CHAPTER 4

BASICS OF NON-DESTRUCTIVE METHODS AND SELECTION OF NON-DESTRUCTIVE TECHNIQUES FOR THE PRESENT WORK

4.1 INTRODUCTION

Non-Destructive Testing (NDT) is a method to find the defects present, or the damage induced in the material without harming it. In the aircraft industry, NDT is used to look for internal changes or signs of wear on airplanes. Hence, often finding the nature and size of the defects present or the damage induced in the material will help to take the necessary action for the repair or rejection of the material. With the NDT, defects can be identified before they become dangerous, and the safety of the user ensured. Nowadays, composite material defects and damages are determined precisely by many advanced NDT methods. The selection of a suitable technique for the present work and their basics are discussed in detail in this chapter.

4.2 STUDY OF NON-DESTRUCTIVE METHODS AND SELECTION OF A SUITABLE METHOD FOR THE PRESENT WORK

Many NDT methods such as Visual Inspection (VI), Liquid Penetrant Technique (LPT), Eddy Current Technique (ECT), Infrared testing (IR), Laser testing, X-ray Radiography, Ultrasonic Technique (UT), Acoustic Emission Technique (AET), etc., are available.
NDT is widely used in a variety of applications that cover a wide range of industrial applications, namely, automotive, aviation/aerospace, construction, maintenance, repair and operations. NDT is also used in industrial plants, such as Nuclear, Petrochemical, Power, Pulp and Paper, Fabrication shops and Mine processing.

Visual Inspection involves the illumination of the material being investigated, with a light ray in the visible region. The Visual Inspection Technique (VIT) can be used for the identification of the shape and measurement of the area of impact damage. These techniques cannot be used to detect the damage present inside the materials. Liquid Penetrant inspection is based upon the ability of the liquid to wet the material’s surface. This technique may not be applied to the GFRP composite laminate, since drop impact damages cannot be seen on the surfaces of composite materials.

Magnetic particle inspection is used for the testing of ferromagnetic materials. Eddy current testing is based on electromagnetic induction, and used to inspect the materials which are electrically conductive in nature. Radiography is the method of using shorter wavelengths of electromagnetic radiation to penetrate the object. The variations in the absorption of X-ray radiation by the materials are used for flaw size characterisation. It is widely applied to measure the porosity, voids, and planar defects present in materials, whether metallic or non-metallic. The main disadvantage of X-ray radiography is that the X rays are harmful to the environment and human beings.

Ultrasonic Technique can used for the assessment of the surface and internal discontinuities, such as flaws, seams, discontinuities, voids, cracks, blow holes, inclusions, lack of bond, etc can be found.
Infrared cannot be applied to find the delamination due to impact, because there is no sharp temperature difference across the delamination boundary, and the temperature maps do not directly indicate the size of delamination. The tapping technique is also used to detect the presence of the internal defects by lightly tapping the specimen, as the impact location is changed from an undamaged zone to a region containing a delamination. The most commonly used NDT are the Ultrasonic and X-ray methods. The disadvantage of ultrasonic, radiographic or other techniques is that they require interruption from normal operation. Accessibility between personnel and equipment is difficult, and more time is also required for inspection.

Acoustic emission inspection detects and analyse minute AE signals generated by discontinuities in materials under an external stimulus. This technique can be applied for monitoring active damage source.

The Ultrasonic Technique is a versatile NDT method, which can be applied to the inspection of any materials, metallic or non-metallic in nature. Therefore, UT is selected for the offline assessment of drop impact damage on composite material. AET is selected for online assessment of drop impact damage

4.3 BASICS OF THE ULTRASONIC TECHNIQUE

(Courtesy: Practical Non-Destructive Testing by Jayakumar et al)

Any sound waves, whether audible or ultrasonic, are mechanical vibrations involving movement through the medium in which they are travelling. A sound wave may be transmitted through any material, which behaves in an elastic manner. Ultrasonic waves are classified on the basis of the mode of vibration of the particles into the medium, with respect to the
direction of the propagation of the waves, namely, longitudinal, transverse, and surface waves.

4.3.1 Sound Wave Terminology

Velocity of the Ultrasonic Waves

The velocity of sound (v) wave in a material is determined by the relation

\[ v = f \lambda \]  \hspace{1cm} (4.1)

where,

\[ f \] - Frequency in Hz,
\[ \lambda \] - Wave length in meter.

This equation is valid for all kinds of waves.

