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Nondestructive Inspection Journeyman

Volume 3. Advanced NDI Techniques

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Volume 3 of your CDC expands on the basic knowledge that you have received in the previous volumes and introduces advanced nondestructive inspection (NDI) techniques. The term *advanced* is used to describe testing methods that go beyond simple inspections of the exterior surfaces of aircraft parts. These testing methods allow you to explore components below the surface or within complex structures without affecting their serviceability. Many of the testing methods in this volume are critical to the daily operational capability of individual aircraft and entire installations. Your understanding of advanced NDI techniques will enable you to completely test and interpret any component you need to inspect.

Unit 1 covers eddy current inspection methods. We discuss the principles of eddy currents and eddy current inspection equipment. We also look at eddy inspection interpretation and conductivity testing.

Unit 2 deals with ultrasonic inspection methods. We begin with principles of ultrasonics, and then we cover ultrasonic equipment and hazards, inspection application and techniques, and process controls.

Unit 3 presents bond testing inspection principles. The lesson starts with understanding bonds and composite structures and introduces you to a new NDI technique called shearography. The lesson continues on with bond testing inspection techniques and the equipment used.

A glossary is included for your use.

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This volume is valued at 15 hours and 5 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Page

Unit 1. Principles of Eddy Current Inspection

IN 1881, PRESIDENT JAMES ABRAM GARFIELD lay dying from an assassin's bullet. Doctors knew they had to remove the bullet to save his life; however, they were unable to operate because the exact position of the bullet could not be determined. Apprised of this situation, Alexander Graham Bell literally invented a makeshift metal detector using a balanced coil system. This metal detector made a click in a telephone receiver when the probe coil was near a bullet. The device worked well, but it failed to save the president's life because Bell's instructions to the doctors were not understood or followed. Bell had instructed the doctors to ensure all metal objects near the president were removed to prevent interference with the detector. The doctors did not think about removing Garfield from his bed and the steel springs of the bed caused a continuous signal in the instrument.

Today, eddy current techniques have developed into one of the most important tools in nondestructive inspection (NDI), both in the Air Force and in the civilian community. In the future, the use of eddy current techniques will continue to expand in many directions.

Eddy current is a method of electromagnetic testing. To perform this type of inspection, you must understand its theory, operation, application, and interpretation. Most limitations in the use of eddy currents today are due to a lack of understanding of the basic principles, not due to an inadequacy of the instrument. For this reason, you need to study this unit carefully.

1–1. Principles of Eddy Current

Reliable inspections using eddy current require you to have working knowledge of the variables encountered in electromagnetic testing and their effects on the test instrument. Since you may need to develop inspection techniques, we use this section to cover the fundamentals you will need to know to accomplish this task. Keep in mind, however, that ours will be a simplified explanation of a very complex subject. In fact, we only outline the bare foundation of eddy current testing. You will begin by learning the theory of eddy current.

401. Theory of eddy current

Eddy current detects discontinuities in parts that are conductors of electricity. An *eddy current* is a circulating electrical current induced in a conductor by an alternating magnetic field. A coil of copper wire is placed in a holder called a "probe." The *probe* produces the alternating magnetic field used in eddy current testing. Eddy currents induced in an electrical conductor vary in magnitude and distribution in response to specimen properties such as electrical conductivity, magnetic permeability, geometry, and discontinuities.

Eddy current

Eddy currents are electrical currents induced in a conductor by a time-varying magnetic field. Eddy currents flow in a circular pattern, but their paths are oriented perpendicular to the direction of the magnetic field. Eddy currents in a test part are created when the time varying magnetic field from the probe penetrates the test part (electromagnetic induction process). Figure 1–1 illustrates eddy currents flowing in various configurations.

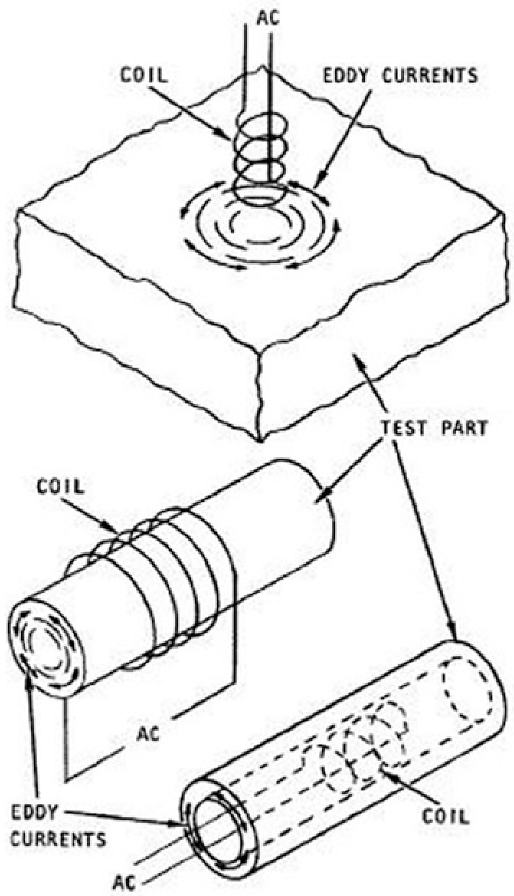


Figure 1–1. Eddy currents in various configurations.

During operation, you will connect a probe to the alternating current (AC) output of the oscillator and place it on a conductive material test part. As current flows through the coil in the probe, first in one direction and then in the other, an alternating magnetic field builds up and collapses within the conducting material. The test material *does not* electrically connect to the test equipment. When the magnetic field passes through a conductive material, an induced electric current is created. This current flows parallel but in an opposite direction to the current in the coil.

Because it is adjacent to the conductive test part, a portion of the probe's magnetic field is inside the part. The eddy currents produced are also inside the part, and the magnetic field they generate surrounds the eddy currents. Since two magnetic fields are in the same place and formed in opposite directions, they oppose each other. The opposition to the primary magnetic field by the secondary magnetic field is the basis for eddy current inspection.

Electrical conductivity

The measure of the ease that electrons can move within a material is called electrical conductivity. Metals have greater conductivity than nonmetals, but even within metals, there is a wide range of conductivity. A perfect lattice is one in which there is no interruption in the orderly arrangement of the atoms making up the material. This situation offers the fewest obstacles to electron flow, and the highest conductivity. Any irregularity or distortion of the atomic lattice impedes the flow of electrons. During NDI inspections, it is important to note that cracks and other discontinuities will impede electron flow.

Factors affecting current flow

Factors that exist inside a probe coil circuit that influence the current flow and magnetic field are below:

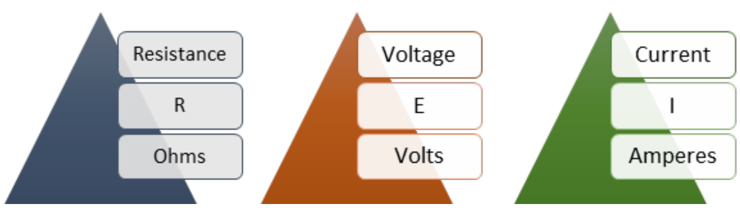
- Electromotive force.
- Resistance.
- Inductance.
- Inductive reactance.
- Impedance.

Electromotive force

Electromotive force (EMF) is the work or energy that causes the flow of an electric current and is expressed in volts. The EMF for a probe coil is ether a battery or AC. To produce eddy currents in a part, the EMF changes the primary magnetic field from a coil.

Resistance

Resistance is the opposition to the flow of an electrical current through a conductor and is expressed in ohms. When direct current (DC) flows through an element of an electric circuit, or AC flows through a circuit element having negligible inductance, the impedance is resistance only and is expressed as:



R = E / I

Where:

R = Resistance (ohms)

E = Voltage drop across the resistor (volts)

I = Current flowing through circuit (amperes)

Phase quantities

A coil is a resistor in series with an inductor. Applying an AC to this series circuit will result in two voltages, one across the resistor and another across the inductor. The net voltage across the combination of the resistor and inductor (i.e., across a real coil), will be the combination of the two voltages. The voltage across the resistor will be in phase (fig. 1–2) with the current while the voltage across the inductor will lead the voltage across the resistor by 90 degrees. The combination of the two voltages, as illustrated in (fig. 1–3), results in a voltage that will be out of phase with the current but not by a full 90 degrees.

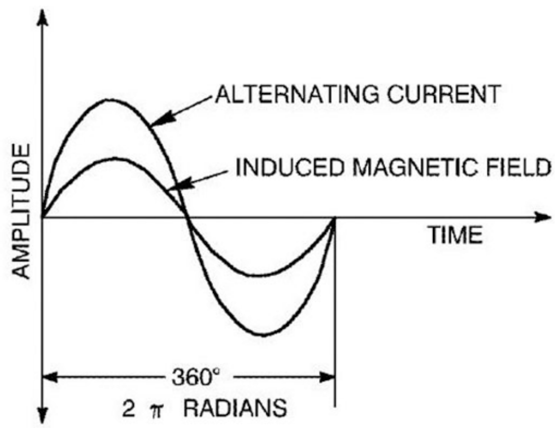


Figure 1–2. Voltages in-phase.

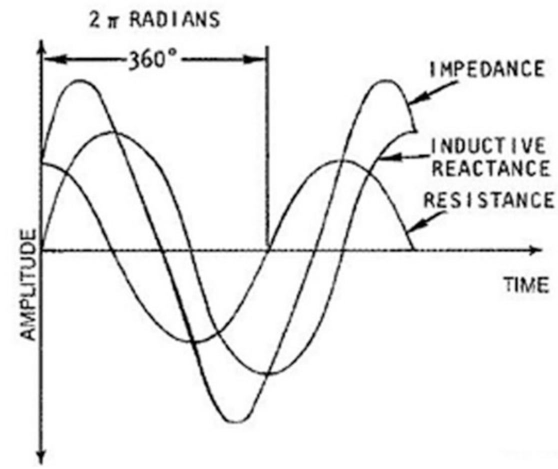


Figure 1–3. Voltages out of phase.

Inductance

The inductance (L) of an eddy current probe is the result of a magnetic field effecting an alternating electric current inside the probe. Inductance is a measure of the capability of a circuit to induce current flow in another circuit. It is proportional to the ratio of the magnetic flux encircling a circuit to the current (I) that produced the flux. For eddy current testing, we consider only the inductance of a single circuit element, specifically, the coil used to sense changes in eddy current flows in test specimens. This inductance is called self-inductance. The value of inductance depends on the number of turns in the coil, size of the coil, permeability of the core, and total magnetic flux in the coil.

Inductive reactance

Inductive reactance is the opposition to current flow in an AC circuit resulting from an inductor (the probe) placed in the circuit. It is dependent upon the value of the inductance of the coil and the frequency of the AC. Inductive reactance increases as frequency increases. As stated by the following equation:

$$XL = 2 \pi fL$$

The inductive reactance results from the electromotive force generated across a coil by the AC. The value of this induced voltage, increases and decreases as the rate of change of the applied AC increases and decreases as shown in figure 1–4. The voltage is at its maximum value when the rate of current change is at its maximum; this occurs when the current value is at zero. Conversely, the voltage is zero when the rate of current change is zero; this occurs when the current is at its maximum value. Considering 360 degrees to be one complete cycle, the induced voltage leads the current (i.e., is out of phase with the current) by 90 degrees as illustrated in figure 1–4. The induced voltage is in opposition to the electromotive force applied to the coil, reducing the amplitude of the resultant current.

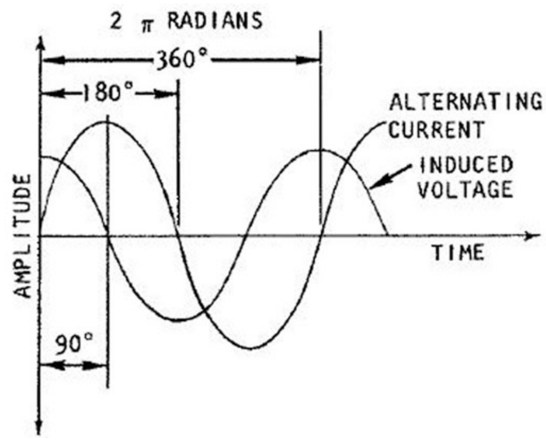


Figure 1–4. Variation of AC and induced voltage in a coil.

Impedance

Impedance is the total opposition to current flow due to resistance and inductive reactance. It is represented on an impedance-plane diagram shown in figure 1–5. Changes in material properties cause a characteristic change in the phase angle. *Phase angle* is the angle formed between resistance and total impedance on an impedance plane diagram.

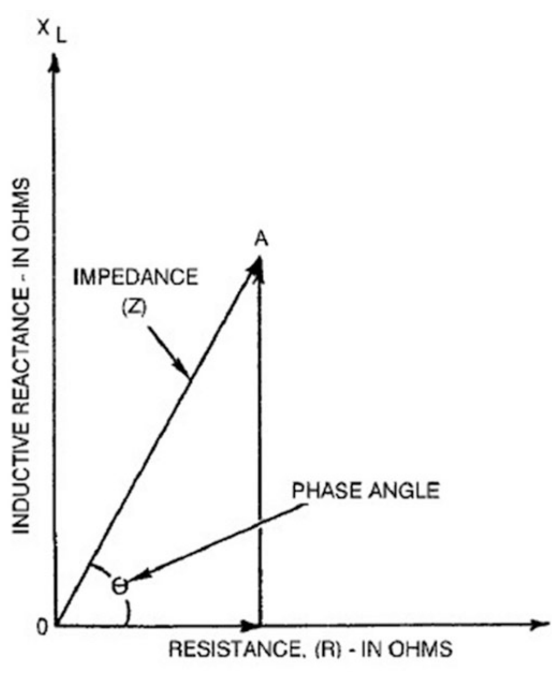


Figure 1–5. Impedance plane diagram.

The impedance of a coil appears to change when placed adjacent to an electrically conductive or ferromagnetic part. Eddy currents induced in the part produce a secondary magnetic field that opposes the primary field. This opposing field also induces a current flow in the coil in opposition to the primary current. If the part is *not* ferromagnetic, the net magnetic field resulting from the combination of the primary and secondary fields decrease in magnitude, as is the current flow in the coil. This is equivalent to decreasing the inductance and increasing the resistance of the coil.

If the part is ferromagnetic, the net magnetic field increases due to the magnifying effect of the relative magnetic permeability, but the current flow in the coil decreases because of the opposing effect of the secondary magnetic field from the induced eddy currents. This is equivalent to increasing both the inductance and resistance of the coil. Figure 1–6 shows an example of this process.

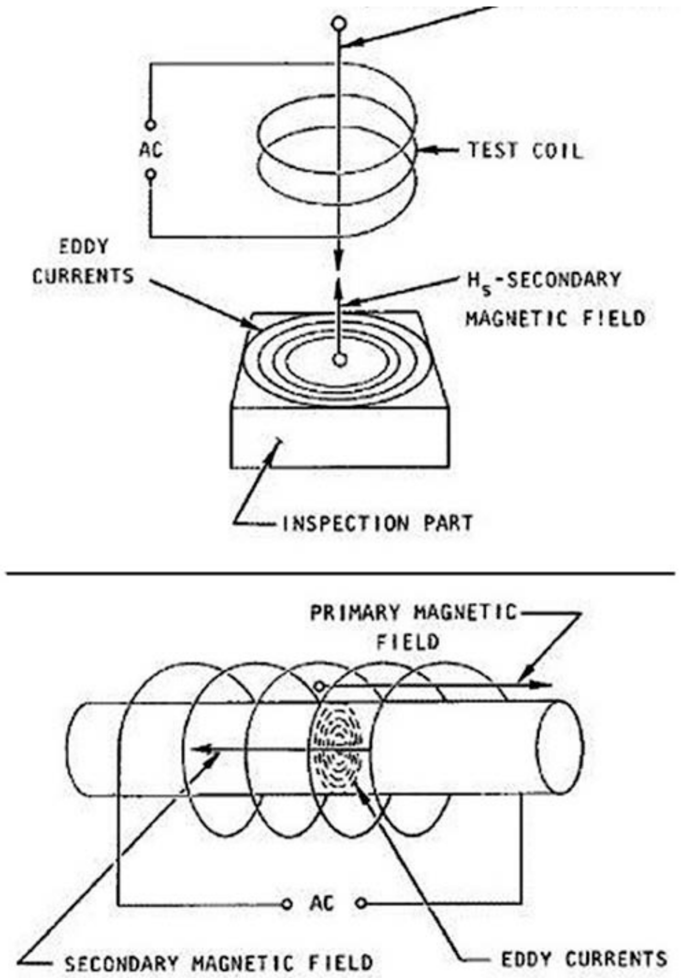


Figure 1–6. Primary and secondary magnetic fields.

Phase detection

Phase angle measurements are a good way to detect a variety of flaw conditions. The information in figure 1–5 illustrates this. Decrease of conductivity (e.g., cracks) and permeability changes could produce the same signal amplitude, and it would be difficult to differentiate between cracks and normal permeability changes in a part; however, the phase angle of a conductivity change is very different from a permeability change if the correct test frequency is chosen.

When using phase detection techniques, it becomes a simple matter to detect the difference between permeability variations and cracks. This also applies to determining the depth of a flaw, which is phase sensitive, or separating lift-off effects from flaw conditions. The presentation of the impedance plane on an eddy current instrument uses two-phase sensitive detectors to provide horizontal and vertical phase detection. This information produces a dot or point on the screen, which represents the relative phase and amplitude of an eddy current signal.

Electromagnetic field

Eddy currents generate when a time-varying magnetic field penetrates an electrically conductive material. The source of the varying magnetic field is the electromagnetic field produced by a coil carrying an alternating electric current. This field is called electromagnetic because the magnetic field is produced from electricity rather than from a permanent magnet. The rate at which the electromagnetic field varies is called *frequency*.

The strength of the electromagnetic field at the surface of the conductor depends on the

- coil size and configuration.
- amount of current through the coil.
- distance from the coil to the surface.

As the electromagnetic field from a coil penetrates a conductor, it generates eddy currents parallel to the surface of the part at right angles to the direction of the applied field. The frequency of eddy current flow is the same as the electromagnetic field.

The opposition of the secondary field to the primary field decreases the overall electromagnetic field strength and reduces both the current flowing through the coil and the resultant eddy currents. Changes to the properties of the inspection article produce changes to the eddy currents and thus their secondary magnetic fields. In this manner, changes in the inspection article produce effects by monitoring either the source of the primary electromagnetic field or the overall electromagnetic field.

402. Inspection conditions and material properties

During eddy current inspection, the impedance of the test coil remains constant provided there is no change in inspection conditions or material properties. When variations in impedance do occur, the rates of change in the impedance and eddy current signal are proportional to the material properties.

In the following lesson, you will learn how the major components of NDI equipment interact and produce eddy currents as well as their material properties.

Inspection with eddy current can do the following:

- Detect surface and some subsurface cracks.
- Detect discontinuities in materials.
- Determine material properties.
- Measure thickness of thin metals, conductive coatings, and non-conductive coatings.

Frequency

The magnitude of the induced eddy currents increase as the frequency of the inducing current increases. In turn, the higher intensity eddy currents generate a stronger opposing magnetic field, reducing the penetration of the primary field; therefore, all other factors remaining constant, higher frequencies result in shallower depths of penetration as shown in figure 1–7.

