic (longitudinal waves) is generated into test piece with the help of piezoelectric transducer having single element, normal working temperature, working frequency lying between 20MHz-200MHz and having no contact angle with test piece. Figure 9 and Figure 10 represent Ultrasonic Working principle and mathematical model.

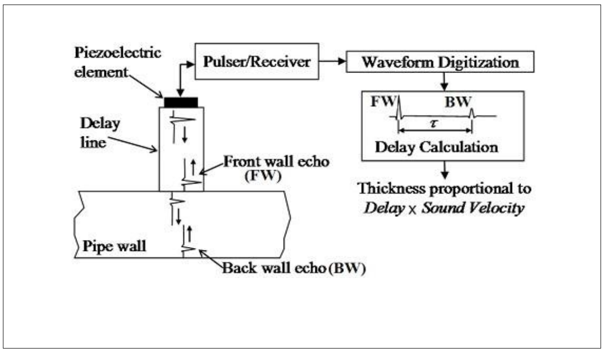

Figure 9: Working principle of ultrasonic tool

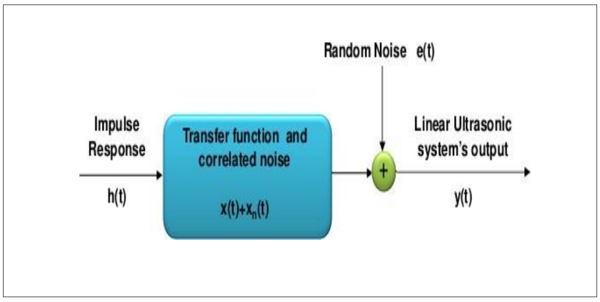

Figure 10: Mathematical model of ultrasonic testing

In Linear Ultrasonic Model Output:

$$y(t)=[x(t)+x_n(t)]*h(t) \quad (1)$$

Mathematical Model:

$$y(t) = [x(t) + x_n(t)] * h(t) + e(t) \quad (2)$$

Where Y(t)= linear ultrasonic system output, X(t)= transfer function, Xn(t)=correlated noise, h(t)= impulse response, e(t)= random noise.

Model Based Estimation (MBE) Algorithm:

$$y'(\theta, t) = \beta e^{-\alpha(t-\tau)^2}\cos(2\pi f\ (t_T-\tau) + \varphi) \quad (3)$$
$$\theta = (\alpha,\ f_c,\ \varphi,\ \beta,\ \tau)$$

Objective Functions:

For all echoes-

$$\sum_P \min_\theta \left(\| y_P(t) - (y'_{P_1}(\theta_{P_1}, t_{P_1}) + y'_{P_2}(\theta_{P_2}, t_{P_2}))\|^2\right)$$
$$=> (\alpha, f_c, \varphi) \quad (4)$$

For each echo-

$$\min_\theta \left(\| y_i(t) - (y'_{i_1}(\theta_{i_1}, t_{i_1}) + y'_{i_2}(\theta_{i_2}, t_{i_2}))\|^2\right)$$
$$=> (\beta, \tau) \quad (5)$$

According to a scholar, ultrasonic results are simulated and analysis with the help of tomo-view also a hot topic for research scholar in coming time [17,18]. The finite element method plays an important role in the development of straight flaw detection in small diameter pipelines. Know two important key issues of above system are:

1) How to build more precisely 3D FE model

2) Way of predicting defects in service.

5.1 Here it is important to note the advantage of FEM is to reduce the cost of straight flaw detection

Crawler also required eye catching attention for use in non destructive testing especially in oil industry due to their capability of reaching up to unapproachable zones where human labor warned to reach. Crawler carry ultrasonic thickness gauge, clearance gap measurement tool, grinding head, cameras and zigbee. Camera plays an important role to provide information related to the real condition of pipeline. Zigbee used for transferring a data to and fro. Although some signal processing techniques also have been presented to estimate pipe wall thickness, a real- time signal processing used in ultrasonic inspection called the Intelligent Signal Extraction System. In this method ratio of signal to noise improves with the help of finite impulse response filtering, results came in the form of reliability and guaranteed system meet expected deliveries.