Acoustic Impedance

The resistance offered to the propagation of an ultrasonic wave by a material is known as the acoustic impedance (Z), and is determined by,

\[ Z = \rho V \]  \hspace{1cm} (4.2)

where,

\[ \rho \] - Density of the material in kg/m\(^3\),
\[ V \] - Sound velocity through the material in m/s.

Attenuation

Attenuation is generally expressed in the form,
A = A₀ eʳ  \hspace{5cm} (4.3)

where,

A₀ - Amplitude of the machined surface in dB,

ₑ - Attenuation coefficient in nepers/mm,

r - Distance between the two reference locations in mm.

It is well known that the sound energy decreases with the distance travelled. Attenuation is the decrease of sound intensity with distance. The combined effect of scattering and absorption is attenuation.

Attenuation Coefficient

The attenuation coefficient is defined as the ratio of the amplitude of the incident echo to the amplitude of the echo after travelling distance ‘r’.

\[
\text{Attenuation coefficient} = \frac{1}{r} \ln \left( \frac{A₀}{A₁} \right) \hspace{5cm} (4.4)
\]

where,

A₀ - Reference amplitude in dB,

A₁ - Amplitude of the echo after travelling distance ‘r’ in dB,

r - Distance between the two reference locations in mm.

4.3.2 Various Modes in the Ultrasonic Technique

Communicating the flaw size and shape to others is a very crucial part of the NDT process. Decisions on the removal of the part, repair or continued service, need full information about the flaw characteristics. The various types of ultrasonic presentations are given below.
A-Scan

Echoes can be displayed just as seen on an ordinary oscilloscope; the X-axis represents the time of flight of the pulses converted into distance travelled by the pulses, and the deflection parallel to the Y-axis represents the amplitude of the echoes. This type of presentation is called the A-scan. It shows the situation with the probe stationary in one position. A-scan presentation is still the most used mode of display in ultrasonic testing.

B-scan

In the B-scan display, the Y-axis is used in a different way. When moving the probe along a straight line on the surface of the test object, the displacement of the probe can be converted into an electrical signal by a potentiometer, and is used to shift the spot on the oscilloscope screen. This dimension is normally displayed along the X-axis and the travel of the ultrasonic pulse in the object is represented by the base, which is done by moving the spot in the Y-direction. The beam is always cut off; only the echo signals cause it to brighten up, producing a spot across the screen, whose brightness is proportional to the echo amplitude. In this way, only one line scan appears on the screen at any one time.

C-scan

In some testing problems, the depths of defects are irrelevant, but their distribution parallel to the test surface is an important feature. For this purpose, the presentation rotated by 90° such that, the X-and Y-directions are now both in the plane to the surface as the test object, i.e. the plan of scan.

Gao & Kim (1999) reported that the B-scan images provide a cross-sectional view of the laminate along a designated line, while the ply-by-ply
C-scan analysis generates the images of the damage accumulated through the laminate thickness. The Time of Flight (TOF) technique displays the 3D perspective of the multi-layer damage.

4.3.3 Advantages and Disadvantages of Ultrasonic Testing

Advantages of Ultrasonic Testing

1. Testing can be carried out from a single side.
2. Using guided waves, inaccessible regions can be inspected.
3. A high degree of penetration is possible in many commonly used materials, which is in contrast with the lower degree of penetration encountered with the radiological testing of metals.
4. High sensitivity to planar defects such as delamination and disbands.
5. Accuracy in locating and measuring defects.
6. Compatibility with automatic scanning devices namely micro-processor and computers.

Disadvantages of Ultrasonic Testing

- Manual operation requires careful attention and experienced technicians.
- Parts that are rough, of irregular shape, very small or thin, and non-homogeneous, are difficult to inspect.
- Reference standards are needed.
- Couplants are needed between the sensor and the workpiece, to provide effective transfer of ultrasonic waves.
4.3.4 General Applications of Ultrasonic Testing

- It is used for the inspection of finished and semi-finished products, made from ferrous as well as non-ferrous materials.
- It is used in defect detection of multilayed structures.
- Delamination detection in composites and adhesively bonded structures.
- Forgings are tested using automatic or semi automatic test stations.
- Inspection of defects, such as fatigue crack and effects of corrosion in a power plant.
- Inspection of boiler components for the presence of fatigue crack in the welds.