Temperature

The temperature at when you perform an inspection affects both the electrical conductivity and the ferromagnetic properties of the inspection article. Electrical conductivity generally decreases with increasing temperature, and increases with decreasing temperatures.

Because of the thermal effects on conductivity, increasing temperature of the inspection article slightly decreases the intensity of eddy currents at the surface of a part and slightly increases the depth of penetration. Temperature variations also affect the inductance of the coil. Remember, changes in temperature affect eddy current results; therefore, during inspections, you should allow time for the test system and the test part to stabilize to the ambient temperature. An example test would be to see if a part and standards feel the same to the bare hand.

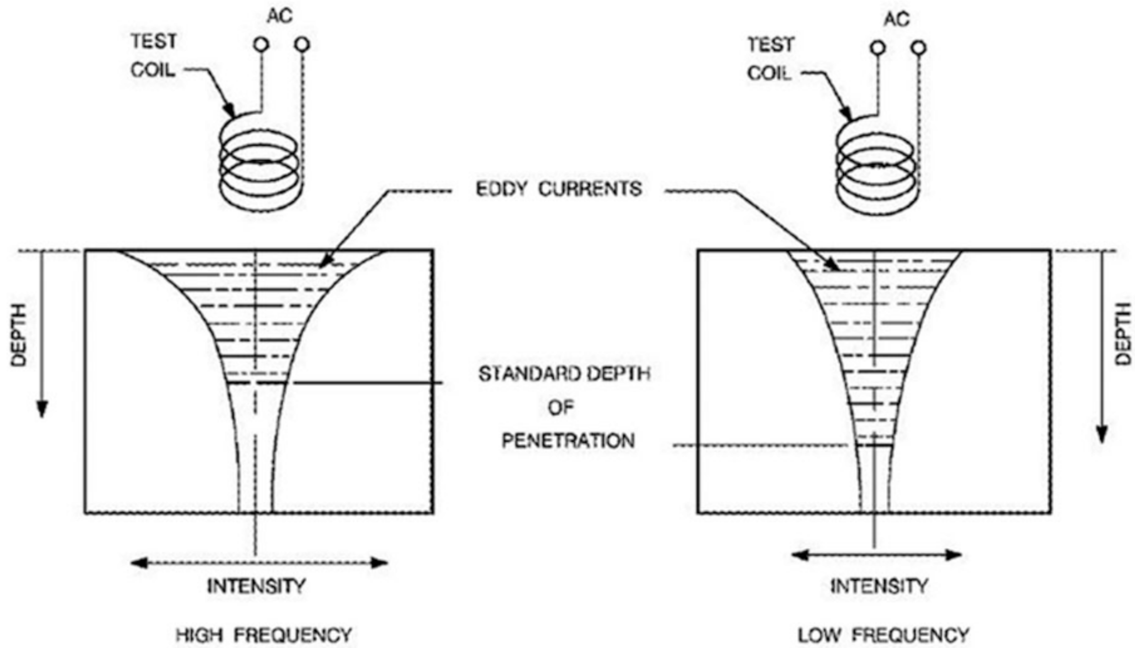


Figure 1–7. Frequency and depth of penetration.

Depth of penetration

The intensity of eddy currents decreases exponentially with depth in a material. The intensity at any given depth is affected by the same variables that influence the surface intensity of eddy currents, although not always in the same manner or by the same amount. Generally, any parameter that increases the depth of penetration would increase the detectability of discontinuities deeper in the part.

Standard depth of penetration

Standard depth of penetration is the depth below the surface of the inspection article at which the magnetic field strength, or the intensity of the induced eddy currents reduces to 36.8 percent of the value at the surface shown in figure 1–8.

There are three variables used to define standard depth of penetration:

- Conductivity.
- Relative magnetic permeability.
- Frequency.

NOTE: Frequency is the *only* factor *controlled* by the inspector.

Effective depth of penetration

Effective depth of penetration is the depth in the inspection article at which the magnetic field strength or intensity of the induced eddy currents *reduces* to 5 percent of the value at the surface. This depth is approximately 3 times the standard depth of penetration. The effective depth of penetration determines the test frequency when working with thin materials. The overall electromagnetic field does not extend beyond the back surface of the test part and thickness variations can be suppressed. The minimum material thickness required for conductivity testing various alloys at 60 kilohertz (kHz) and 480 kHz.

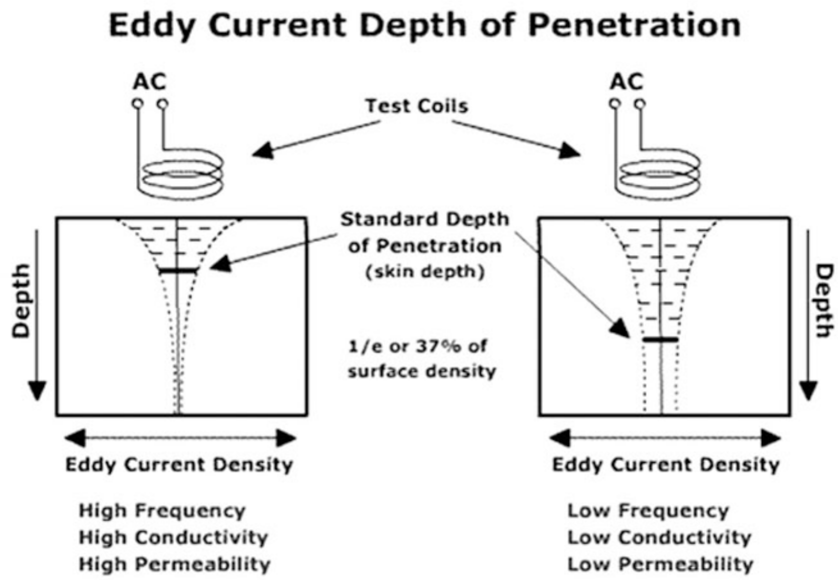


Figure 1–8. Eddy current standard depth of penetration.

Magnetic coupling

The interaction between the primary electromagnetic field generated by the coil and the inspection article is referred to as electromagnetic coupling. Because the field decreases in strength with increasing distance from the coil, resultant eddy currents at the surface of the part will also decrease in intensity. We will look at the following two factors of magnetic coupling.

- Lift-off.
- Fill factor.

Lift-off

The effects of lift-off can be used to measure coating thickness. As a test coil moves away from a part (increasing lift-off) the *coupling* between the test coil and inspection part *decreases*. The magnitude of the impedance change for a specific change in an inspection variable also *decreases*. For probe coils, the dotted lines connecting points representing the same material properties but with various amounts of lift-off have some curvature shown in figure 1–9. The line A-B-C represents the increase lift-off for material one. Line D-E-F represents the increased lift-off for material two. The line from point A to point D represents the increase in conductivity of material two compared to material one at one lift-off value. Liftoff lines B-E and C-F are increasingly shorter, indicating a smaller change in the conductivity.

Fill-factor

Fill-factor applies to parts passed through an encircling coil and is similar to lift-off. It can be used to gauge some dimensions. When you use an encircling coil to inspect a cylindrically shaped part, the degree of magnetic coupling is dependent upon the difference between the internal diameter of the coil and the external diameter of the part.

Material properties

Material properties will alter the distribution and intensity of eddy currents, the strength of induced magnetic fields, and the difficulties you could encounter when interpreting output signals. You need to understand these properties and the effects on eddy currents because we are unable to change them. We will look at the following material properties:

- Conductivity.
- Edge effect.
- Magnetic permeability.
- Geometry.
- Metal thickness.
- Discontinuities.

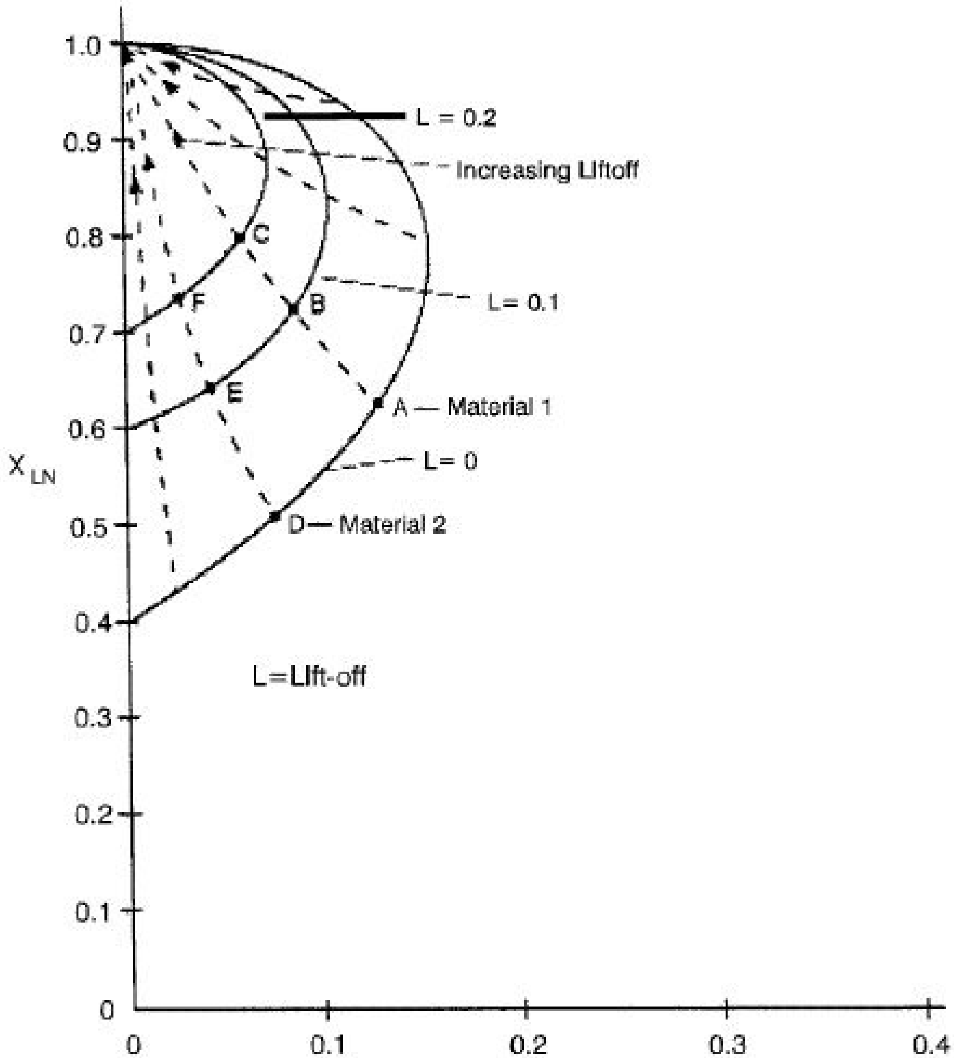


Figure 1–9. Effects of lift-off in an impedance diagram.

Conductivity

Distribution and intensity of eddy currents in nonferromagnetic materials strongly affects conductivity. Materials with high conductivity allow generation of strong eddy currents at the surface. This results in a stronger secondary magnetic field opposing the primary field and a rapid reduction in primary field intensity below the surface. Material with poor conductivity has weaker surface eddy currents, a *weaker* secondary field, and a *greater* depth of penetration. Figure 1–10 shows an example of electrical conductivity.

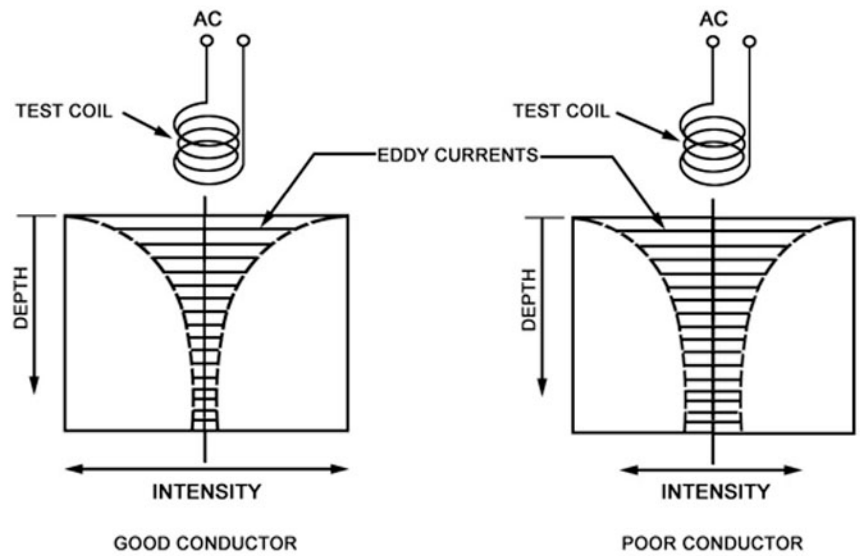


Figure 1–10. Effect of conductivity on magnitude and distribution of eddy currents.

Edge effects

If the electromagnetic field of a probe is affected by the geometry of the edge of a test part, an error will occur in the measurement of the conductivity. The probe should be located several probe diameters away from the nearest edge or transition boundary. When the circular flow of eddy currents are distorted by an edge, corner, or radius of the part as shown in figure 1–11, it confines eddy currents to a smaller area and an indication will be displayed on the screen. This is simply a false indication because of the distorted eddy currents.

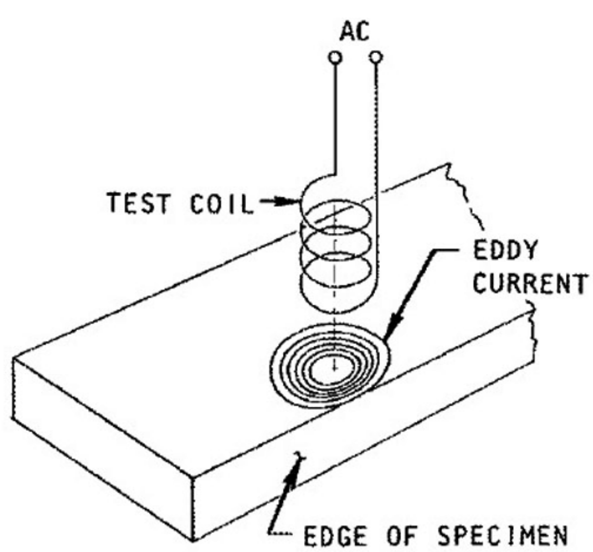


Figure 1–11. Edge effect.

Magnetic permeability

Permeability affects eddy currents in much the same way as conductivity. Figure 1–12 shows an example of the effect of electrical permeability. Say you have two items with very similar conductivity values. In a material with high permeability, the secondary magnetic field will be strong and oppose the primary field. This results in a *reduced* depth of penetration. The material with a lower permeability will have a weaker secondary magnetic field and a greater depth of penetration.

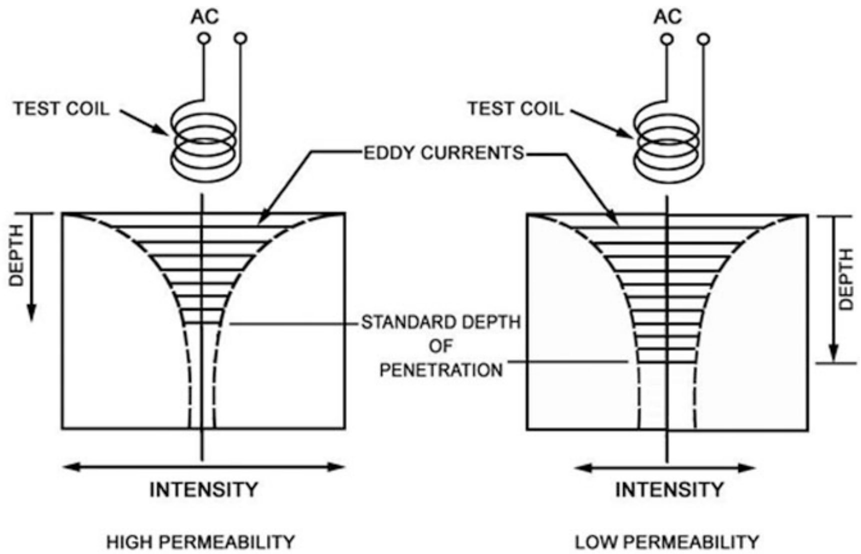


Figure 1–12. Effect of permeability on magnitude and distribution of eddy currents.

Geometry

Any change in part configuration that affects distribution or penetration of eddy currents will result in flawed readings. The following sources of error are included in these geometric categories:

- Proximity to part edges or adjoining structure.
- Metal thickness less than the effective depth of penetration in the metal.
- Excessive curvature of a part surface.

Part geometry is important when material thickness is less than the effective depth of penetration or when inspecting near the edge of a part.

Metal thickness

If metal thickness is less than the effective penetration of the eddy currents, the measured conductivity will differ from the true value. Notice the effective penetration depth is approximately three times the standard depth of penetration. The operating frequency must not exceed the effective penetration depth of the tested material. Eddy current equipment has a very wide range of operating frequencies, which is adjusted to limit penetration to less than the effective depth. The material thickness must be greater than the effective depth or errors in conductivity measurement will occur.

Thinner materials are more resistive, and thicker materials are more conductive. This will allow you to display different thicknesses based on the changes in conductivity and resistance.

NOTE: Eddy current inspections require calibration shims to compensate for nonconductive coating thickness.

Discontinuities

Discontinuities in a test part change eddy current flow and detect changes with the test probe. This changes the magnitude of the secondary field and produces an indication.

Examples include, cracks, inclusions, voids, seams, pits, laps, and other discontinuities related to the production, fabrication, and use of metallic parts as seen in figure 1–13.

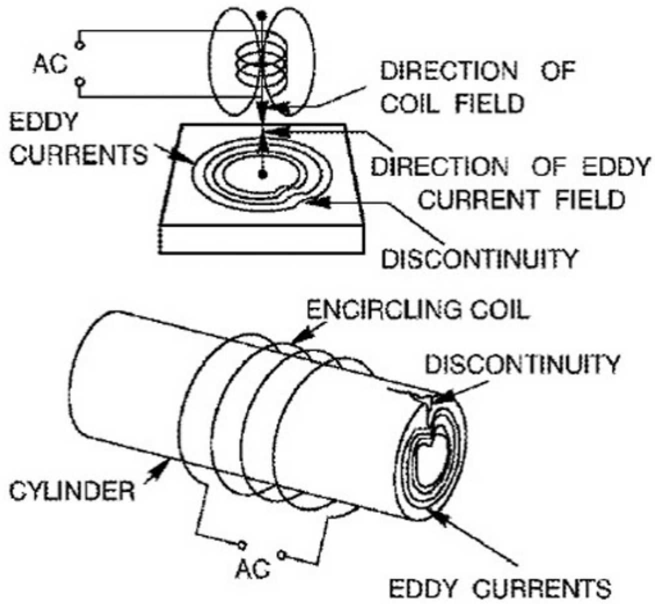


Figure 1–13. Distribution of eddy currents with discontinuities.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

401. Theory of eddy current

1. What is eddy current?

2. What is an eddy current flow pattern and directional path?

3. How is an induced electric current created?

4. What is the ease with which electrons can move within a material called?

5. What impedes the flow of electrons in electrical conductivity?

6. Which type of current flow opposes flow of electrical current and is measured in ohms?

7. What happens when voltage across an inductor leads voltage across a resister by 90°?

8. What is inductance of an eddy current probe?

9. What does inductive reactance result from?

10. What is the angle formed between resistance and total impedance on an impedance plane diagram?

11. When does impedance of a coil change?

12. What does a dot on an eddy current screen represent?

13. What is frequency?

14. How does an electromagnetic field generate eddy currents?

402. Inspection conditions and material properties

1. What happens to frequency when induced eddy currents increase?

2. If all other factors remain constant, what effect does higher frequency have on eddy current depth of penetration?

3. What happens to electrical conductivity when temperature increases?

4. Eddy currents are reduced to what percent of the value surface in a standard depth of penetration?

5. What three variables define standard depth of penetration?

6. How many times deeper than the standard depth of penetration is the effective depth of penetration?

7. What two factors make up magnetic coupling?

8. What can lift-off be used to measure?

9. List the material properties associated with eddy currents?

10. What strongly affects the distribution and intensity of eddy currents in nonferromagnetic materials?

11. Where should the probe be located on a test part to avoid edge affect?

12. What happens to the secondary magnetic field and depth of penetration when a material has low permeability?

13. When is geometry of a test part important?

14. What is used to compensate for nonconductive coating thicknesses?

15. What changes eddy current flow and detects changes with the test probe?

1–2. Eddy Current Equipment Types and Safety

The basic operating principle of most eddy current instruments is the bridge circuit. The bridge circuit balances the probe and the test part. When there are no variations in the test part (such as conductivity or defects), there will be no movement on the eddy current meter or cathode ray tube (CRT). In basic instruments, analysis of the signal consists of measuring the change in relative magnitude of the current flowing through the bridge circuit.