5.2 Signal processing technology (SPT)

Although some signal processing techniques also have been presented to estimate pipe wall thickness, a real-time signal processing used in ultrasonic inspection called the Intelligent Signal Extraction System. In this method ratio of signal to noise improves with the help of finite impulse response filtering, results came in the form of reliability and guaranteed system meet expected deliveries. With the speedy development of IT (signal processing), more and more computer signal processing technology is being applied in in-service ultrasonic detection widely, SPT is also used in in-service monitoring field which as an important to improve strength of signal and sensitivity by filtering a noise. SPT having a large number of tools for improving strength and sensitivity i.e. cross correlation, wavelet method, bind source separation, convolution and split spectral processing. In SPT we focus on to determine the following parameters: 1) location of defect 2) shape of defect 3) size of defect is badly affected by noise present in signal and sometimes noise due to interfering features. All above three parameters are described on the basis of Signal-to-noise rate (SNR). All detection methods have a goal to raise a signal to noise ratio for increasing a detect ability [19].

5.4 Wavelets

Wavelets, a wave like oscillation having amplitude value increase or decrease and finally come back to zero. In a research work [20], wavelets analysis used to detect pipe wall thickness was introduced. The most popular technique of wavelets is Fourier analysis, which breaks down a signal into sinusoidal forms of different frequencies, transforming a signal from time domain to frequency domain. Fourier analysis is satisfactory, in case of well defined signal frequencies. However, there are a number of disadvantages occurs especially in the situation of 1) sudden change in signal 2) fluctuations 3) discontinuities etc. The Wavelet theory focused on limitations of Fourier analysis and also tries to remove them. Its depend on the windowing/conversation of signal into variable sized regions with the help of time interval for e.g. sort time interval for high frequency and long time interval for short range frequencies therefore analysis of localized area possible without losing time information. Wavelet transform have two types 1) Continuous wavelet transform (CWT), and 2) Discrete wavelet transform (DWT), as introduced below:

5.5 Continuous wavelet transforms (CWT)

The wavelet transform breaks down a signal into wavelets with varying in "scale" and "location". Based on a study, scale is defined in terms of stretched or compressed, and location defined in shift [21]. The time of whole signal duration multiplied by wavelet function (Φ) is called continuous wavelet transform, depends on scale and shift, as define in mathematical equation form shown below :

$$C_{s,l} = \frac{1}{\sqrt{s}}\int x(t)\Phi\left(\frac{t-l}{s}\right)dt \quad (6)$$

Where s=scale, l=shift, (Φ) = wavelet function and x (t) = the signal function.

5.6 Discrete wavelet transforms (DWT)

Scaling and shifting of the wavelet function (Φ) define on the basis of orthogonal:

$$\Phi_{(s,l)}(x) = 2^{-\frac{s}{2}}\Phi(2^{-s}x-l) \quad (7)$$

Where s=scale, l=shift, (Φ) = wavelet function and x (t) = the signal function.

In Equation (4), the wavelets are stretched / shrinked in the powers of 2 i.e. 2,4,6,8 and so on.

$$W(x) = \sum_{k=-1}^{N-2} (-1)^k c_{k+1} \Phi(2x+k) \quad (8)$$

W(x) = scale function of the function Φ(x)

Ck = wavelet coefficients

$$\sum_{k=0}^{N-1} c_k = 2 \ , \ \sum_{k=0}^{N-1} c_k c_{k+2L} = 2\delta_{l,0} \quad (9)$$

δ= delta function, l= location.

5.7 Components of the testing system

In service thickness measurement system setup (architecture) has been divided into two basic subsystems:

1) Data Acquisition 2) Data Processing Functions and their working are shown below in Figure