4.4 ACOUSTIC EMISSION TECHNIQUE

(Courtesy: www.vallen.de)

The Acoustic Emission Technique is used to monitor the defect formation and failures in the structural materials, used in services or laboratories. The difference between the AE Technique and other Non-Destructive Evaluation (NDE) methods are

1. AE detects the activities inside the materials, while other NDE methods attempt to examine the internal structures of the materials.
2. AE only needs the input of one or more relatively small sensors of the surface on the structure or specimen being
examined, so that the structure or specimen can be subjected to in-service or laboratory operation, while the AE system continuously monitors the progressive damage. In other NDE methods, such as the Ultrasound and X-ray, one has to access the whole structure or specimen, and therefore, the structure or specimen often needs to be disassembled and taken to the laboratory to be examined. Since, the AE technique is an online monitoring method, it has been selected for the experimental observation of the impact damage in real time application.

4.4.1 Sources of Acoustic Emission

Acoustic Emission is a very versatile, non-invasive way to gather information about a material or a structure. Acoustic Emission (AE) refers to the generation of transient elastic waves, produced by a sudden redistribution of stress in a material. Acoustic Emissions can result from the initiation and growth of cracks, slips and dislocation movements, twinning, or phase transformations in metals. In any case, AE is originating with stress. When a stress is exerted on a material, a strain is induced into the material as well. Depending on the magnitude of the stress and the properties of the material, an object may return to its original dimensions or be permanently deformed after the stress is removed. The amplitude of the emission is proportional to the velocity of crack propagation and the amount of damage created. Large and discrete crack jumps will produce larger AE signals, than cracks that propagate slowly over the same distance. The components used for the AE signal acquisition process are shown in Figure 4.1.
4.4.2 Acoustic Emission generation process

When a structure is subjected to an external load or localised sources, it triggers the release of energy, in the form of stress waves, which propagate to the surface, and are recorded by sensors as shown in Figure 4.2. The motions of an elastic stress can be identified with the right equipment and setup in the order of 10-12 pico-meters. Sources of AE vary from natural events like earthquakes, rock bursts, the initiation and growth of cracks, slip and dislocation movements, melting, twinning, and phase transformations in
metals. In composites, matrix cracking, fibre breakage, delamination, debonding, etc. contribute to acoustic emissions.

![Figure 4.2 Description of the Acoustic Emission generation process](image)

**Figure 4.2 Description of the Acoustic Emission generation process**

The advantage of the AET is the complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, absence of the need to disassemble and clean a specimen. The main drawbacks of AE systems are the loud service environments, which contribute extraneous noise to the AE signals. The successful application to signal discrimination and noise reduction, becomes crucial.

### 4.4.3 AE signal and Parameters

There are two types of AE signals generated during the plastic deformation of any material, such as burst and continuous signals as shown in Figure 4.3.

1. Burst AE is a quantitative description of the discrete signals, related to individual emission events occurring within the material.
2. Continuous AE is a qualitative description of the sustained signal, produced by time-overlapping signals.

![Burst AE and Continuous AE](image)

**Figure 4.3 Types of AE Signals emitted from a source** (www.vallen.de)

The characteristics of AE signals are described by the following AE parameters, such as amplitude, rise time, count, threshold, energy, etc. These parameters are schematically shown in Figure 4.4.

![AE Hit Waveform](image)

**Figure 4.4 AE Hit Waveform**
1. **Hit** – The detection and measurement of an AE signal on a channel.

2. **Amplitude** – It is the greatest measured voltage in a waveform and is measured in decibels (dB). This is an important parameter in acoustic emission inspection, because it determines the detectability of the signal.

3. **Energy** – Integral of the rectified voltage signal over the duration of the AE hit.

4. **Duration** – The time from the first threshold crossing to the end of the last threshold crossing.

5. **Counts** – The number of AE signals that exceeds the threshold.

6. **Average Frequency** (A.F) – Determines the average frequency in kHz over the entire AE hit. $A.F = \frac{AE \text{ counts}}{Duration} \text{ [kHz]}$

7. **RMS** – Root Mean Square is the measure of continuously varying AE signal “voltage” into the AE system.

8. **Rise Time** – The time from the first threshold crossing to the maximum amplitude.

9. **Count Rate** – Number of counts per time.

10. **Counts To Peak** – It is the measure of the number of AE counts between the AE Hit start and the peak amplitude of the AE Hit.

11. **Channel** – A single AE sensor and the related equipment components for transmitting, conditioning, detecting and measuring the signal that comes from it.

12. **Location** – Relating to the use of multiple AE sensors for determining the relative position of the AE source.
13. **Signal Strength**- It is mathematically defined as the integral of the rectified voltage signal over the duration of the AE waveform packet. This feature is similar to the energy, except that it is called over the entire signal dynamic range, and is independent of gain.