This section provides you with a better understanding of how eddy current probes and equipment units work.

403. Probe components

The eddy current test instrument performs three basic functions.

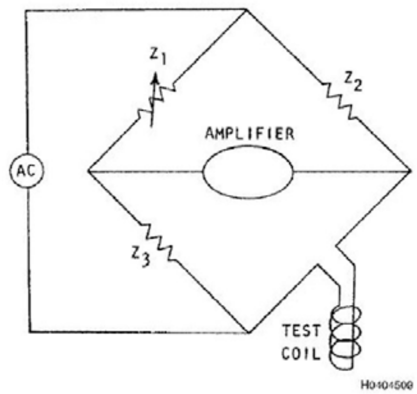
- First, it generates the AC that induces the eddy current flow in the part.
- Second, it processes responses to the induced eddy current flow.
- Third, it displays the responses in a manner to aid interpretation.

First, we must first look at the components of an eddy current system and the use of probes.

Components of an eddy current system

In its simplest form, an eddy current system consists of the following components:

Equipment Configuration	
Component	**Function**
Oscillator	The oscillator provides an alternating current of one or more frequencies to the test coil. The frequency determines the intent of the inspection and the material inspected. Frequencies used range from less than 100 hertz (Hz) to greater than 6 megahertz (MHz).
Coil assembly (probe)	The coil assembly induces eddy currents into a part and detects changes in eddy current flow. For some applications, a single coil is used for both functions. More commonly, multiple coils are employed in an assembly. A common configuration has one coil inducing the eddy current flow and separate coils used as detectors. Another configuration uses one coil as both an inducer and a detector on the test part.
Bridge circuit	The bridge circuit *converts* changes in eddy current magnitude and distribution into signals that are ultimately processed and displayed. A common mode of operation is to have the output of the bridge equal zero for a “good” or “non-flaw” condition. Presence of a flaw or an “other-than-good” condition results in an unbalance of the bridge, thus producing a relatively small signal. This signal becomes the input to subsequent circuits. Figure 1–14 shows an example of a bridge circuit.

Equipment Configuration	
Component	**Function**
	 Figure 1–14. Simplified bridge circuit.
Signal processing circuits	The processing of the signal from the bridge circuit depends on the type of information displayed. Simple eddy current devices can be built to detect and amplify signals or convert signals into digital format.
Output display	Some common output devices are meter readout, a strip chart, an X-Y recorder plot, an oscilloscope display or a video screen presentation. Eddy current instruments with a two-dimensional graphical display are used where both the eddy current signal amplitude and phase must be measured. These are the most common instruments available, and provide inspectors with the greatest capability to interpret cracks.

A block diagram of an inspection system is shown in (figure 1–15) with the coil applied to a test part. Systems may be constructed for multiple purposes or for very specialized functions.

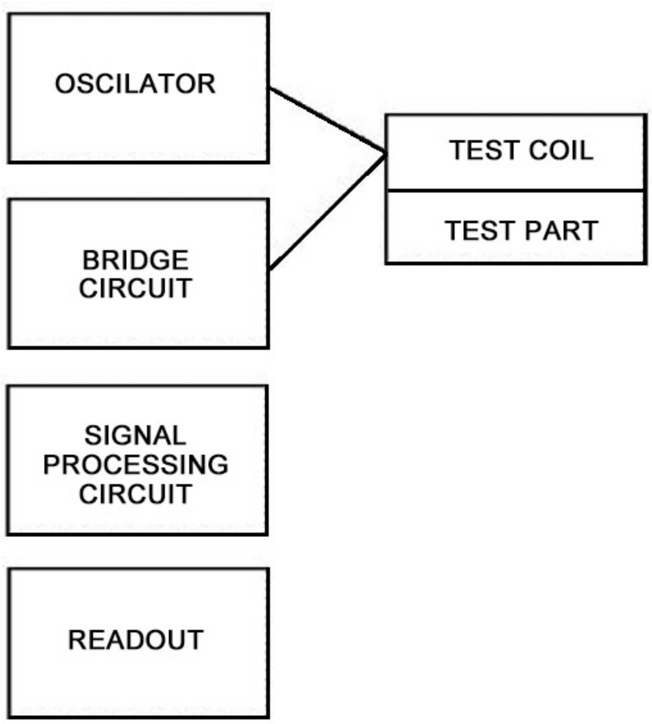


Figure 1–15. Block diagram of an eddy current inspection system.

Classification of probe coils

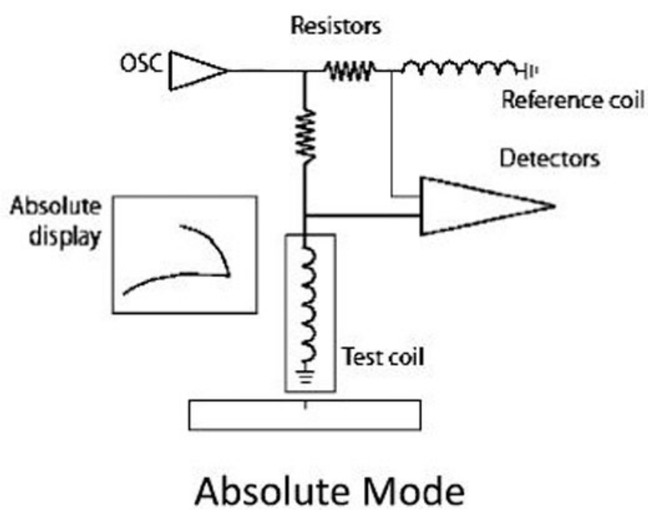
Eddy current probes consist of one or more coils designed to induce eddy currents into a part and detect changes within the eddy current field. A fundamental consideration you must make in selecting a probe is its intended use. A small diameter probe or narrow encircling coil will provide increased resolution of small defects. A larger probe or wider encircling coil will provide better averaging of bulk properties with a loss in sensitivity to small defects. The probe or coil must also match impedance ranges of the eddy current instrument with which it is used.

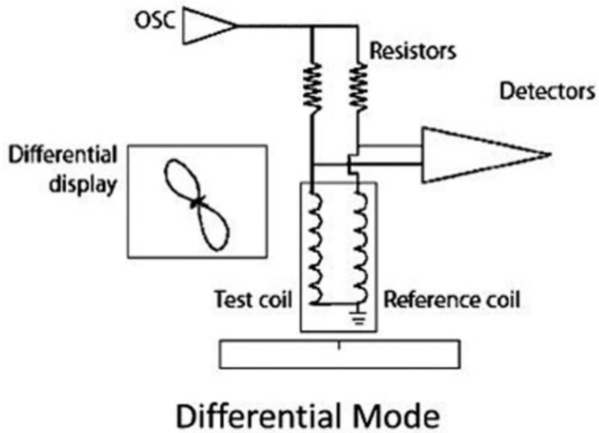
The following lists three things that classify eddy current probes and coils.

- Mode of operation.
- Application.
- Design.

Mode of operation

There are three general modes of operation for eddy current coil assemblies; absolute, differential, or driver/receiver (also called reflection) as shown in the table below.

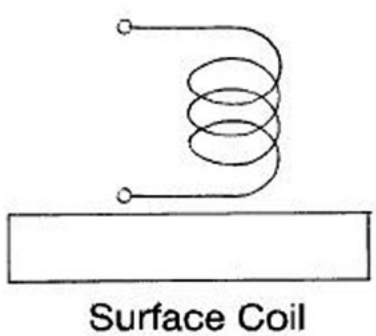
Eddy Current Modes of Operation	
Type	**Function**
Absolute	Absolute probes consist of a single coil and interrogate the area immediately adjacent to the coil. They may have other discrete electrical elements such as capacitors included in the probe housing for matching to specific equipment requirements as shown in figure 1–16.  **Figure 1–16. Absolute mode.**
Differential	Differential probes, *on the other hand*, consist of two or more coils and operate by comparing the response of one coil to the response of another coil. Normally, in both surface and bolt-hole differential probes, two small sensing coils are wound side-by-side in the shape of two back-to-back capital D's. They are wired in series, with one wound clockwise and the other counterclockwise. This produces an indication from a crack that deflects first one way, and then the opposite way, while producing little or no indication from conditions that affect both coils equally, like lift-off or conductivity change as shown in figure 1–17.

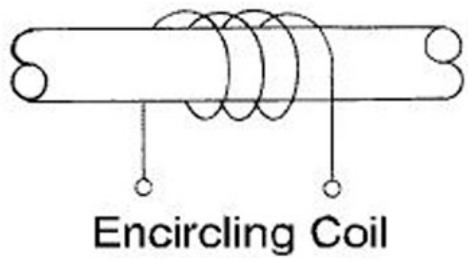
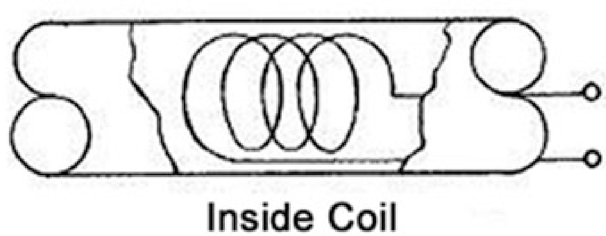
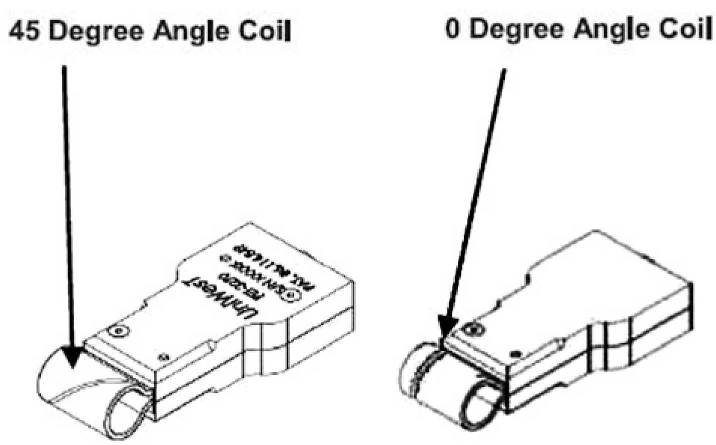
Eddy Current Modes of Operation	
Type	**Function**
	 **Figure 1–17. Differential mode.**
Driver/Receiver (reflection)	Reflection probes can have a wide variety of configurations, but all have a driver coil wired separately from one or more receiver coils. A probe with one receiver coil is called *reflection-absolute*, and a probe with two receiver coils is "reflection-differential." Reflection probes generally deliver better signal-to-noise levels, but are harder to make and therefore more expensive.

Application

Probe applications operate in either absolute or differential modes (figs. 1–16 and 1–17). They can also be classed according to their shape. For example, very thin probes are called *pencil probes*. Probes with special electromagnetic shielding are called *shielded probes*. Probes used in rivet or bolt holes are called bolt-hole probes and discussed more in detail later in this section.

The table below has a basic description of each application used in eddy current inspection.

Eddy Current Coil Types	
Type	**Function**
Contact or Surface coil	This is the most common application for flat or relatively flat surfaces of parts but also used to inspect inside holes as well. Figure 1–18 shows a basic coil configuration of a surface coil.  **Figure 1–18. Surface coil.**
Outside diameter (OD) coil	Eddy current coils made from an outside diameter are used to encircle a part and can inspect parts from the outside in as shown in figure 1–19.

Eddy Current Coil Types	
Type	**Function**
	 **Figure 1–19. Encircling coil.**
Inside diameter (ID) coil	These coils are just the opposite of OD coils. They are most commonly wound around the circumference of a probe so that the probe can inspect the entire circumferential area of a part at one time. This is shown in figure 1–20.  **Figure 1–20. Inside diameter coil.**
Conformal or Ribbon coil	Most commonly called conformal, ribbon, or radius flex coils, they have differential sensors that are directionally sensitive and provide detection of crack tips. For radius inspections, a 0° coil orientation of the ribbon only has capability of detecting axial cracks whereas transverse cracks need a coil orientation of 45°. An example is shown in figure 1–21.  **Figure 1–21. Conformal coil.**

Design

Eddy current probes have several conflicting requirements. First, they must be a reasonable match to the electrical impedance requirements of the instrument to which they are connected. The closer the impedance match, the higher the signal-to-noise ratio. In addition, you need to select coils designed for the flaw size inspected. Smaller flaws require smaller coils.

The majority of eddy current testing you will perform in the field will utilize surface probes. Surface probes are used for plates, sheets, irregularly shaped parts, and in holes. The extent of the area tested is controlled by the coil diameter and by the presence of coil shielding. When the area is a large pancake-type, use surface coils or overlapping multi-coil probes to reduce the time required to inspect the part. When targeting small flaws, coils, as small as 1/32 inch in diameter, are available to examine areas with size constraints.

Probe shielding

Probe shielding is used to prevent or reduce the interaction of a probe's magnetic field with nonrelevant features in close proximity of the probe. Shielding reduces edge effects when testing near a step or an edge. Eddy current probes are most often shielded using magnetic or eddy current shielding.

Probe selection

As with many other flaw detection applications, the use of small diameter probes (radiused) are recommended. These probes permit better visibility of probe coil location and permit more flexibility in establishing spacing between the probe and the fastener. Radiused probes are also less susceptible than flat surface probes to lift-off variations with changes in probe-to-surface angle.

Regardless of names of surface probes, the coil diameter and shielding determine the surface area inspected by a probe. Remember that the purpose of any eddy current probe is to generate an electromagnetic field and detect changes in eddy current flow. In crack detection, the field produced by the coil should be concentrated and strong as practical for the instrument used. A small field is shown in view A of figure 1–22. This field will have a proportionally greater disruption from a small crack than a large field (fig. 1–22, view B).

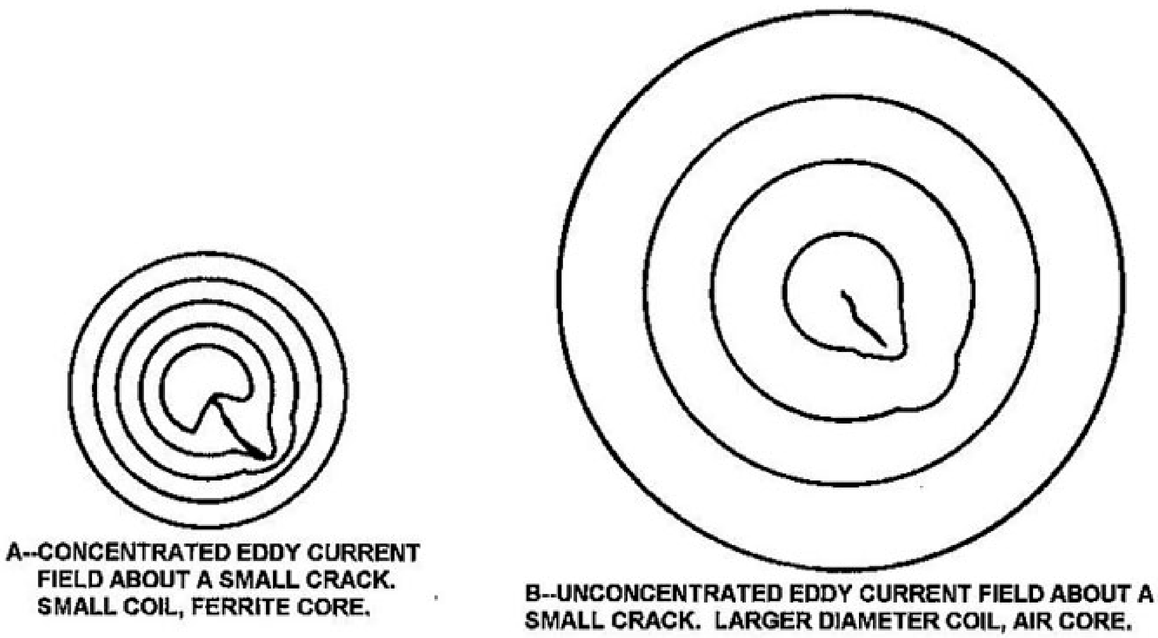


Figure 1–22. Concentrated and unconcentrated eddy current fields.

In crack detection, the smallest defect you can detect depends on the size of the eddy current field. Normally, it must disrupt eddy current flow 50 percent or more of the generated field.

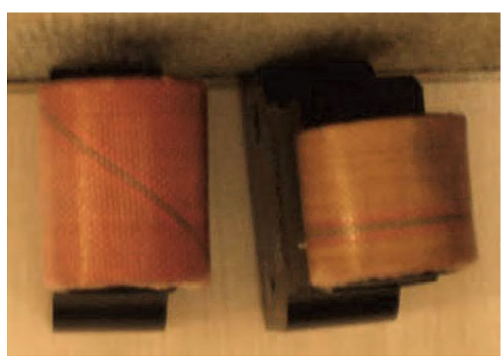
An important factor in retaining good sensitivity is *maintaining a minimum* distance between the sensing element and the part's surface. In an eddy current probe, the closer the coil arrangement is to the test surface, the greater the sensitivity to detect small cracks.

Advances in coil design have given rise to an improvement in shielded probes. Unshielded probes have a field leakage outside the diameter of the coil, making edge effect a potential problem. In contrast, shielded probes concentrate the field directly under the coil and overcome many of the problems associated with the edge effect. This allows you to inspect closer to the edge of a part or closer to other structures, such as fasteners and rivets. By reducing the field leakage around the outside of the probe and concentrating the field underneath the probe, you can reduce the probe's signal noise. When you reduce the noise, you gain more sensitivity to detect small flaws.