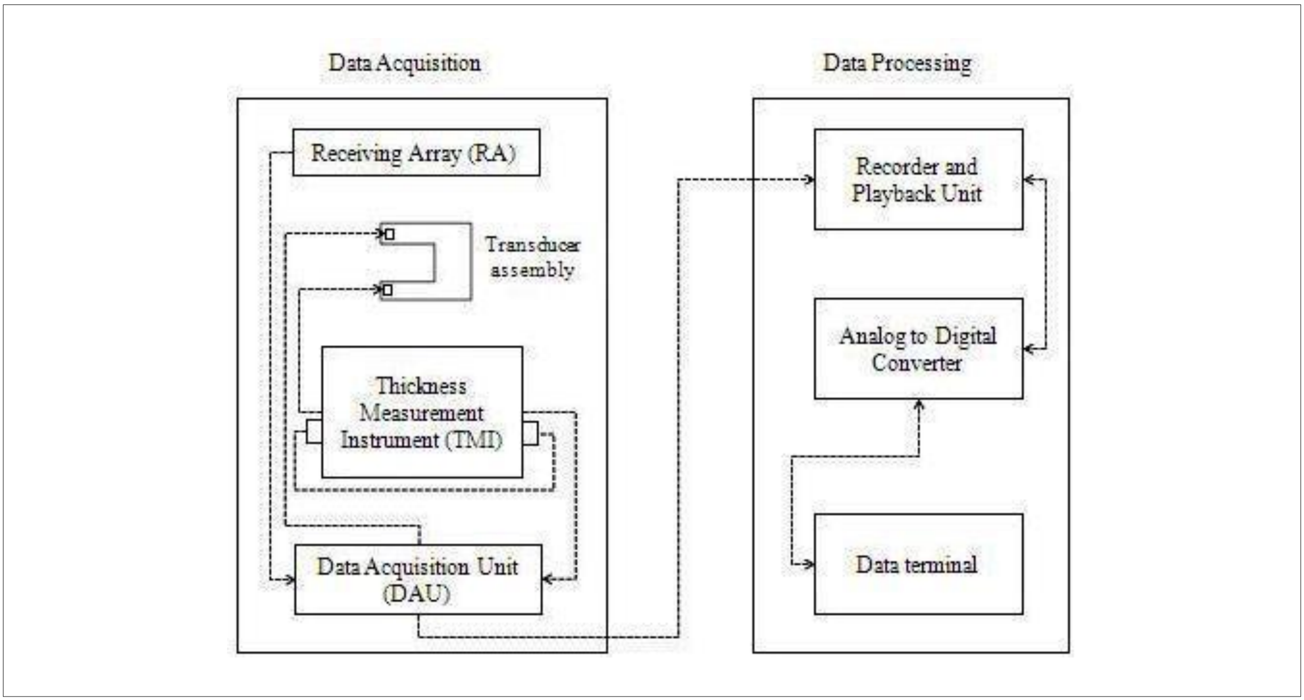

Figure 11: Thickness measurement setup (Architecture)

5.8 Data Acquisition Subsystem

Before making any examination, microprocessor of DAQ subsystem setup must be programmed. It must be told to the microprocessor about the radius of pipeline, number of sensors, minimum thickness, optimum thickness, maximum thickness, and actual thickness for valid programming. This is a way to overcome erroneous signals/readings that may occur due to couplant (grease/water/oil) or improperly placement of probe. Once these essential parameters are feed into DAQ unit, the following sequence of steps takes place (shown in Figure 12) [22,23].