### 4.4.4 AE sensors

- The purpose of the AE sensors is to detect the motion of the stress waves, which causes the local dynamic material displacement, and converts this displacement to an electrical signal.

- AE sensors are typically piezoelectric sensors, made of special ceramic elements like Lead Zirconate Titanate (PZT). The mechanical strain of a piezo element generates an electric signal.

- Sensors may have an internally installed preamplifier (integral sensors).

### 4.4.5 Application of AET

The Acoustic Emission Technique (AET) is applied to inspect and monitor pipelines, pressure vessels, storage tanks, bridges, aircraft, trucks, a variety of composites and ceramic components. It is also used in process control applications, such as the monitoring of welding processes. A few examples of AET applications are as follows.

- Laboratory and R&D studies

- Online weld monitoring
• Vessels testing [ambient, hot or cryogenic, metallic and FRP, spheres]
• Nuclear component’s inspection (valves, lift beams, steam lines)
• Investigating processes, such as fatigue, stress corrosion, corrosion, etc.
• Pipeline testing
• Railroad tank car testing
• Tube trailers & high pressure gas cylinders
• Advanced material’s testing (composites, ceramics)

4.5 STUDY OF AN ACOUSTIC EMISSION ANALYSER

(Courtesy: Catalogue supplied by Physical Acoustic Corporation)

The AE Analyser comprises of signal detection, data acquisition and analysis. The selection of the sensor and filters plays a crucial role in acquiring data in the AE Analyser. The features and description of AE the Analyser are as follows.

4.5.1 Overview of the PCI-2 Analyser

The Peripheral Component Interconnect 2 (PCI-2) is a 2-channel AE analyser, data acquisition and digital signal processing system, on a single full size PCI card. Superior low noise and low threshold performance have been achieved with this revolutionary AE Analyser design, through the use of an 18 bit analog to digital (A/D) conversion. PCI-2 AE Ultrasonic Technique cards can be implemented inside the most standard computers.
4.5.2 **Key Functions of the PCI-2 AE Analyser**

- Built-in, real time AE feature extraction and independent direct memory access transfer for each AE channel, provide high speed transient data analysis at high hit rates.
- AE data streaming is also built into the PCI-2 board, allowing continuous recording of AE waveforms to the hard disk up to 10 Msamples/sec rate.
- High pass and 4 low pass filter selections for each channel are totally under software control.
- Digital signal processing circuitry virtually eliminates drift, thereby achieving high accuracy and reliability.

4.5.3 **AE Win Software**

AE Win Software is a WINDOWS based AE acquisition, analysis and reply software, provided with a PCI-2 as the standard. It also includes waveform processing and display, multiple graphs per screen, and zonal and linear location modes as the standard.

4.5.4 **AE-Win Post**

AE-win Post is a fully featured utility in AE-win for post processing Acoustic Emission data. This utility allows data to preview, using graphs, plots and tabular views. The data can be sorted and filtered through user-selected actions or user defined advanced filters. Waveform viewing and feature extraction, first hit extraction and many more operations can be done in this software. The treated data can be exported to a new DTA or TDA file for use with AE-win.
4.6 SCHEMATIC DIAGRAM SHOWING EXPERIMENTAL SETUP FOR THE PROPOSED WORK

4.6.1 Assessment of Drop Impact Damage using the Ultrasonic Technique

Drop impact damage can be assessed, using ultrasonic techniques after the material is tested by the low velocity impact test. The impact tested composite samples were taken from the impact test apparatus and scanned by the ultrasonic flaw detector in the A-scan mode. By analysing the A-scan ultrasonic signal, the nature of the impact damage will be understood. This method was applied to the inspection of easily reachable components and those which are smaller in size. The schematic experimental diagram for ultrasonic observation of GFRP composite laminates is shown in Figure 4.5.

![Schematic Diagram](image)

Figure 4.5 The schematic experimental diagram of the ultrasonic setup

4.6.2 Assessment of Drop Impact Damage using the Acoustic Emission Technique

Drop impact damage was monitored by the AE system, during the drop impact testing of the composite laminate, and the AE signals were captured. The characteristics of impact damage were known from the analysis of the acquired AE signals during the impact test. AET was applied as a...
monitoring tool for any active source present within the material under investigation, as shown in Figure 4.6.

Figure 4.6 The schematic setup for Acoustic Emission monitoring of the drop impact test