Types of probes

The last way a probe is classified, is by the geometry or configuration. Shape or some significant feature normally identifies these probes. For example:

Types of Probes	
Type	**Function**
Pencil probes	Used for mostly surface crack detection with a small coil encased in a long slender housing as shown in figure 1–23. They come in different shapes and sizes depending on their use. These probes are prone to wobble because of their small diameter base and may sometimes be difficult to null on parts. Pencil probes can also operate at various frequencies depending on the type of material tested.  **Figure 1–23. Pencil probes.**
Bolt-hole probes	Designed for a bolt-hole scanner, these probes have a surface coil that is mounted inside a housing, which matches the diameter of the inspection hole. When the probe is inserted into the standard and inspection holes, the scanner rotates the probe automatically shown in figure 1–24.  **Figure 1–24. Bolt-hole probe and scanner.**

Types of Probes	
Type	**Function**
ID or Bobbin probes	The probe housing intends to keep the *coil centered inside* the test part and used on *hollow* parts, such as pipes or cylinders. These probes can inspect from the inside out and inspects the entire circumference of the part.
OD or Encircling probes	These are very similar to ID probes in how they function only used in the opposite way as seen in figure 1–25. They are used to inspect solid parts such as bars or landing gear parts.  **Figure 1–25. Outside Diameter or encircling probes.**
Conformal or Ribbon Probes	This probe is designed to detect cracks that run along the length of a parts radius. Cracks that extend beyond the footprint of the sensor may exhibit a reduced amplitude response. Figure 1–26 shows two different types of conformal probes while figure 1–27 illustrates both 0° and 45° angle conformal probes.  **Figure 1–26. Conformal or ribbon probe types.**  **Figure 1–27. 0° and 45° angle conformal probes.**

404. Eddy current instrument

Eddy current instrumentation is the foundation of an eddy current system, whether the system is a simple instrument/coil combination or a fully automated scanning inspection station. When choosing an eddy current test instrument you must take into account the type of flaw to be detected, the permeability of the material, type of probe to be used, display method, test frequency, and signal processing requirements, portability, and any accessories used.

Requirements of an eddy current instrument

Most eddy current nondestructive test instruments used in the field are portable AC or battery powered units. They are generally lightweight, less than 6 pounds (lbs.), with batteries that provide up to 12 hours of operation. They can have a liquid crystal display (LCD), or electroluminescent (EL) displays. Some units have dual frequency operations with interchangeable display features. Newer units have state-of-the-art circuitry with advanced microprocessors. Frequency ranges of approximately 100 Hz to 6 MHz for detection of large and minute discontinuities. These units can be used to inspect first and second layer cracks, coating, plating thicknesses, and conductivity testing.

To assure reliable operation of eddy current instruments, they *must* have the capabilities listed below:

Capabilities of an Eddy Current Unit	
Requirement	**Description**
Sensitivity	A term that refers to the instruments capability to find the most difficult to locate flaws; with reference to the size and type that need to be detected.
Low noise	The noise should be low enough so the signal from the smallest flaw found (or smallest calibration flaw) is at least three times the noise level of the instrumentation.
Response time	The response time of the circuitry must be fast enough to process and display signals at the required scanning rate.
Selectivity	The instrumentation should be immune to external sources of electromagnetic interference.
Stability	The instrumentation display should remain frequency drift-free, during the required testing period.
Ruggedness	The instrumentation must be capable of operating in the test environment. This may include a variety of environmental extremes of temperature, humidity, dust, and vibration.

Testing capabilities have greatly increased by the upgrading of existing test techniques and newer instrumentation. The use of modern impedance plane equipment has greatly increased the flaw analysis capability of the inspection process. Signal phase and amplitude present analysis of eddy current information. The display consists of a point of light rather than a waveform. Changes in the test article relative to the reference standard will cause the point of light to move. Movements of the point of light are analyzed to determine which test variable (conductivity permeability or dimension) causes change.

Eddy current equipment design

Eddy current instruments measure one or more of these *three* signal qualities:

- Amplitude.
- Phase.
- Frequency.

Most small, portable instruments measure only the relative amplitude of the impedance change in the test coil. Eddy current testers identify differences in phase and amplitude of detected signals. Because material variables provide known changes in the impedance plane, these instruments can often be used to establish the specific cause of any eddy current signal. Eddy current instruments can be calibrated using a sweep display to measure amplitude changes only. When in this mode, impedance plane testers ignore phase changes and perform only as impedance measurements.

Other types of eddy current equipment are designed for modulation analysis. These testers provide selective response to signals of specific frequency ranges. Modulation analysis uses either impedance testing or phase-sensitive equipment.

Some eddy current instruments facilitate application of one or more of these general modes of testing. These instruments use a variety of circuit designs to employ one or a combination of changes in impedance, reactance, frequency, or phase to measure or detect changes in properties like conductivity, magnetic permeability, thickness, and discontinuities.

Eddy Current Signal Definitions	
Type	**Description**
Amplitude	That property of the test system whereby the amplitude of the detected signal is measured without regard to phase.
Phase	An instrumentation technique that discriminates between variables in a test part by different phase angle changes produced in the test signal.
Frequency	Frequency in uniform circular motion or in any periodic motion is the number of revolutions or cycles completed in unit time. Frequency is expressed in Hz. For example 1 Hz = 1 cycle per second.

Frequency variables

A basic eddy current instrument, while operating at a single frequency during a particular test, usually has an operating frequency range that is adjustable to meet a large variation of inspection situations. Low frequencies increase depth of penetration and consequently would be used for subsurface flaw detection in high conductivity materials. Higher frequencies limit the depth of penetration and are used for low conductive materials as well as for detecting smaller flaws.

Some instruments also incorporate a fine adjustment of frequency as a mechanism for suppressing lift-off. The frequency selected for operation causes a meter deflection off resonant enough to where lift-off causes less of an impedance change than caused by a defect, and the impedance change for increasing lift-off is opposite to that for a defect.

Frequency selection

The optimum test frequency is one that suppresses noise indications while leaving the desired signal information intact. In general, lower frequencies have less noise than higher frequencies. However, if you use too low a frequency, you will produce a large, unconcentrated eddy current field with no sensitivity for detecting small cracks. If you use too high a frequency, you could reduce penetration into the part to the point where you cannot detect cracks just below the surface due to peening or smearing of surface metal. Instrument frequencies in the range of 50–5,000 Hz are generally suitable for crack detection. Frequency selection to maximize crack response and minimize instrument response to other variables could give added sensitivity to cracks.

Digital display

Many eddy current units provide waveform output on a two-dimensional display of small, square spots called pixels. Light generates on a screen by applying a small voltage to the individual pixels. A waveform is then created by energizing the pixels needed to shape the appropriate waveform. Since the persistency of a digital display is controlled by an applied voltage rather than by electron impact with a phosphor coating, the operator can control the persistence.

In general, the lighted pixel will remain lighted until the operator 'erases' them by turning off the voltage to the pixels.

Linear time base display (Sweep mode)

Some types of eddy current test equipment use a linear time base display. The display's vertical signal is received from the test coil. The display's horizontal signal (e.g., time), is received from a timing voltage. The timing voltage adjusts to the frequency or period of the generator and provides a linear horizontal sweep of the vertical input voltage. A change in reactance of the test coil result, in a phase change of the voltage across one of the bridge circuit arms (vertical signal). A shifting (along the horizontal base line) evidences this phase change. During operation, the sweep voltage *adjusts* the display to show the desired number of waveform cycles (usually one). Generally, control is also included to control the horizontal position of the waveform on the screen.

Magneto-optic imaging

Magneto-optic imaging (MOI) depends on the ability of certain materials to rotate the plane of polarization of light in the presence of a magnetic field. This Faraday Effect detects disturbances in the magnetic field produced by passing an alternating current in a thin planar foil of doped yttrium iron garnet. When the foil is placed near the surface of a metallic test object, eddy currents are produced, which modify the magnetic field in the foil.

When defects or other material discontinuities, such as rivets or holes, divert the otherwise uniform flow of electric current near the surface of the test piece, magnetic fields perpendicular to the surface of the test piece are produced, which can be imaged in real time by an appropriately designed optical system. Since the system provides optical information, the results can be videotaped for analysis and permanent documentation.

405. Eddy current safety and maintenance

The laboratory supervisor on a continuing basis will ensure compliance with provisions outlined in applicable and current technical orders (TOs) should review safety requirements. Recommendations of the base bioenvironmental engineer and the manufacturer regarding necessary personnel protective equipment will be followed.

Safety precautions

Exercise safety precautions when performing eddy current inspection because of exposure to electrical current. It is important to check the following when working with this method:

- Check connectors, cables, and wires going into the unit to ensure they are not frayed, cracked, bent, missing, or broken.
- Power cords must not have exposed or loose wires.
- Internal adjustments are only made by Test and Measurement Diagnostic Equipment laboratory (TMDE).

Maintenance

Even though there is no specific process control inspections used for eddy current, you must still take care to ensure longevity and maintenance of equipment. The following maintenance procedures should be followed *before* an eddy current inspection takes place.

- Replace probes if tips expose coil windings.
- Replace cords if they fail the operational check.
- Batteries should be charged or replacement after use.

Operator checks

Electrical operational checks are part of periodic preventive maintenance. You should perform these tests on a regular schedule established in your duty section. You should also be perform tests whenever there is visual evidence of damage to the unit or when electronic operations appear to be functioning improperly. The operational checks can isolate any problems to software, internal electrical damage, or operator error. The operation and service manual for each piece of equipment contains specific instructions to verify the electronic performance of the instrument; therefore, consult the appropriate operation and service manual for the procedures whenever you are performing tests on your equipment.

Periodic cleaning

General cleaning procedures suitable for most electronic equipment will suffice for most eddy current testers. *Do not* use any solvents, harsh cleaning agents, or other chemicals. Remove dust or loose dirt with a soft lint-free cloth. Remove heavier accumulations of dirt or grease using a mild detergent. You may use isopropyl alcohol to clean electrical connectors when necessary.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

403. Probe components

1. What is the basic operating principle of most eddy current instruments?

2. What three basic functions do eddy current test instruments perform?

3. What provides an AC of one or more frequencies to the test coil?

4. What shows a presence of a flaw or an "other-than-good" result in a bridge component?

5. What consists of one or more coils designed to induce eddy currents into a part and detect changes within the eddy current field?

6. What mode of operation consists of a single coil and interrogates an area immediately adjacent to the coil?

7. What mode of operation has a probe with two receiver coils?

8. What probes are used in rivet or bolt holes?

9. What may be used on tubes, pipes, or other cylindrical parts where the geometry is regular and the interior is accessible?

10. Which mode of operation is used for radius inspections, and requires a 0° coil orientation to detect axial cracks or a 45° coil for detection of transverse cracks?

11. Most eddy current testing in the field is accomplished with what type of probes?

12. What two types of eddy current probes are most often used for shielded operation?

13. What probes are less susceptible than flat surface probes to lift-off variations with changes in probe to surface angles?

14. The size of the smallest defect you can detect in crack detection is affected by what?

15. How can you can reduce a probe's signal noise?

16. What probes are prone to wobble because of their small diameter base and may sometimes be difficult to null on parts?

404. Eddy current instrument

1. Describe most eddy current nondestructive test instruments used in the field.

2. What are the frequency ranges used on eddy current instruments for detection of large and minute discontinuities?

3. List the six eddy current instrument capabilities.

4. What term refers to the instruments capability to find the most difficult to locate flaws, with reference to the size and type that need to be detected?

5. The response time of the circuitry must be fast enough to process and display signals at the required scanning rate, this is called?

6. What two signals are directly presented for analysis of the eddy current information when using impedance plane equipment?

7. What can eddy current instruments be calibrated with to measure amplitude changes only?

8. What is expressed in Hertz?

9. What increases depth of penetration and used for subsurface flaw detection?

10. What is the optimum test frequency when using eddy current inspection?

11. What instrument frequencies range are generally suitable for crack detection?

12. What is generated on a display screen by applying a small voltage to the individual pixels?

13. An eddy current display has a horizontal signal that is received from a timing voltage called?

14. What inspection type depends on the ability of certain materials to rotate the plane of polarization of light in the presence of a magnetic field?

405. Eddy current safety and maintenance

1. What safety precautions need to be exercised when performing eddy current inspection?

2. What tests are part of periodic preventive maintenance and should be performed on a regular schedule established in your duty section?

3. What do you check for each piece of equipment to find specific instructions to verify the electronic performance of the eddy current instrument?

4. What should you *not* use for general cleaning suitable for most electronic equipment will suffice for most eddy current testers?

1–3. Eddy Current Inspection Process

All inspections you will perform for cracks or other in-service flaws are critical. You are entrusted with fellow Airman's lives during every aircraft and weapon system inspection you perform. Always setup your eddy current instrument in accordance with the established procedures. The inspection you perform may be the last line of defense against a possible failure due to crack growth. Not finding a defect in an area during a previous inspection, does not discount the odds of it presenting itself in the future. Approach each inspection as if there were a known flaw in the area you are inspecting.

406. Eddy current standards and scanning techniques

When eddy currents encounter an obstacle, such as a crack, the normal path and strength of the currents is changed. You will detect this change on a display or a meter. Eddy current is a "reference" type inspection. The term "reference" means that you will use a standard to setup the equipment. Results are only as good as the reference standard(s) used. For flaw detection, a minimum of three flaws of varying sizes is recommended for your setup.

Calibration standards are also used for thickness measurements and conductivity testing which will be covered in a later section. The term "calibration" refers to the use of standards directly traceable to a National Institute of Standards and Technology (NIST) standard that is government controlled.

In this section, we focus on the inspection of materials by means of eddy currents. We will discuss test standards, scanning techniques, and interpretation or evaluation of indications. First, we need to understand eddy current standards and why they are important when determining crack detection.

Eddy current standards

The primary requirement for eddy current reference standards is they provide uniformity of response, which correlate to the condition or material property detected or measured. The settings that you will use to standardize instruments prior to inspection are based on response to a specified reference standard. When setting up eddy current instruments for detection of cracks, the sensitivity of the test system is sufficient to detect the smallest required crack size. Ideally, the best standard would be a section of the same material containing a crack of this minimum size. Cracks of specified sizes are difficult to obtain. With few specimens to choose from, such situations are rare.

Fatigue cracks of specified size can be grown under laboratory conditions, but this method is extremely expensive. The length of the crack along the surface and its width is easily measurable. The depth of the crack is generally unknown and therefore approximated from other data. These eddy current standards are discussed in the following paragraphs.

Calibration should be checked approximately every 10 minutes during continual use *and* whenever abnormal values are obtained. Whenever an instrument is out of calibration, all measurements performed since the previous calibration verification will be rechecked.

General purpose standard

In the field, you will notice that each NDI lab will have at least three different types of general-purpose standards. General-purpose standards are constructed of aluminum, titanium, and steel. Three plates are fastened together with different sized holes drilled in increments from 5/32”– ¾” in size. Each hole contains a slot at varying locations to facilitate equipment calibration for bolt-hole inspections. This is demonstrated below in figure 1–28. This standard is for the following purposes:

- Shall be the common standard used for eddy current inspection unless specified otherwise by proper authority.
- Determining flaw size and sensitivity level.
- Establishing acceptance or rejection criteria.
- Checking and calibrating equipment performance.

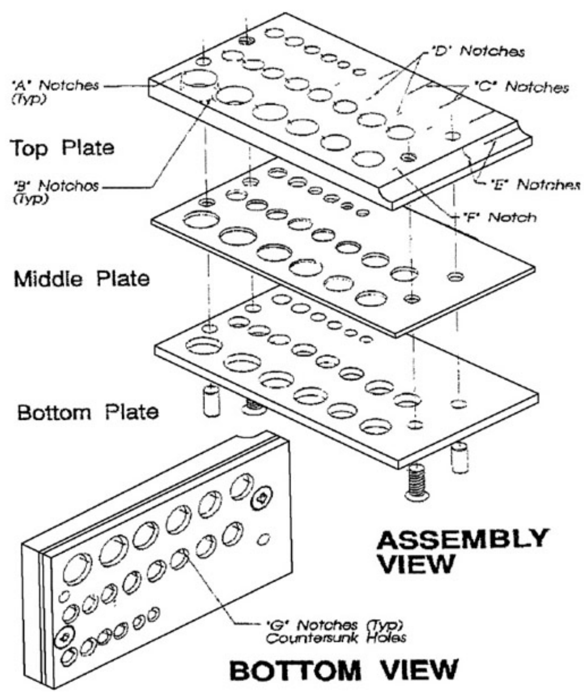


Figure 1–28. Eddy current general-purpose standard.

NOTE: Check the most current update of 33B–1–1 and 33B–1–2 for current use of standards used by Air Force personnel.

The general purpose standard sets up instruments for bolt-hole inspection, surface and subsurface crack detection. Other standards may also be used for specific part inspections and may require their own kits equipped with specific probes, cords, and standards. Figure 1–29 and figure 1–30 is an example of a special conformal probe used with standard.

Figure 1–29. Conformal probe used with standard.

Figure 1–30. Conformal probe standard.

Bolt-hole calibration

You will use a wide variety of test standards for bolt-hole inspection. They include cracked parts, electrical discharge machined notches, notches cut with a jeweler’s saw, and a multitude of other standards with larger notches and/or cracks. The bolt-hole wall finish and dimensions influence both the occurrence and the detectability of cracks in part fastener holes. Reasons for bolt-hole inspections are caused by hole wall damage such as scratches, chatter, and grooves created during manufacturing. This can create additional stress concentrations in the hole wall and increase the likelihood of a cracking.

NOTE: Drilled holes or electro-discharge-machining (EDM) notches in an aluminum block should not be used to test for material thickness or alloy composition of titanium or stainless steel parts.

Surface flaws calibration

Fatigue cracks have also been grown under laboratory conditions, but reproducible sizes in sufficient quantity for standards are impractical. Artificial flaws, such as drilled holes, EDM notches, saw cuts, or chemically simulated corrosion are made in a variety of ways. You must base the estimation of flaw size from the response to artificial flaws by correlating previous known flaw sizes with the response from the artificial flaws. Ideally, an artificial flaw will produce an eddy current response identical to the response from a real flaw with the same characteristics:

- Size.
- Orientation.
- Location.

Surface inspection standard

Another type of standard is the surface inspection standard made for surface defects and only has three slots of .005, .010, and .020 for calibration. Figure 1–31 shows a typical standard used for quick surface inspections and should be used as directed by the TO.

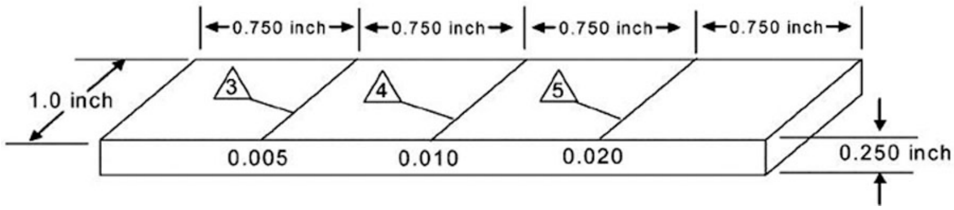


Figure 1–31. Eddy current standard for surface inspections.

If calibrated correctly, the eddy current instrument should look relatively close to the image below demonstrated in figure 1–32.

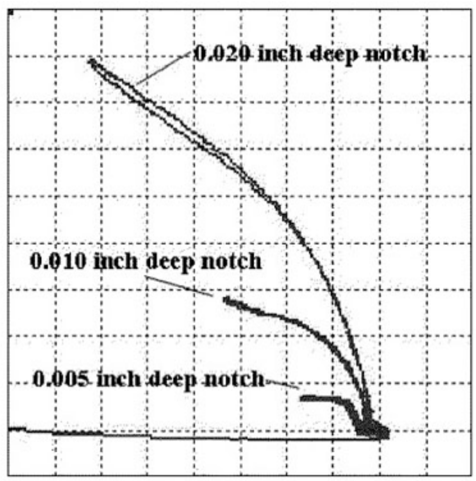


Figure 1–32. Crack size display using eddy current standards.