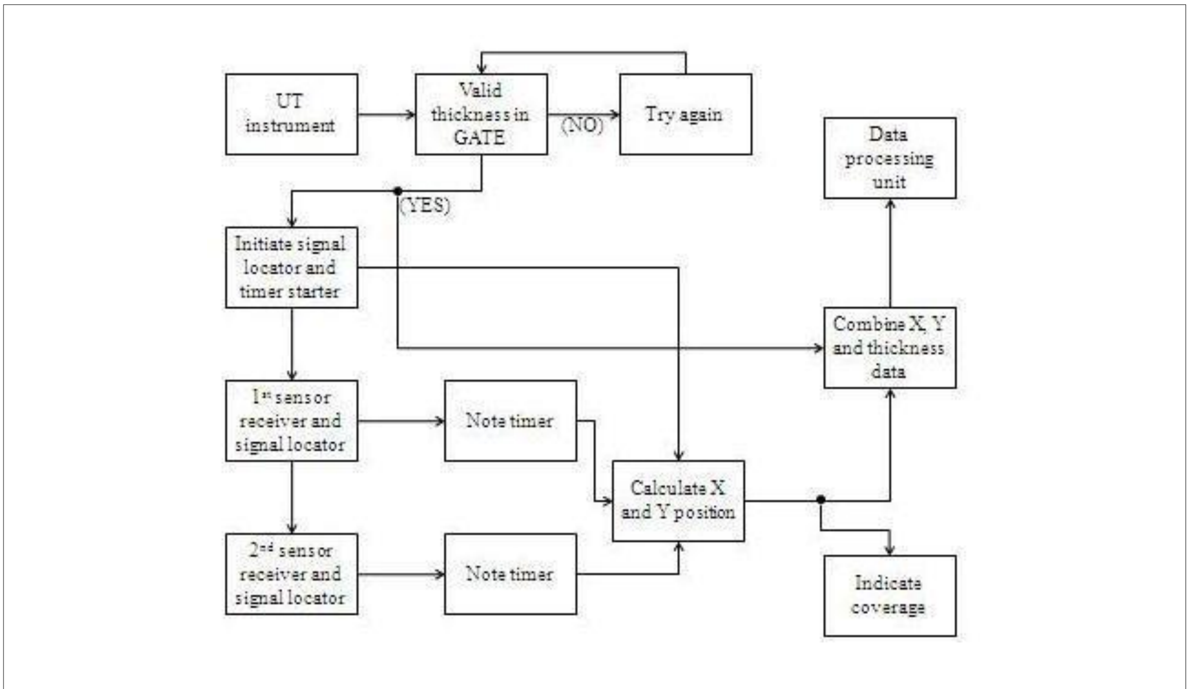

Figure 12: Data Acquisition Subsystem

5.9 Data Processing Subsystem

Data processor has two blocks for data storage 1) for data processing 2) Data from tape/Playback. The working of data processing subsystem is shown below in Figure 13 and Figure 14.

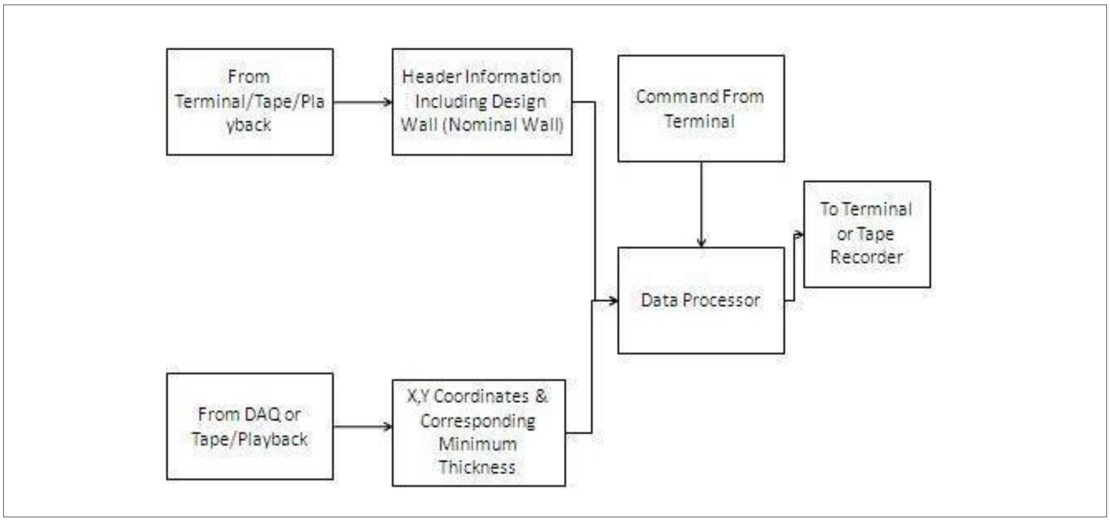

Figure 13: Data processor operation

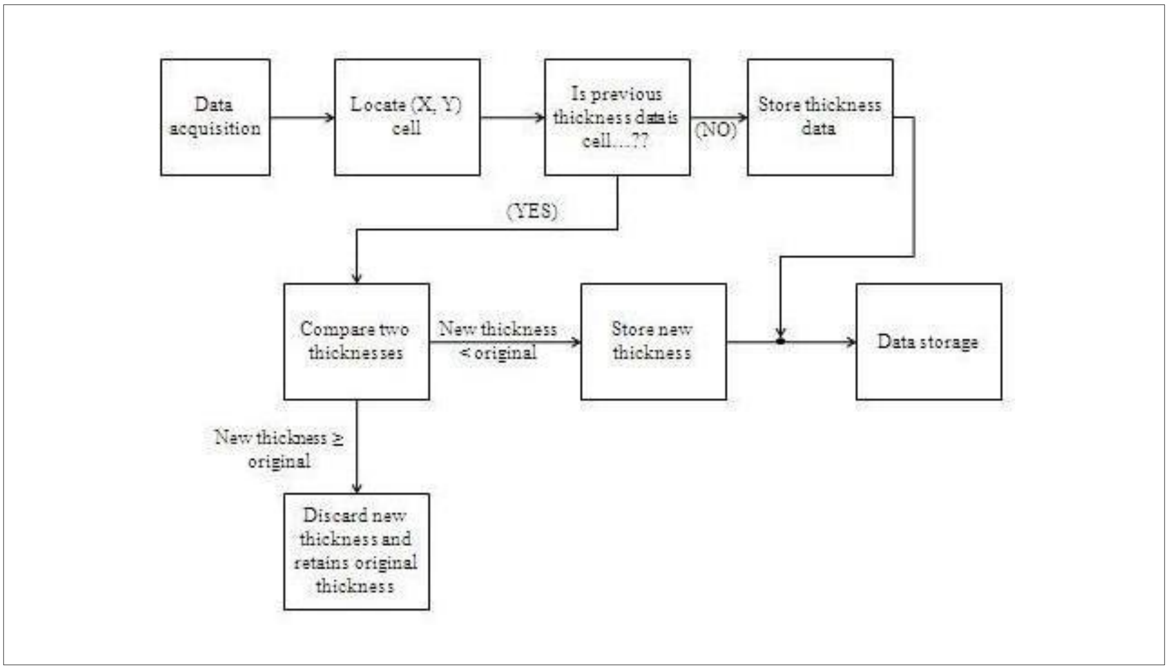

Figure 14: Data processor thickness storage operation

6. RESULTS AND DISCUSSION

Calibration completed with respect to two aspects i.e. gain and time-base range. Before making calibration water or oil is used as a couplant for mismatching acoustic impedance of probe and test piece for accurate data directly depends on the signal noise ratio in case of small diameter pipelines. With the development of an automation with the help of microprocessor gave a birth to more and more new in-service ultrasonic inspection techniques with accuracy and reliability, and digital signal processing technologies also play a important role in this field. In sum, the trends of in-service ultrasonic inspection technologies for thin steel pipelines are described as follows: Although some signal processing techniques also have been presented to estimate pipe wall thickness, a real- time signal processing used in ultrasonic inspection called the Intelligent Signal Extraction System. For extracting a maximum accuracy the time-base range for the pipeline wall thickness is used, gain is adjusted according to first back wall pulse value, which is slightly below full screen height. The gain setting plays an important role in the scanning of subject throughout. But, the reflectivity at the corrode pipe is poor in comparison to the normal pipeline.

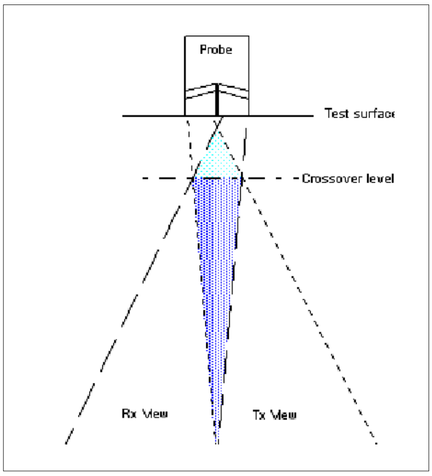

Figure 15: Probe setting with test piece

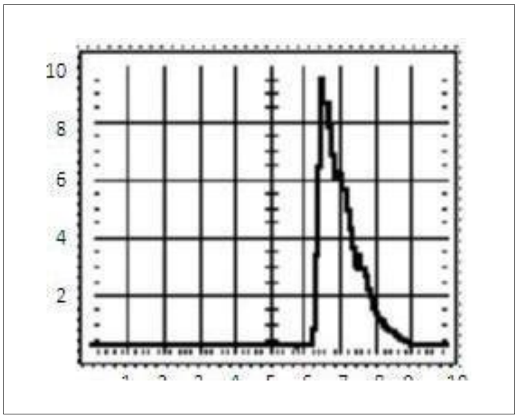

Figure 16: Gain and time-base

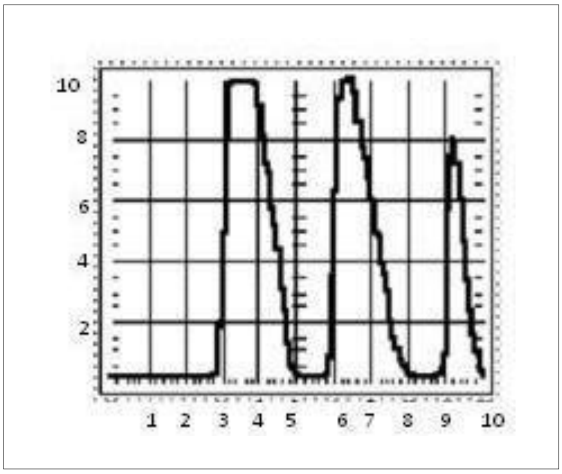

Figure 17: Pulse echo set 3, 6, 9

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