Use of standards

Estimation of flaw sizes based on responses to artificial flaws relies on extensive historical data. This data consists of comparisons between previously detected flaws and the artificial flaws. For this reason, material specifications and fabrication requirements of eddy current standards must be strictly controlled. Any changes in these controls will alter signal response and require a new baseline for analyzing flaw responses.

Before calibrating your unit with a standard, visualize the inspection area for paint, dirt, and other coatings that may be present on parts. *Nonconductive* coatings (e.g., paint) in *excess* of 0.010 inch thick or having wide variation in thickness should be *removed*.

NOTE: Perform lift-off compensation for inspections performed over painted surfaces. Lift-off caused by the paint thickness affects sensitivity and requires compensation during instrument standardization.

You must also determine if the material inspected is aluminum, titanium, or steel so that you can calibrate with the correct standard.

Conditions for standards

These calibration standards are used for direct comparison to the response seen on the part tested. Use great care when handling these types of calibration standards. Scratches, dents, distortion, oxidation, or other conditions can alter the calibration standards making them useless for comparison and calibration purposes. Primary standards are usually maintained under laboratory storage conditions, and may be traceable to the NIST.

Scanning techniques

Consistent positioning of the probe in relation to edges and interfaces during setup and scanning to ensure maximum response from flaws with minimum interference from other sources of indications. If conditions exist (which may result in false indications or could mask true indications from flaws) note it as a means of evaluating false indications. In determining maximum distance between scans, consider the change in magnitude of flaw response as the probe coil center position increases in distance from the center of the crack. Use the following steps when scanning:

1. Scan the inspection area. Use the same scan speed as used during calibration.
2. If numerous scan lines are required, index 1⁄2 the probe diameter between scan lines to ensure full coverage, unless otherwise specified.
3. Watch for indications on the display similar to those obtained during calibration.

The scanning speed used for cracks depends on the type of equipment and the inspection technique used. Slower scanning speeds are necessary when the inspector is required to interpret the readout while manually directing the probe in the specified scanning pattern. However, if the high pass filter (HPF) is used during the inspection process, consistent scanning speed is critical to ensure that the signal response received for a flaw is accurate. The HPF may diminish the signal response if the scanning speed is reduced during the evaluation process from the speed used during the initial standardization. The higher the HPF, the more dramatic the change in signal response when scan speed is reduced.

Scanning pattern

The scanning pattern required for inspection is based on the possible location of the crack, the orientation of cracks, and the size of cracks detected. If cracks initiate from an edge in thin material eddy current is usually limited to a single scan of the edge. For thicker materials, scans might be required on both surfaces adjacent to the edge and one or more scans of the material between the edges. When cracks initiate beneath the heads of non-removable fasteners, the pattern usually consists of a single scan around the protruding head of the fastener to detect cracks growing outward from the hole.

Scanning fixtures

The single most important requirement for detecting a small crack is that the coil passes over the crack. Specially shaped probes, fixtures, and guides can help ensure this happens. Probe guides increase detectability and should be used whenever possible. The simplest scanning guide is a section of thin flexible plastic cut to conform to the inspection area with allowance for probe positioning. Such a guide can be easily prepared from used x-ray film. The flexibility permits fitting of the guide to compound curvatures. It is necessary that the edge used to guide the probe be smooth to allow steady movement at a constant distance from the edge of the opening. The guide is either held in place or taped in the required position.

Another type of probe guide (used for small openings including holes with bushings) consists of a circular insert, which fits into the hole and has a larger diameter at one end to provide the required offset distance from the edge of the hole. Probe guides should be constructed to provide the required offset from the edge for a specified type of probe and should NOT interfere with movement of the probe.

407. Setup and standardization

All inspections for cracks or other in-service flaws should be considered critical during eddy current inspection and the following steps should be followed:

1. Always setup your eddy current instrument in accordance with the established procedures.
2. Be sure to check your setup several times during the inspection to ensure your equipment is responding properly.
3. Take time to ensure you have carefully scanned the entire area of inspection, double-checking your scans if necessary.

The inspection you perform may be the last line of defense against a possible failure due to crack growth. Not finding a defect in an area during a previous inspection, does not discount the odds of it presenting itself in the future. Approach each inspection as if there were a known flaw in the area you are inspecting.

In this lesson, we will look at how to set up for an eddy current inspection.

Part preparation

Visually inspect the test part surface for irregularities that may interfere with inspection. Remember to remove nonconductive coatings in excess of 0.010-inch thick from the inspection area prior to inspection. Also, remove any sealant, soils, dirt, grease, and other debris, which might interfere with inspection or damage inspection equipment. If necessary, clean the area with approved solvent.

Unit setup

To give you an understanding of how the functions of an eddy current instrument are used, we will go through an example of a test setup. In this way, we show you how controls are used together to calibrate the eddy current instrument. In all examples used below and in this section, assume you have already attached the probe to the instrument. Where possible, protect all probe coils with a layer of tape (Teflon® or equivalent).

Initial Settings of Aluminum Surface Scan	
Soft Key	**Description/Setting**
MAIN MENU	
FREQUENCY 1	200 kHz
FREQUENCY 2	OFF
HORIZONTAL GAIN	60.0 dB
VERTICAL GAIN	75.0 dB
ANGLE	70°
FILTER MENU	
LP FILTER	100
HP FILETER	OFF
CONT NULL	OFF
DISPLAY MENU	
SWEEP	OFF
VERTICAL POS	10 percent
HORIZONTAL POS	80 percent
SCREEN MENU	
PERSIST	OFF
DISP ERS	(No less than 2 seconds)
DOT/BOX	DOT
GRATICLE	ON
SETUP MENU	
1	FREQ/SINGLE
4	PRB DR/MID

NOTE: Always check your inspection TO for correct setup procedures.

Evaluation factors

There are many factors involved with evaluating eddy current indications. We cover *four of the most important* considered during and after your standardization settings and scanning speed. They are as follows:

- Null point.
- Filters.
- Modulation analysis.
- Frequency response.

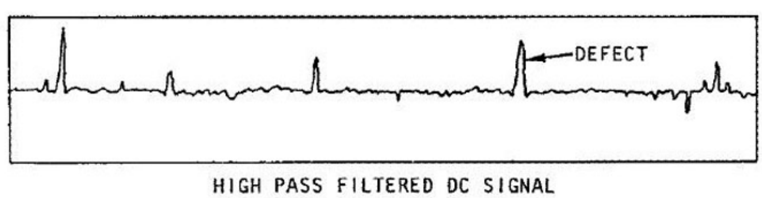
Null point

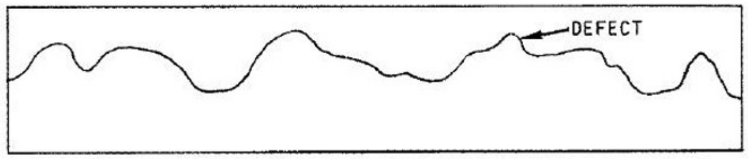
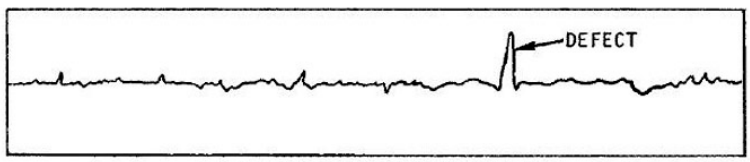
The null point, is the location on an impedance plane at which the eddy current instrument is *nulled*. For instrumentation with two-dimensional displays, the null point is usually the "good" or reference condition.

Initial Nulling of Aluminum Surface Scan	
Step	**Description**
a	Place probe on the calibration standard surface so the coil is a minimum of twice the probe diameter from all notches and edges (using appropriate shims if required).
b	Ensure the probe is perpendicular to the surface.
c	Press the NULL key. Hold the probe still until nulling is complete.
d	Repeatedly place the probe on and off the reference standard (using appropriate shims if required); at least two probe diameters away from all notches and edges, to generate a lift-off response.
e	Adjust the phase ANGLE until a substantially horizontal, right-to-left, lift-off signal is achieved.
f	Press the NULL key. Hold the probe still until nulling is complete.

Filters

Filtering improves the signal-to-noise ratio in the eddy current signal display. Three types of filters used are:

Filters	
Type	**Description**
High-pass filter (HPF)	This *removes the low frequency* components of the eddy current signal from the bridge as seen in figure 1–33. This type of filtering can eliminate the effect of gradual variations in conductivity or dimensions on the eddy current response.  **Figure 1–33. High-pass filtered signal.**

Low-pass filter (LPF)	This *removes* rapid (*high* frequency) response from electronic noise and from harmonic frequencies related to variations in magnetic permeability shown in figure 1–34.  LOW PASS FILTERED DC SIGNAL **Figure 1–34. Low-pass filtered signal.**
Bandpass filter	Band pass filters *combine low and high pass* filters to allow a response over a specific range of frequencies and suppress frequencies above and below this range shown in figure 1–35.  BAND PASS FILTERED DC SIGNAL **Figure 1–35. Bandpass filtered signal.**

Modulation Analysis

A technique useful in *separating* signals of interest from other signals relies on an *analysis of time*. A good example of this is using a sweep display or a strip chart where the amplitude of the signal appears on the vertical scale and the times at which the signal appears and disappears on the horizontal line.

When using a CRT in the sweep mode during a rotating bolt-hole inspection, the equipment is often set so each trace across the sweep represents one rotation in the hole. The clock position of an indication in the hole determines its location across the sweep.

Frequency response

Frequency response analysis is the most common form of modulation analysis. During eddy current, the impedance of the test coil remains constant provided there is no change in inspection conditions or material properties. The rates of change in the impedance and resultant eddy current signal are proportional to the rates that material properties are changing and the scanning speed. Consequently, a small crack would provide a rapid change in impedance during scanning and a corresponding high frequency eddy current signal. These signals can be viewed on a video display or a strip chart recorder as a function of time. The effect on amplitude, while encountering different kinds of material variations, and scanning at a constant speed is shown in figure 1–36.

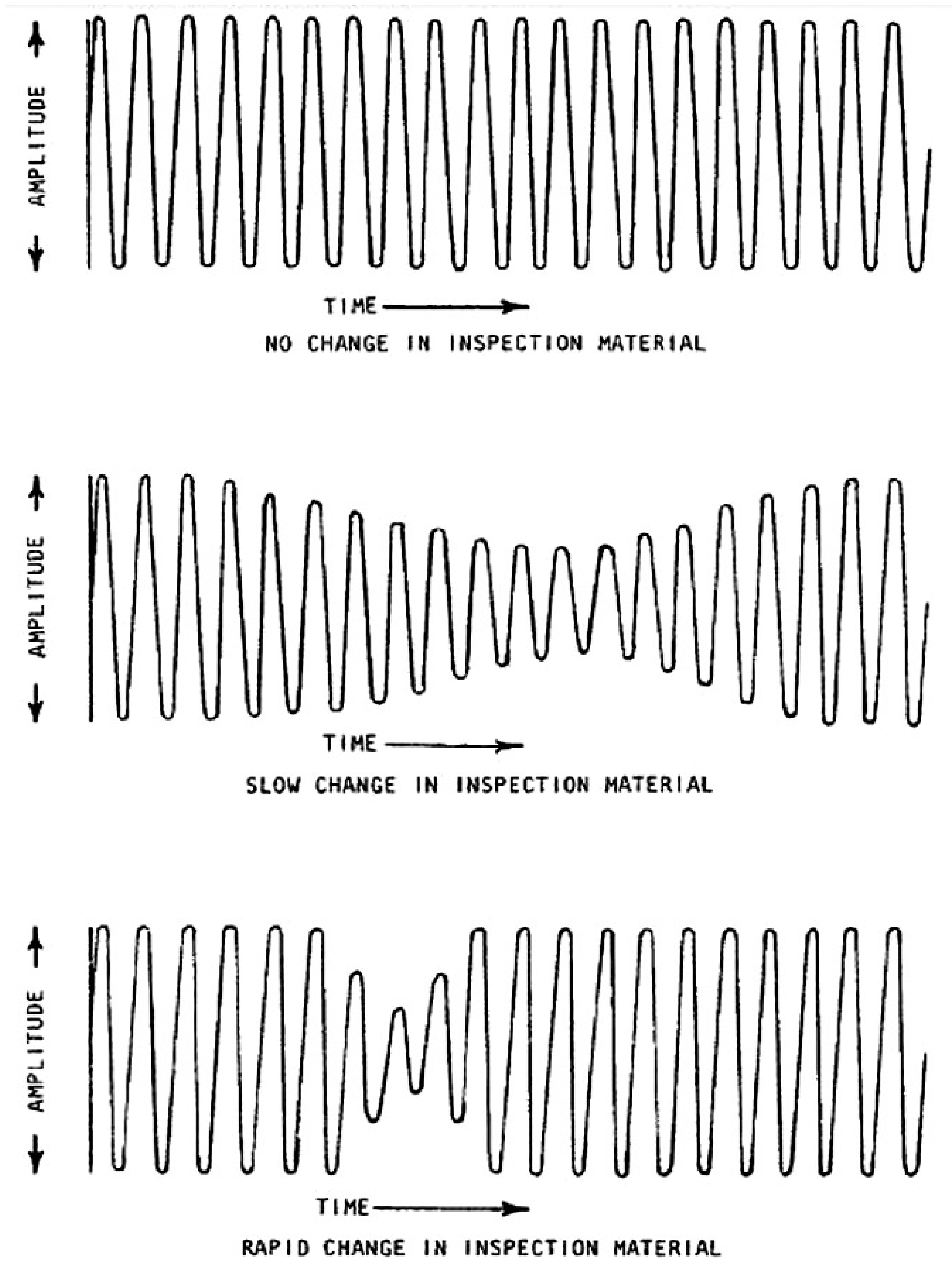
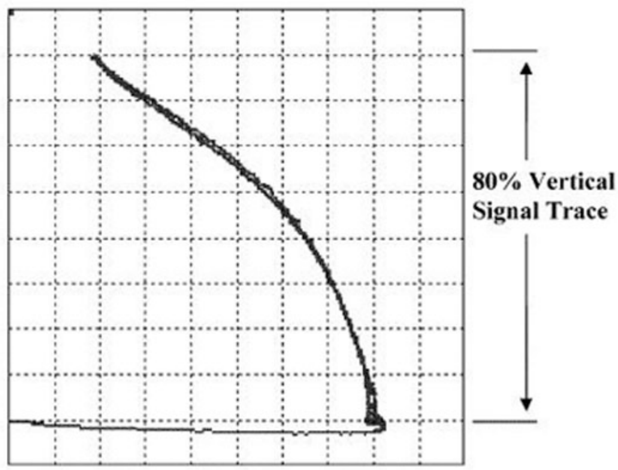


Figure 1–36. Frequency response.

Impedance testing for surface scan

The settings to standardize the instrument prior to inspection are based on response to a specified reference standard. The following table shows the steps used to standardize your unit after nulling the probe on the standard.

Initial Nulling of Aluminum Surface Scan	
Step	**Description**
a	While *repeatedly* scanning across the 0.020-inch deep notch adjust V-GAIN and H-GAIN independently until a signal trace of 80 percent full screen height (FSH) deflection is obtained from the standard notch.
b	Decrease the H-GAIN if the notch signal goes off the left side of the screen display. Set up screen should look like figure 1–37.  **Figure 1–37. Signal response from a 0.020-inch notch in aluminum.**
c	Check the sensitivity of your inspection set-up by placing the appropriate thickness of nonconductive shim on the standard (if required) and scan over the 0.005, 0.010, and 0.020 inch deep reference notches.
d	The three responses should appear similar to figure 1–32. The response from the 0.005 notch should produce a minimum 5 percent FSH vertical response (one-half of one division) and should be clearly discernible from the baseline noise.

NOTE: Failure to maintain the dot between the right and left boundaries of the display may result in missed cracks and potential catastrophic failure of an aircraft, depending upon the criticality of part or structure inspected.

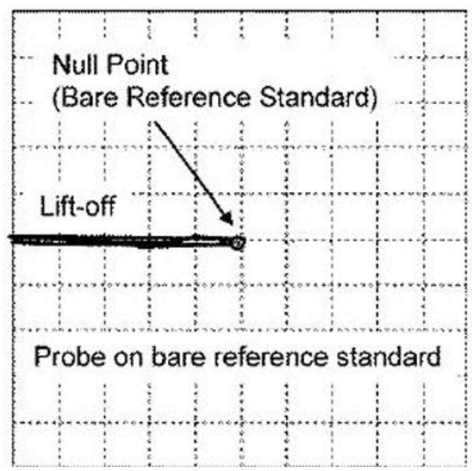
You are now ready for inspection on a test part.

Lift-off compensation

The lift-off compensation procedure prescribes general setup and standardization to perform lift-off compensation for painted or coated surfaces prior to performing and eddy current inspection. This procedure will provide the inspector with valuable information that will affect the sensitivity of an eddy current inspection. The first question to answer is if lift-off compensation is required for a particular test part. The second is how much compensation is required in terms of shim thickness applied to the reference standard prior to standardization. Figure 1–38 is an example of different shims used for standardization.

Figure 1–38 Shims used for lift-off compensation.

Check TO 33B–1–2 WP 400–00 for unit setup.

Lift-off compensation procedure	
Step	**Description**
a	Place the probe onto the surface of the bare reference standard at least 0.25 inch from all notches and edges and NULL instrument. Hold probe still until nulling is complete.
b	Flying dot should be located at 50 percent vertical and 50 percent horizontal screen position when nulling is complete as shown in figure 1–39.  **Figure 1–39 Phase angel for lift-off compensation.**
c	Place approximately 10 mils (0.010-inch) of nonconductive shims between the probe and reference standard.
d	While holding the probe still, adjust the H-GAIN (increase to move left, decrease to move right) until the horizontal position of the flying dot is located at 10 percent full screen width (FSW).
e	Remove the nonconductive shims from the reference standard. Place the probe on the bare reference standard and observe the screen to be sure the flying dot returns to the null point (50 percent vertical and 50 percent horizontal).
f	Place approximately 4–5-mils (0.004–0.005 inch) of nonconductive shim between the probe and reference standard. The flying dot should be located between 20 percent and 30 percent FSW (horizontal screen position).
g	Place the probe onto coated test surface and NULL instrument. Hold probe still until nulling is complete. Flying dot should be located at 50 percent vertical and 50 percent horizontal screen position when nulling is complete.
h	Place the probe on the bare reference standard. Do not renull. The flying dot should move to the right of the null point.
i	Observe the horizontal position of flying dot when placing the probe on the reference standard. If the flying dot is to the right of 90 percent FSW (horizontal) the coating thickness is greater than 0.010 inch (10 mils) and must be removed before inspection is accomplished. If the flying dot is between 50 percent and 90 percent FSW (horizontal) insert various thicknesses of nonconductive shims between probe and reference standard to find the shim that places the flying dot as close to 50 percent FSW as possible (the null point established on the coated surface to be inspected). This shim most closely represents the thickness of the coating on the part and is the correct shim thickness required for lift-off compensation.
j	Place this thickness of nonconductive shims on reference standard for all phases of inspection standardization.

Using conformal probes

When selecting the type of conformal or ribbon probe make sure you consult the applicable TO and understand the inspection area. If inspecting a radius, properly seat the probe on the surface.

Check TO 33B–1–2 WP 409–00 for unit setup.

<table>
<tr><th colspan="2">Conformal probe setup procedure</th></tr>
<tr><th>Step</th><th>Description</th></tr>
<tr><td>a</td><td>Press the NULL key. Hold the probe still in the air until nulling is complete.</td></tr>
<tr><td>b</td><td>Place the probe on the reference standard. Tilt the probe slightly and repeatedly to generate a lift-off response or repeatedly place the probe on and off the reference standard. Adjust the instrument ANGLE until a horizontal, right/left, lift-off signal is achieved as is shown in figure 1–40. Scan direction must be parallel to the notch length.

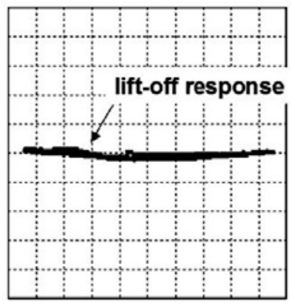


Figure 1–40. Liftoff response from conformal probe.</td></tr>
<tr><td>c</td><td>With the appropriate thickness of non-conductive shim in place (if required per WP 400 00), repeatedly scan over the 0.060 inch long notch located on the top side of the reference standard in the appropriate radius. See figure 1–41 for correct scan orientation.

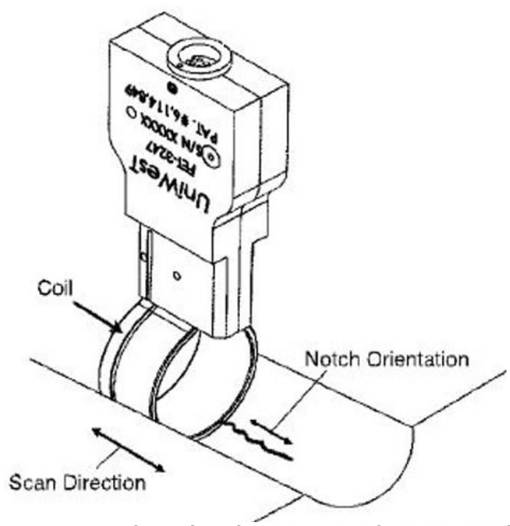


Figure 1–41. Conformal probe scan on reference standard.</td></tr>
<tr><td>d</td><td>Adjust the GAIN until a looped signal trace of 60 percent vertical peak-to-peak (PTP) deflection is obtained from the notch. The orientation of the signal shall be at a 45 degree angle with respect to the lift-off signal. This will require separate adjustments of both H-GAIN and V-GAIN. The polarity of the signal will reverse when scanning in the opposite direction, but remain 60 percent vertical PTP.</td></tr>
<tr><td>e</td><td>If the signal appears rough rather than a smooth loop, slight adjustment of the LPF setting between 95 and 105 Hz is permitted. Recheck notch signal for smoothness and required amplitude. Readjust GAIN if needed.</td></tr>
<tr><td>f</td><td>Scan over the 0.040, 0.060, and 0.100 inch notches on the reference standard. The notch responses should be approximately 25–40 percent vertical PTP (0.040 notch), 60 percent vertical PTP (0.060 notch), +90 percent vertical PTP. If these responses are not achieved, check the instrument setup and repeat the standardization.</td></tr>
</table>

Rotary fastener inspection

A common application of eddy current in aircraft structures is the detection of cracks in fastener holes or walls. These cracks are usually generated by fatigue, stress corrosion, or a combination of fatigue and corrosion. The progress of these cracks is initially slow; however, early detection can prevent possible catastrophic failure.

Proper probe fit is critical in this inspection. The probe should be shimmed so that the inspector feels light friction all the way around the hole as the probe rotates between the thumb and index finger. With the high-pass filter settings of this work package, if the probe is too small or fits very loosely, or if the hole is out of round, the probe coil could leave the hole surface and miss a small crack without any indication of excessive lift-off on the display.

NOTE: The high-pass filter settings of this procedure will filter out indications from conditions from poor probe fit and will greatly reduce indications from medium frequency conditions like gouges and scoring.

Check TO 33B–1–2 WP 405–00 for unit and filter setup. The following setup example is based on an automatic bolt-hole scanner. The Nortec Spitfire and Minimite Scanners are two bolt-hole scanners typically used in the Air Force and are shown in figure 1–42 and 1–43.

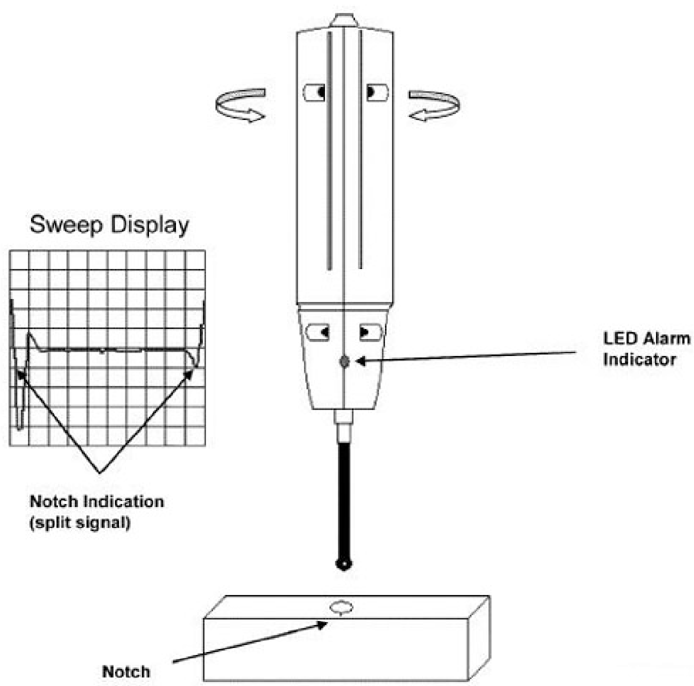


Figure 1–42. Nortec Spitfire Scanner.

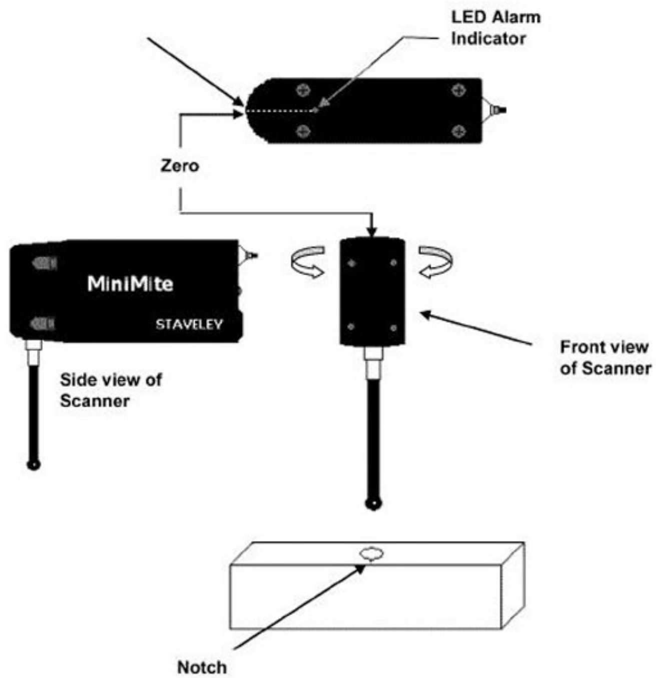
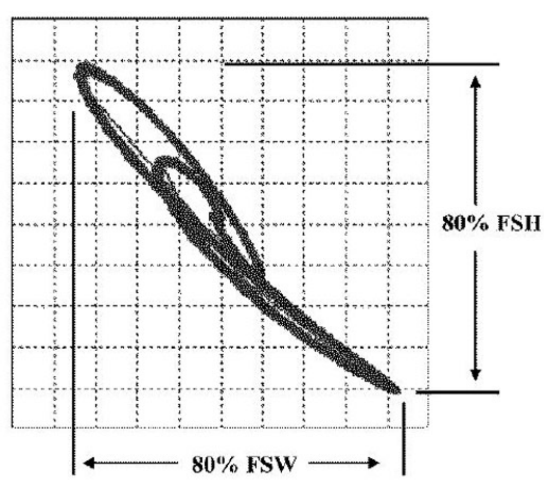
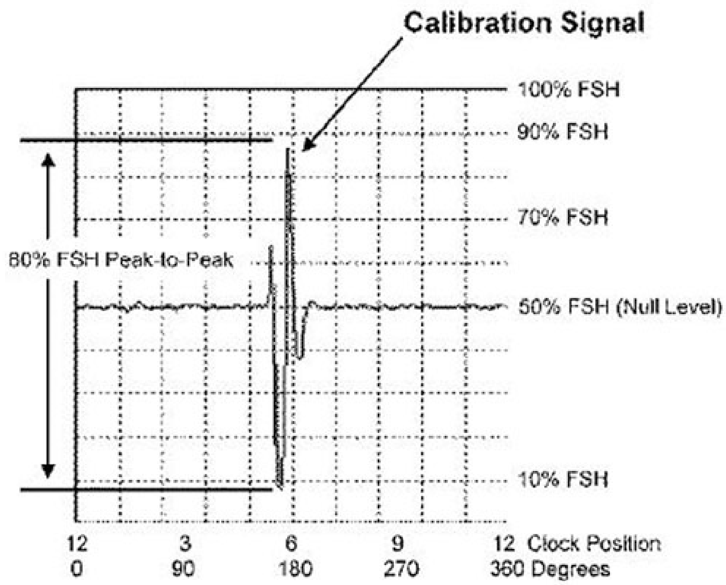


Figure 1–43. Nortec Minimite Scanner.

Rotary fastener scan procedure	
Step	**Description**
a	Press NULL. Hold the probe still in air until nulling is complete.
b	With the scanner turned on, insert the probe into the appropriate size hole in the reference standard. Verify the probe fits snug and rotates freely in the hole without binding.
c	With the probe inserted into the appropriate hole size in the reference standard locate the 0.030 inch corner notch located at the interface of the first and second layers.
d	Maximize the reference notch signal. Adjust the GAIN to place entire notch response within the boundaries of the display.
e	Adjust the ANGLE until the notch response is at a 45 degree angle from the top left corner of the display down to the bottom right corner of the display shown in figure 1–44.  **Figure 1–44. Response from 0.030-inch notch.**
f	Return to the DISPLAY menu. Press the SWEEP key twice to enter the SWEEP EXTRN mode. The instrument is now in sweep mode.

Rotary fastener scan procedure	
Step	**Description**
g	If the sweep signal is not centered at 50 percent FSH (vertical), remove the probe from the hole, press NULL and allow the null to complete.
h	Turn the scanner on and reinsert into the reference standard hole. Maximize the signal from the 0.030 inch interface notch. Push the GAIN button and adjust the GAIN (both horizontal and vertical gains will be adjusted simultaneously) as necessary to obtain an 80 percent vertical PTP signal from the notch. The notch signal should appear narrow and nearly symmetric above and below the baseline as seen in figure 1–45.  **Figure 1–45. Calibrated sweep display.**
i	Ensure the signal response from good areas of the hole is relatively smooth across the sweep display. Noise level in good areas shall be no more than 20 percent vertical PTP. If the noise level is less than 20 percent vertical PTP proceed to inspection.

408. Interpreting eddy current signals

Evaluating depth of flaws detected by eddy current *cannot* be directly measured. In almost all cases, the eddy current signals of flaws must be compared to the eddy current signal produced by the reference standard. The relationship between response to the standard and the corresponding response to the defect size must be established prior to the test and should be considered an essential part of the setup process. Prior to the start of any test, the instrument setup process should confirm that the test be conducted with the required sensitivity.

Discontinuities

Discontinuities in an electrically conductive material can change the circular eddy current flow pattern as shown back in figure 1–13. Discontinuities include cracks, inclusions, voids, seams, pits, laps, and numerous other material variables related to the production, fabrication, and use of metallic parts. The change in the magnitude and distribution of the eddy currents is roughly proportional to the size of the discontinuity intercepted by the eddy currents.

Any repeatable indication that exhibits a specified percentage of a vertical deflection separated from the background noise and not caused by lift-off or part geometry is a defect.

Inspection for cracks, measurement of conductivity, or hardness can often be complicated by surface damage and manufacturing processes. This category includes scratches, gouges, pitting, and metal smearing.

Surface damage and manufacturing processes	
Scratches Gouges Pitting	These may result in eddy current signals similar in magnitude from cracks. As test frequencies increase, the sensitivity to scratches tends to increase, because the eddy current field is more concentrated at the surface.
Metal smearing	Flowing of surface metal may result from machining operations, abrasion during service, or by deformation during assembly or disassembly of an aircraft or component. The depth of smearing in nonmagnetic materials will rarely exceed 0.002–0.003 inch. At normal crack detection frequencies, the metallurgical changes created by smeared metal may not affect eddy current response.

Location and orientation of cracks

An opening or cutout in a stressed aircraft part serves as a stress riser and a potential source of fatigue cracks and/or stress corrosion cracks. Fatigue cracks initiate at the edges of an opening, hole, or cutout and grow away from the edge at right angles to the direction of stress. Stress corrosion cracking usually occurs in sections subject to either an applied or residual tensile stress. The direction of tensile stresses can often be analyzed by engineering stress testing or from history of previous cracking in the part.

Evaluation

Cracks have three dimensions of length, width, and depth. All three of these dimensions have an effect on the eddy current response from the flaw. In general, the length of the flaw relates to the distance over which a signal above a specified level is obtained. When the crack is perpendicular to the surface and is less than two standard depths of penetration deep, the approximate depth of the crack can be estimated from the eddy current indication. With impedance plane analysis, the depth is determined by the phase angle and amplitude of the indication. The width of the crack also influences the magnitude of the indication. The signal shape, phase, and amplitude estimate the depth and area of the crack as well. In general, a crack will be deeper than indicated by comparing its response to the response from the reference EDM notches.

Fastener hole defects

Fastener hole defects are any repeatable indication that exhibits a vertical response greater to or equal to 40 percent vertical height in the sweep display and exhibits a phase response similar to the reference notch (upper left and lower right quadrants) when viewed in the impedance plane display and shall be considered a defect. This also should be reported as a defect even with lift-off noise greater than 40 percent FSW.

Repeatable indications below 40 percent vertical height, which exhibit a phase response similar to the reference notch, are below the established threshold for reporting. Report below-threshold indications only if explicitly required per the aircraft specific NDI TO, time compliance technical orders (TCTO), or other engineering requests.

The following table expresses more fastener hole defects.

Rotary fastener hole defects	
Type	**Description**
Fatigue cracks	These usually cause *repeated* cyclic loading of a structure at *lower* stress levels than required for visible deformation. Because stress is concentrated at areas of localized weakness, such as holes, fatigue cracks often initiate at such points. The cracks usually propagate normal to the direction of the maximum applied tensile stress. The following describe two types of

Rotary fastener hole defects	
Type	**Description**
	fatigue: *High Cycle Fatigue (HCF)*: means the stress applied is low compared to the ultimate tensile strength of the material but subjects to a very high number of cycles (Examples: Vibration or air turbulence stresses). *Low Cycle Fatigue (L*CF): means the stress applied is high compared to the ultimate tensile strength of the material but subjected to a very low number of cycles (Examples: take-off and landing stresses).
Stress corrosion cracks	These occur under the combined influence of a tensile stress and a corrosive environment on a material susceptible to stress corrosion cracking. The tensile stress may result from either an applied stress or a residual stress. Moisture in the air combined with a sufficiently corrosive environment may create stress corrosion cracking in some instances. In addition, a combination of cyclic fatigue in the presence of corrosion cracks can cause rapid growth of cracks.

409. Conductivity testing

Impedance plane analysis test equipment are able to separate magnetic permeability and conductivity, allowing an accurate measurement of conductivity of ferromagnetic materials and allowing us to use eddy current effectively.

Conductivity variations

Conductivity variations can occur in metals resulting in improper heat treatment or from exposure to excessive temperatures during service and cold working. Conductivity variations can stem from other sources as well. Separation of elements during solidification of metals can lead to either localized or uniform differences in conductivity. For instance, a variation in conductivity can exist with increasing depths beneath the part surface particularly in heavier sections. Slight differences in heat treating time, temperature, or quenching rates imposed by limitations in heat-treating facilities or changes in part configuration also lead to variations in conductivity of a part. Localized cold working of metals, when not followed by heat treatment to relieve residual stress, can reduce electrical conductivity.

Many of the variations are considered normal when processing parts because conductivity lies within an acceptable range for alloy specification and temper. Conductivity outside the specified range for a given alloy and temper should be considered unacceptable and further investigation should be performed using hardness testing techniques.

Percentage of International Annealed Copper Standard

An alternative way of expressing conductivity is a percent of the conductivity of a known material. The International Electrotechnical Commission has designated the conductivity of a specific grade of high purity copper to be the standard for this alternative method with a conductivity of 100 percent. It is called the International Annealed Copper Standard (IACS).

The conductivity of all other metals is expressed as a percentage of this standard. Some common values of conductivity used on engineering materials are covered in the table below. Percent IACS is the usual way of expressing conductivity in aerospace NDI.

Conductivity values of commonly used engineering materials				
Metal	**Conductivity**	**60 kHz Probe**	**480 kHz Probe**	**Resistivity**
	Percent IACS	**Minimum Thickness (Inch)**	**Minimum Thickness (Inch)**	**μ Ω cm (micro ohm centimeter)**
Silver	105	0.028	0.010	1.64
Copper, annealed	100	0.028	0.010	1.72
Aluminum Bronze 5 percent annealed	17	0.068	0.024	10.14

Conductivity values of commonly used engineering materials				
Metal	**Conductivity**	**60 kHz Probe**	**480 kHz Probe**	**Resistivity**
	Percent IACS	**Minimum Thickness (Inch)**	**Minimum Thickness (Inch)**	**μ Ω cm (micro ohm centimeter)**
Gold	73.4	0.033	0.012	2.35
Magnesium	37	0.046	0.016	4.66
Nickel, 99.95 percent	25.2	0.056	0.020	6.84
Titanium	3.1	0.160	0.057	55.62
430 Stainless steel	2.9	0.166	0.059	59.46
Inconel 600	1.7	0.217	0.077	101.43
Cobalt	27.6	0.054	0.019	6.24

Electrical conductivity is the *reciprocal* of electrical resistivity. Conductivity is commonly expressed in units of mhos per unit length such as mho/inch or mho/meter. The relationships between conductivity, resistivity, and resistance are expressed by the equation below.

Formula: $\sigma = L/RA = 1/\rho$; therefore, $R = \rho L/A$

Where:

σ = electrical conductivity (mhos/unit-length)

L = length

R = resistance (ohms)

A = cross-sectional area

ρ = resistivity (ohms–unit-length)

Alloy effects on conductivity

Generally, atoms that most severely differ in size and electron distribution from the base metal cause the greatest decrease in conductivity. The lattice distortion caused by the alloying atoms and particles of different chemical composition inhibits the flow of electrons through the lattice. Because of variations in chemical composition resulting from the tolerances in alloy additions, a conductivity range rather than a specific conductivity value is obtained for each alloy. Some effects on conductivity are listed below.

Alloy effects on conductivity	
Type	**Description**
Annealing	The annealing process reduces obstacles to electron flow; therefore, annealing improves the conductivity of a metal.
Solution heat-treating	The distortion and stresses established by the substitution of alloying atoms for those of the base metal reduces conductivity of metal. The greater the number of solute atoms of a specific material, the greater the reduction there will be in conductivity.
Precipitation hardening	The removal of foreign atoms from the parent lattice during precipitation hardening removes much of the distortion of the electron distribution in the lattice. This action favors the movement of electrons through the metal and results in higher conductivity. As increased amounts of foreign atoms are removed, and particle growth occurs during over-aging, conductivity continues to increase.

Temperature

Changing the temperature of a part changes its electrical conductivity as well. All metals become less conductive as temperature rises. This would be seen on the impedance plane as a movement along the conductivity curve toward the zero (air) end of the curve. For aluminum alloys, conductivity decreases about one percent IACS for a 20° F increase in temperature. If a conductivity meter is being used to check for proper alloy or heat treat condition, the temperature of all parts and calibration standards must be the same and kept constant. A change in temperature is interpreted as a change in alloy or hardness since all three factors may change the conductivity of a metal.

The conductivity of standards is usually determined at a specific temperature; 68°F is most commonly used. If all instrument calibration and conductivity measurements could be performed at this temperature, errors in conductivity measurement related to temperature variation would not occur and/or temperature compensation would not be required. In field applications, testing temperatures can conceivably be anywhere in the range of 0°F–120°F. Unless precautions are taken in selection of standards, calibration of the instrument, and testing, errors will occur in the measured conductivity values. Two ways in which erroneous readings may occur are:

- Difference in temperature between standards and test part.
- Difference in temperature at which conductivity of the standard was originally established and the temperature at which instrument calibration and conductivity measurements are performed.

To prevent errors from differences in temperature between the standard and test part, stabilize the instrument and standards to the test part temperature before calibration and conductivity measurements. Do not take measurements if a part and standard temperature differ by more than 10°F.

Standards

For convenience of transportation and storage, conductivity standards are usually relatively small. Standards must have sufficient size to prevent edge effects or thickness from having a bearing on conductivity readings. These requirements can be satisfied by requiring length and width to be 1 inch greater than the probe diameter and the thickness greater than 3.5 times the standard depth of penetration at the test instrument frequency. Standards should be flat and free of any coatings.

Standards used for calibrating instruments immediately prior to measuring conductivity should be accurate within ±0.5 percent IACS of the nominal value. A second set of standards accurate within 0.35 percent IACS should be periodically made available for checking the performance of instruments and field calibration standards.

The conductivity range of the standards must be within the range of the instrument and cover the range of the measured conductivity values. The calibration blocks shall have the same change in resistivity with temperature as the test parts.

Frequency

There is a relationship between conductivity and optimal inspection frequency. As an example, eddy current cracks in aluminum alloy 7075–T6, with a conductivity of about 30 percent IACS uses a frequency of 200 kHz. To perform an inspection with comparable depth of penetration on a titanium alloy, TI 6Al–4V with a conductivity of about 1 percent IACS, a frequency of about 6 MHz would be required.

General setup

Select two conductivity standards that bracket the range of conductivity to be tested. Probe selection is based on the test part’s metal thickness. It is necessary to determine the test parts metal thickness by reviewing the parts’ specifications or measuring with a micrometer, caliper, or ruler. Use TO 33B–1–2 WP 407–00 for specific material thickness for the alloy and temper inspected with the 60 kHz probe.

Select one nonconductive shim equal to 0.004 inch (4 mils) thick for coating thickness. Fold or stack thinner shims as needed to match thickness. The following table shows procedure standardizations for a typical Nortec inspection unit. We will assume that the probe is already connected to the unit.

Conductivity Procedure	
Step	**Description**
a	Press the SETUP key and set unit to UNITS % IACS.
b	Press the MAIN key to bring up the conductivity display.
c	Press the CAP TYPE softkey.
d	Rotate the SmartKnob until CONT appears in the CAP TYPE frame.
e	Set the first calibration point by pressing the CAL PT.
f	Rotate the SmartKnob until 1 appears on the display.
g	Press the VALUE softkey and rotate the SmartKnob until the conductivity value matches the low conductivity reference standard.
f	Hold the probe on the low conductivity standard. Do not rock the probe; this will cause changes in the lift off value.
g	Press the SAVE softkey to highlight the SAVE frame.
h	Quickly press and release the SAVE softkey once again to save the first signal. Hold the probe on the standard until NULLING no longer appears on the display and CAL PT advances to 2.
i	Set the second calibration point by pressing the VALUE softkey and rotate the SmartKnob until the conductivity value matches the high conductivity standard.
j	Hold the probe on the high conductivity standard and press the SAVE softkey to highlight SAVE.
k	Press the SAVE softkey once more to save the second signal.
l	To set the third calibration point, place a 4 mil (0.004 inch) nonconductive shim on the low conductivity standard.
m	Press the VALUE softkey and rotate the SmartKnob until the lift-off value matches the thickness of the shim.
n	Hold the probe on top of the shim directly over the metal standard and press the SAVE softkey to highlight SAVE.
o	Press SAVE softkey once more to save the third calibration signal.
p	Set fourth calibration point by placing the probe and nonconductive shim on the high conductivity calibration standard.
q	Press the VALUE softkey and rotate the SmartKnob until the lift-off value matches the thickness of the shim.
r	Hold the probe on top of the shim directly over the high conductivity standard and press the SAVE softkey to highlight SAVE.
s	Press SAVE softkey once more to save the fourth calibration signal.
t	Now place the probe on the parts or coupons to obtain conductivity/coating thickness readings.

Checking standardization

You must check standardization at 10 minute intervals during the course of inspection. Readings have to be obtained from the high and low standard. Each reading shall be within ±0.5 percent IACS and ± 1 mil (0.001-inch) of the known values of the standards. If the readings are not within limits, you must recalibrate the instrument and all parts since the last standardization must be reinspected. Standardize the instrument whenever power has been turned off or an operator, probe, or cable changed.

Conductivity measurement

To determine conductivity directly, eddy current instruments are available to provide a value of conductivity in percent IACS. If direct conductivity measuring equipment is not available, general-purpose eddy current equipment may be adapted for measuring conductivity. Use of general-purpose equipment requires a larger number of standards to establish a calibration curve. The number of standards necessary for a conductivity measuring application is determined by the range of conductivity to be covered and the accuracy required.

General-purpose equipment can also be used in a go no-go function to separate metals above and below a specified conductivity value. A standard representing the minimum acceptable or disallowable conductivity must be available.

Evaluation

Conductivity readings outside the acceptable range are cause for rejection unless the appropriate engineering authority gives other directions. Acceptable ranges can be found in 33B–1–2 for different metals and temper.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

406. Eddy current standards and scanning techniques

1. What is the primary requirement for eddy current reference standards?

2. When an eddy current instrument is setup for detection of cracks, what must be provided to assure that the sensitivity of the test system is sufficient?

3. What information about a crack is easily measurable when using an eddy current standard?

4. What are the three different types of general-purpose standards?

5. What should not be used to test for material thickness or alloy composition of titanium or stainless steel parts?

6. In an artificial flaw, an eddy current response is identical to the response of a real flaw of what three characteristics?

7. What size slots are on the surface inspection standard?

8. What is the estimation of flaw size responses based on?

9. What is completed for inspections performed over painted surfaces?

10. The primary standards are usually maintained under laboratory storage conditions, and may be traceable where?

11. What is critical if the HPF is used during the inspection process to ensure that the signal response received for a flaw is accurate?

12. What increases detectability of flaws and should be used whenever possible?

407. Setup and standardization

1. Paint or nonconductive coatings in excess of how much thick should be removed from the inspection area prior to inspection?

2. What should all probe coils be protected by before calibrating or setting up for an inspection?

3. What are four important evaluation factors considered during and after your standardization settings and scanning speed?

4. What is the minimum probe diameter distance from all notches and edges when placing probes on the calibration standard surface?

5. What is often used to improve the signal-to-noise ratio in an eddy current signal display?

6. What type of filter removes rapid (high frequency) response from electronic noise and from harmonic frequencies related to variations in magnetic permeability?

7. How do you check the sensitivity of your inspection during the initial nulling of aluminum surface scan set-up?

8. What may happen if failure to maintain the dot between the right and left boundaries of and eddy current display?

9. What is the first step in the lift-off compensation procedure?

10. What happens during the lift-off compensation procedure if the flying dot is to the right of 90 percent FSW (horizontal)?

11. What should you do during the conformal probe setup procedure if the signal appears rough rather than smooth?

12. What is critical in the rotor fastener inspection?

13. What will filter out indications from conditions like poor probe fit and will greatly reduce indications from medium frequency conditions like gouges and scoring in a rotor fastener scan?

14. What are the two bolt-hole scanners typically used in the Air Force?

408. Interpreting eddy current signals

1. Any repeatable indication that exhibits a specified percentage of a vertical deflection separated from the background noise and not caused by lift-off or part geometry is called?

2. These discontinuities may result in eddy current signals similar in magnitude to those from cracks. As test frequencies increase, the sensitivity to scratches tends to increase, because the eddy current field is more concentrated at the surface.

3. What initiates at the edges of an opening, hole, or cutout and grows away from the edge at right angles to the direction of stress?

4. What can be related to the distance over which a signal above a specified level is obtained?

5. What three factors can be used to estimate the depth and area of the crack?

6. What is any repeatable indication that exhibits a vertical response greater to or equal to 40 percent vertical PTP in the sweep display and exhibits a phase response similar to the reference notch when viewed in the impedance plane display?

7. When would you only report below-threshold indications?

8. What happens when applied stress is low compared to the ultimate tensile strength of the material but subjected to a very high number of cycles?

9. What in the air combined with a sufficiently corrosive environment may create stress corrosion cracking?

409. Conductivity testing

1. What can occur in metals as a result of improper heat treatment or as a result of exposure to excessive temperatures during service and cold working?

2. What should happen if a conductivity range is outside the specified value for a given alloy?

3. What is an alternative way of expressing conductivity by using a percent of the conductivity of a known material?

4. What is the conductivity value of silver?

5. What are the three relationship factors associated between the electrical conductivity formula?

6. What causes the greatest decrease in conductivity?

7. What does the annealing process do?

8. What happens to all metals when the temperature rise?

9. The conductivity of standards is usually determined at what specific temperature?

10. When should measurements not be taken when an instrument and standards are stabilizing at the test part temperature before calibration?

11. Standards used for calibrating instruments immediately prior to measuring conductivity should be accurate within what percentage of the nominal value.

12. How may standards that bracket the range of conductivity are used for testing?

13. How thick of a nonconductive shim is needed for coating thickness during conductivity testing?

14. Which key is used on an eddy current instrument to bring up the conductivity display?

15. How often is standardization checked during the course of your conductivity inspection?

16. What may be used if direct conductivity measuring equipment is not available?

17. What happens when conductivity readings are found outside the acceptable range?

Answers to Self-Test Questions

401

1. A circulating electrical current induced in a conductor by an alternating magnetic field.
2. Eddy currents flow in a circular pattern, but their paths are oriented perpendicular to the direction of the magnetic field.
3. When the magnetic field passes through a conductive material.
4. Electrical conductivity.
5. Cracks and other discontinuities.
6. Resistance.
7. Voltage is in-phase.
8. The result of a magnetic field effecting an alternating electric current inside the probe.
9. Reactance results from the electromotive force generated across a coil by the AC.
10. Phase angle.
11. When it is placed adjacent to an electrically conductive or ferromagnetic part.
12. Phase and amplitude.
13. The rate at which the electromagnetic field varies.
14. Parallel to the surface of the part at right angles to the direction of the applied field.

402

1. Frequency increases.
2. Results in shallower depths of penetration.
3. It decreases.
4. 36.8 percent.
5. Conductivity, relative magnetic permeability, and frequency.
6. 3 times the standard depth of penetration.
7. Lift-off and fill factor.
8. Coating thickness.
9. Conductivity, edge effect, magnetic permeability, geometry, metal thickness, and discontinuities.
10. Conductivity.
11. The probe should be located several probe diameters away from the nearest edge.
12. Materials will have a weaker secondary magnetic field and a greater depth of penetration.
13. When material thickness is less than the effective depth of penetration or when inspecting near the edge of a part.
14. Calibration shims.
15. Discontinuities.

403

1. Bridge circuit.

2. Alternating current that induces the eddy current flow in the part, processing responses to the induced eddy current flow, and displaying the responses in a manner to aid interpretation.
3. Oscillator.
4. Unbalance of the bridge, thus producing a relatively small signal.
5. Eddy current probes.
6. Absolute probes.
7. Reflection-differential probes.
8. Bolt-hole probes.
9. Inside diameter (ID) coil.
10. Conformal or ribbon coil.
11. Surface probes.
12. Magnetic or eddy current shielding.
13. Radiused probes.
14. The size of the eddy current field.
15. By reducing the field leakage around the outside of the probe and concentrating the field underneath the probe.
16. Pencil probes.

404

1. They are portable AC or battery powered units.
2. 100 Hz–6 MHz.
3. Sensitivity, low noise, response time, selectivity, stability, and ruggedness.
4. Sensitivity.
5. Response time.
6. Signal phase and amplitude.
7. Sweep display.
8. Frequency.
9. Low frequencies.
10. One that suppresses noise indications while leaving the desired signal information intact.
11. 50–5,000 Hz.
12. Light.
13. Linear time base display or sweep mode.
14. Magneto-optic imaging.

405

1. Check connectors, cables, and wires going into the unit to ensure they are not frayed, cracked, bent, missing, or broken, power cords must not have exposed or loose wires, and internal adjustments should only be made by Test and Measurement Diagnostic Equipment laboratory (TMDE).
2. Electrical operational checks.
3. The operation and service manual.
4. Solvents, harsh cleaning agents, or other chemicals.

406

1. They provide uniformity of response, which can be correlated to the condition or material property to be detected or measured.
2. It must detect the smallest required crack size.
3. The length of the crack along the surface and width.
4. Aluminum, titanium, and steel.
5. Drilled holes or EDM notches on an aluminum block.

6. Size, orientation, and location.
7. .005, .010, and .020.
8. Historical data.
9. Lift-off compensation.
10. National Institute for Standards and Technology (NIST).
11. Scanning speed.
12. Scanning fixtures or guides.

407

1. 0.010 inch thick.
2. A layer of tape (Teflon or equivalent).
3. Null point. Filters, Modulation analysis, and Frequency response.
4. Minimum of twice the probe diameter.
5. Filters.
6. Low-Pass Filter (LPF).
7. By placing the appropriate thickness of nonconductive shim on the standard (if required) and scan over the 0.005, 0.010, and 0.020 inch deep reference notches.
8. Missed cracks and potential catastrophic failure of an aircraft.
9. Place the probe onto the surface of the bare reference standard at least 0.25 inch from all notches and edges and NULL instrument. Hold probe still until nulling is complete.
10. The coating thickness is greater than 0.010 inch (10 mils) and must be removed before inspection is accomplished.
11. Make a slight adjustment of the Low Pass Filter setting between 95 and 105 Hz.
12. Proper probe fit.
13. High-pass filter.
14. Nortec Spitfire and Minimite scanners.

408

1. A defect.
2. Scratches, gouges and pitting.
3. Fatigue cracks.
4. The length of the flaw.
5. The signal shape, phase, and amplitude.
6. Fastener hole defects.
7. If explicitly required per the aircraft specific NDI technical order, TCTO, or other engineering requests.
8. High cycle fatigue (HCF).
9. Moisture.

409

1. Conductivity variations.
2. It should be considered unacceptable and further investigation should be performed using hardness-testing techniques.
3. International Annealed Copper Standard (IACS).
4. 105 percent IACS.
5. Conductivity, resistivity, and resistance.
6. Atoms that most severely differ in size and electron distribution from the base metal.
7. Reduces obstacles to electron flow.
8. All metals become less conductive.
9. 68°F is most commonly used.

10. When they differ by more than 10°F.
11. ±0.5 percent IACS.
12. Two conductivity standards.
13. 0.004 inch (4–mils).
14. The MAIN key.
15. 10 minute intervals.
16. General purpose eddy current equipment.
17. They cause for rejection unless the appropriate engineering authority gives other directions.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (401) What produces an alternating magnetic field in eddy current testing?
   a. Coil.
   b. Unit.
   c. Probe.
   d. Current.

2. (401) Current that is flowing through a circuit is measured in
   a. volts.
   b. hertz.
   c. ohms.
   d. amperes.

3. (401) What do you use to detect differences between permeability variations and cracks?
   a. Phase detection.
   b. Impedance testing.
   c. Electromagnetic fields.
   d. Electrical conductivity.

4. (402) Eddy current inspection can do all of the following *except*?
   a. Detect surface cracks only.
   b. Determine material properties.
   c. Detect discontinuities in materials.
   d. Measure thickness of thin metals, conductive coatings, and non-conductive coatings.

5. (402) Effective depth of penetration is the depth in the inspection article at which the magnetic field strength or intensity of the induced eddy currents is *reduced* to what percent of the value at the surface?
   a. 3.
   b. 5.
   c. 10.
   d. 15.

6. (402) When a test coil is *moved away* from a part due to lift-off, magnetic coupling between the test coil and inspection part
   a. is increased.
   b. is decreased.
   c. stays the same.
   d. will remain a constant.

7. (402) What effect do surface eddy currents, the secondary field, and depth of penetration have on poor conductivity?
   a. Weaker surface eddy currents, weaker secondary field, and a greater depth of penetration.
   b. Weaker surface eddy currents, stronger secondary field, and weaker depth of penetration.
   c. Stronger surface eddy currents, weaker secondary field, and greater depth of penetration.
   d. Stronger surface eddy currents, stronger secondary field, and weaker depth of penetration.

8. (403) Which mode of operation has two small sensing coils wound side-by-side in the shape of two back-to-back capital D's?
   a. Absolute.
   b. Reflection.
   c. Differential.
   d. Driver/receiver.

9. (403) Which type of eddy current coil has differential sensors that are directionally sensitive and provide detection of crack tips?
   a. Contact coil.
   b. Conformal coil.
   c. Inside diameter coil.
   d. Outside diameter coil.

10. (403) What happens when an eddy current probe coil arrangement is *closer* to the test surface?
    a. Large cracks can be detected due to lower sensitivity.
    b. Small cracks can be detected due to greater sensitivity.
    c. Small cracks can be detected due to lower signal to noise.
    d. Large cracks can be detected due to greater signal to noise.

11. (404) Eddy current instruments *must* have all of these capabilities *except*?
    a. Low noise.
    b. Sensitivity.
    c. Ruggedness.
    d. Dependability.

12. (404) Eddy current instruments are designed to measure what three signal qualities?
    a. Amplitude, phase, and frequency.
    b. Impedance, resistance, and inductive reactance.
    c. Depth of penetration, signal-to-noise, and impedance.
    d. Conductivity, magnetic permeability, and discontinuities.

13. (404) What is used to detect disturbances in the magnetic field produced by passing an alternating current in a thin planar foil of doped yttrium iron garnet?
    a. Bolthole inspection.
    b. Conductivity testing.
    c. Magneto-optic imaging.
    d. Impedance plane testing.

14. (405) How do you remove dust when cleaning an eddy current instrument?
    a. Use soap and water.
    b. Use a lint-free cloth.
    c. Use a solvent and lint-free cloth.
    d. You do not need to clean eddy current instruments.

15. (406) Paint or other nonconductive coatings should be removed when in *excess* of how much?
    a. 0.003.
    b. 0.005.
    c. 0.007.
    d. 0.010.

16. (407) What is the name of the location on an impedance plane at which an eddy current instrument is *usually* called the “good” or reference condition?
    a. Dot.
    b. Lift-off.
    c. Null point.
    d. Response.

17. (407) What type of filter *removes* the low frequency components of the eddy current signal from the bridge?
    a. Bandpass.
    b. Low-pass.
    c. High-pass.
    d. Noise-pass.

18. (407) Modulation analysis is useful in separating signals of interest from other signals and relies on the analysis of what?
    a. Time.
    b. Frequency.
    c. Sensitivity.
    d. Depth of penetration.

19. (407) While repeatedly scanning the 0.020 inch notch on an aluminum standard, vertical and horizontal gain *must* be increased to reach how much of the full screen height during initial nulling?
    a. 50 percent.
    b. 80 percent.
    c. 90 percent.
    d. 100 percent.

20. (408) Inspection for cracks, measurement of conductivity, or hardness can often be complicated by what two factors?
    a. Surface damage and human error.
    b. Human error and service induced processes.
    c. Surface damage and manufacturing processes.
    d. Service induced and manufacturing processes.

21. (408) The direction of tensile stress cracks are *often* analyzed by
    a. stress factors and crack location.
    b. engineer stress tests and historical cracking in the part.
    c. tensile stress cracks are never the same and therefore cannot be analyzed.
    d. nondestructive inspection (NDI) historical data and engineer dispositions.

22. (408) What type of defects are usually caused by repeated cyclic loading of a structure at lower stress levels than required for visible deformation in fastener holes?
    a. Voids.
    b. Stress cracks.
    c. Fatigue cracks.
    d. Stress corrosion cracks.

23. (409) Conductivity is commonly measured in units of
    a. mho.
    b. mhz.
    c. ohms.
    d. amperes.

24. (409) Alloy effects on conductivity are caused by all of these e*xcept*?
    a. Annealing.
    b. Cold working.
    c. Solution heat-treating.
    d. Precipitation hardening.

25. (409) Conductivity decreases about how much in percent International Annealled Copper Standard (IACS) for a 20° F temperature increase for aluminum alloys?
    a. One.
    b. Three.
    c. Five.
    d. Seven.

26. (409) What is conductivity probe selection based on?
    a. Temper.
    b. Thickness.
    c. Material velocity.
    d. Copper standards.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Ultrasonic Inspection Methods

ULTRASONIC TECHNIQUES HAVE A HISTORY spanning back to the earliest days of industrialization**.** In the twentieth century, the development of submarine warfare (in the 1920s) led to the requirement for underwater communication. Early research for a suitable underwater communication method led to the invention of sonar, underwater ranging, and depth indicating devices. These advances represent the beginning of ultrasonics, as we know them today.

In the late 1930s, considerable work was applied to the principles of ultrasonic wave transmission to NDI of materials. The first instruments developed were considered laboratory equipment and mostly used for metallurgical research. Since then, ultrasonic inspection techniques have come a long way, and the need for advanced ultrasonic techniques has grown with newer and better aerospace equipment.

For you to become proficient in ultrasonic testing, it is necessary that you understand the basics of ultrasonic testing. This includes such things as how to generate ultrasonic energy and what happens to ultrasonic energy when it passes through a test specimen. In this unit, we discuss the principles of ultrasonic transmission, test equipment, inspection processes, specialized techniques, and quality control measures.

2–1. Principles of Ultrasonics

The term ultrasonic pertains to sound waves having a frequency greater than 20,000 Hz. For most ultrasonic nondestructive inspections, a device called a transducer, which we discuss at length later in this unit, will generate ultrasound. The more general term ‘‘search unit’’ is also used to refer to the device introducing ultrasound into a part.

410. Theory of ultrasound

Ultrasonics uses (ultra) sound to detect internal discontinuities ranging from cracks to disbonds. Use ultrasound in the following ways:

- Inspect almost any material.
- Locate discontinuities from large disbonds, down to the smallest defects.
- Measure the overall thickness of a material.
- Find a specific depth of a defect.

Parts require little or no preparation; however, knowledge of the internal geometry of a part is critical to interpretation of any defect signal.

Characteristics of sound

Periodic vibrations of molecules or other small volume elements of matter characterize the transmission of both audible sound and ultrasound. The vibration propagates through a material at a velocity distinctive to that material. As the particle displaces from its rest position by any applied stress, it moves to a maximum distance away from its rest position called *maximum displacement*. The particle then reverses direction and moves past its rest position to a maximum location in the negative direction (a second maximum displacement). The particle then moves back to its rest position, which completes one cycle. This process continues until the source of vibration is removed, and the energy passes it on to an adjacent particle.

The amplitudes of vibration in parts ultrasonically inspected impose stresses low enough so that there are no permanent effects to the part. To understand characteristics of sound, the following table describes some terms associated with ultrasonics.

Ultrasonic Terms	
Term	**Description**
Period	The amount of time it takes to complete one cycle.
Propagation	Advancement of a wave through a medium by the transfer of energy from one molecule to another.
Velocity	The distance traveled per unit time (second).
Frequency	The number of complete cycles that occur in one second.
Amplitude	Vertical height of a signal measured from the trace line to signal peak on an ultrasonic instrument display Denotes signal strength from return echo.
Hertz	The cycles per second. For example, 1 hertz (Hz) = one cycle; 1 kilohertz (kHz) = 1,000 cycles; 1 Megahertz (MHz) = 1,000,000 cycles.
Wavelength	The distance a wave travels while going through one cycle (See formula below).

Wavelength is defined by the formula:

$$\lambda \text{ (lambda)} = v/f$$

Where:

λ = wavelength (normally inches or centimeters).

v = velocity (inches or centimeters per second).

f = frequency (hertz).

Generation and receiving of ultrasonic vibrations

Ultrasonic vibrations generate by applying electrical energy to the *piezoelectric element* contained in a transducer. This applied energy will be either a sudden high voltage spike from a discharging capacitor (a spike pulse), or a short pulse of constant voltage called a square wave. The transducer element transforms the electrical energy into mechanical energy (vibration) at a frequency determined by the material and thickness of the element. For aircraft NDI, this frequency will be ultrasonic.

This element is also capable of receiving ultrasonic (mechanical) energy and transforming it into electrical energy (i.e., reverse piezoelectric effect) shown in figure 2–1.

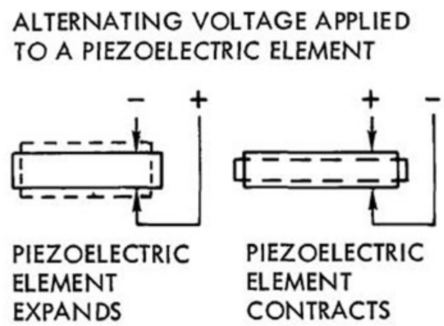


Figure 2–1. Generation of ultrasonic vibrations.

Ultrasonic energy is transmitted *between* the transducer and the test part through a coupling medium (e.g., oil, grease, or water) shown in figure 2–2. The purpose of a coupling material is to eliminate air at the interface between the transducer and the part under inspection. Air has high acoustic impedance, and thus, is a poor transmitter of ultrasound. Like audible sound waves, ultrasonic waves are capable of propagating through *any* elastic medium (solid, liquid, gas), but *not* in a vacuum.

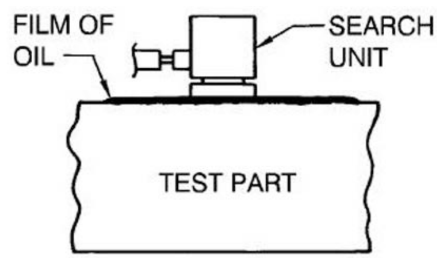


Figure 2–2. Coupling between a transducer and test part.

Frequency

Frequencies commonly used are 2.25 MHz and 10 MHz for flaw detection in ultrasound inspection. The *higher* frequencies in this range provide *greater* sensitivity for detection of *small* discontinuities, but do *not* have the penetrating power of the lower frequencies. The higher frequencies can also be more affected by small metallurgical discontinuities in the structure. Signals from these discontinuities can often interfere with the detection of relevant discontinuities, such as small cracks.

The size of the defect detected should be the prime consideration when selecting the inspection frequency. Typically, defects must have at least one dimension equal to or greater than 1/2 the wavelength in order to be detected. For example, straight beam inspection of aluminum at 2.25 MHz with a wavelength of 0.111 inch, requires a defect be 0.066 inch or larger in order to be detected (e.g., at 5 MHz, the minimum defect size is 0.025 inch and at 10 MHz, it is 0.012 inch).

411. Wave modes of ultrasonics

The manner in which acoustic energy propagates through a material as characterized by the particle motion of the wave is called *wave modes*. Wave modes consists of two parts:

- Compression – molecules packed together.
- Rarefaction – molecules spread apart.

It is important to know where types of sound waves and where they go when it leaves the transducer. In this section, we will discuss the different types of ultrasonic wave modes typically used in ultrasonic inspection. You will also learn how to determine the angle in which sound beams enter the part as well as how it relates to the angle of refraction using the Snell's law formula.

Modes of ultrasonic vibration

Ultrasonic sound transmits energy by vibrating particles within the material. The mode of vibration is dependent upon the direction in which the particles vibrate in relation to the propagation direction of the bulk ultrasonic beam. Ultrasonic waves generate sound by four modes of vibration:

- Longitudinal.
- Transverse.
- Surface.
- Lamb.

Longitudinal waves

Waves in particle motion move in essentially the same direction as the sound wave, which are known as longitudinal waves (also referred to as "compressional waves" or "L-waves"). You can see this in figure 2–3). Longitudinal waves can transmit within solids, liquids, and gases. They do this when the incident longitudinal wave is near normal to the surface of the part under inspection. Wave velocity determines the material's elastic modulus and density, and is a constant for each material.

Use longitudinal wave inspections *extensively* for thickness inspections, corrosion thinning, and for the detection of other defects *parallel* to the inspection surface.

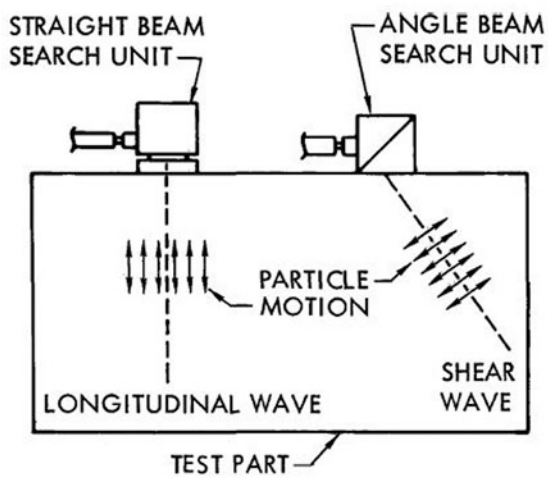


Figure 2–3. Longitudinal and transverse wave modes.

Transverse waves

Transverse (also known as "shear" or "s-wave") denote the motion of waves in which the particle motion is perpendicular to the direction of a part (fig. 2–3). These inspections are also called angle beam inspections because they travel at approximately half of the velocity of longitudinal waves.

Transverse waves can exist in any elastic solid, but cannot in liquids or gases. They generate in a test piece when a longitudinal wave impinges on the surface at an angle within a range of angles other than normal (90°) to the surface. The *incident angle* is the angle *between* the incident longitudinal wave and a line normal to the surface. A portion of the sound reflects throughout the part, but over a wide range of incident angles. Other portions of the sound enter the test piece where mode conversion and refraction occur, resulting in a shear wave at an angle in the part. The portion converted to a shear wave will vary with the incident angle.

Use shear wave inspections where defects (cracks and other defects) are suspect to be located at other than parallel to the inspection surface.

Surface waves

Surface or Rayleigh waves have a particle motion elliptical in a plane, parallel to the material direction, and perpendicular to the surface. Surface waves generate where longitudinal waves impinge on the test piece at an incident angle, just beyond the second critical angle for that material. Once generated, surface waves can travel along curves and complex contours. They travel at approximately 90 percent of the velocity of shear waves. Surface waves are confined to a thin layer of the material under inspection, up to one wavelength deep, and can only be sustained when the medium on one side of the interface is a gas.

An angle beam transducer containing a steeply angled wedge is shown in figure 2–4. The energy of surface waves decay rapidly below the surface of a test part. Surface waves are most suitable for detecting surface flaws, and detecting discontinuities lying up to one-half the wavelength below the surface.

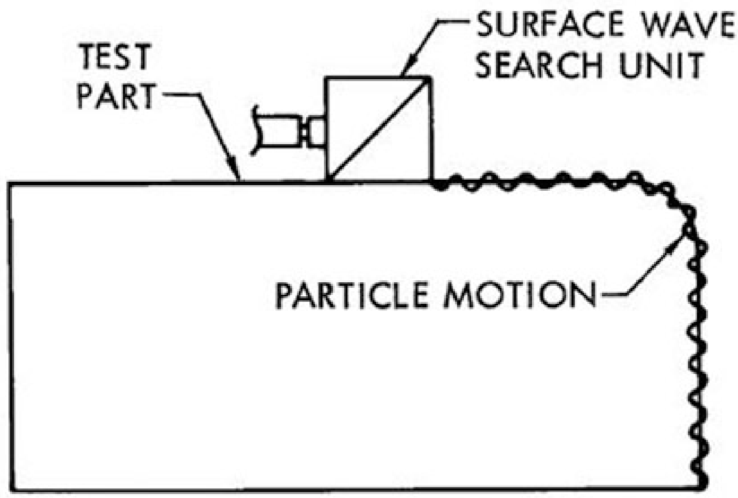


Figure 2–4. Surface wave mode.

Lamb waves

Lamb waves propagate within thin plates, a few wavelengths thick. Waves advance between the two parallel surfaces of the test piece, and can continue for long distances. Lamb waves generate in a complex variety of modes. The material characteristics of Lamb waves are dependent on the properties and thickness of test material, as well as the test frequency. Two basic forms of Lamb waves exist:

- Symmetrical.
- Asymmetrical.

Although not widely used in production, Lamb waves are beneficial in large area inspection applications, such as corrosion and disbonds, because they can advance for long distances.

Refraction, reflection, and mode conversion

These three terms address what happens to the sound beam as it travels from your transducer into the material you are inspecting. Below are the definitions.

Ultrasonic Terms	
Term	**Description**
Refraction	*Change* in direction of an ultrasonic beam as it passes through the interface *between* two materials with *different* acoustic velocity; (see SNELL'S LAW below).

Ultrasonic Terms	
Term	**Description**
Reflection	An indication that results in an incident sound beam returned at the boundary of two materials of dissimilar acoustic impedance.
Mode conversion	Changing from one mode of vibration to another; caused by retraction at an interface.

Refraction

Refraction is a change in wave direction. A portion of the longitudinal incident beam refracts into one or more wave modes traveling at various angles in the test piece as seen in figure 2–5.

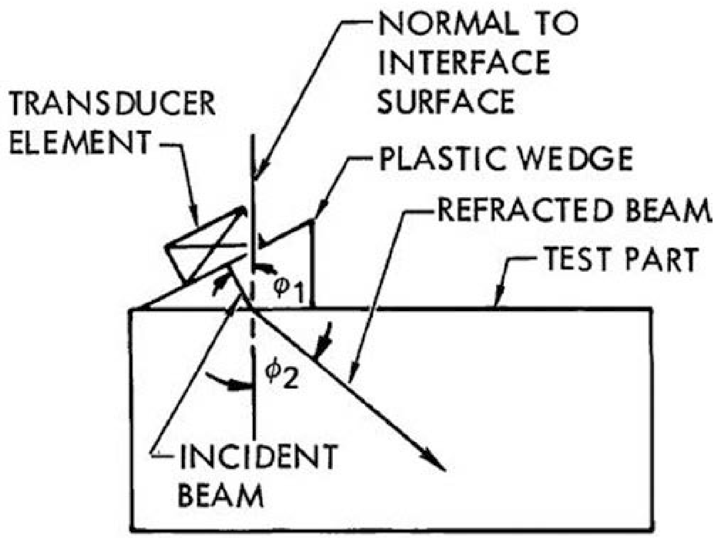


Figure 2–5. Sound beam refraction.

The relative energy for longitudinal, shear, and surface wave beams in steel, for different incident angles of longitudinal waves in plastic, is shown in figure 2–6. The curves use plastic wedges on steel while other shaped curves obtain other test materials (e.g., aluminum, titanium, and water immersion). Refraction angles are greater in water than in plastic.

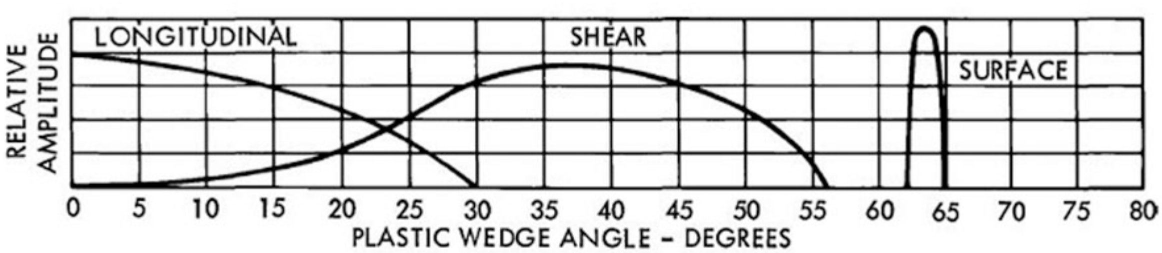


Figure 2–6. Amplitude in steel of longitudinal, shear, and surface wave modes.

Snell's Law *defines* wave refraction at an interface.

Snell's Law

Snell's law is the tool for determining wedge angles for contact testing or the angle-of-incidence in water for immersion testing. When an incident longitudinal beam is normal to the test part surface, the longitudinal sound beam transmits straight into the test part and no refraction occurs. When the incident angle is other than normal, *refraction*, *reflection*, and *mode conversion* occur.

Snell's Law formula:

$$\frac{Sin\,\theta 1}{Sin\,\theta 2} = \frac{V1}{V2}$$

Sinθ1 divided by sin *θ2* = V1 divided by V2

Where:

θ1 = angle of incidence.

θ2 = angle of refracted beam.

V1 = velocity of incident sound beam.

V2 = velocity of refracted sound beam.

Reflection

Ultrasonic sound beams have properties similar to light beams. For example, when an ultrasonic beam strikes an interrupting object, sound beam energy reflects the surface of the interrupting object. The angle of incidence is equal to the angle of reflection (fig. 2–7).

Mode conversion

Mode conversion is a change in the nature of the wave motion. This happens at the junction of the plastic wedge and test specimen, as shown in figure 2–8. The figure shows longitudinal waves converted to shear waves.

Internal mode conversion causes false indications on the instrument display. This is especially prevalent in long bars where, the sound has a considerable distance to travel. The sound beam spreads out and reflects from the sides of the specimen. This internal mode conversion is undesirable because it cannot eliminate or suppress due to geometry of the specimen.

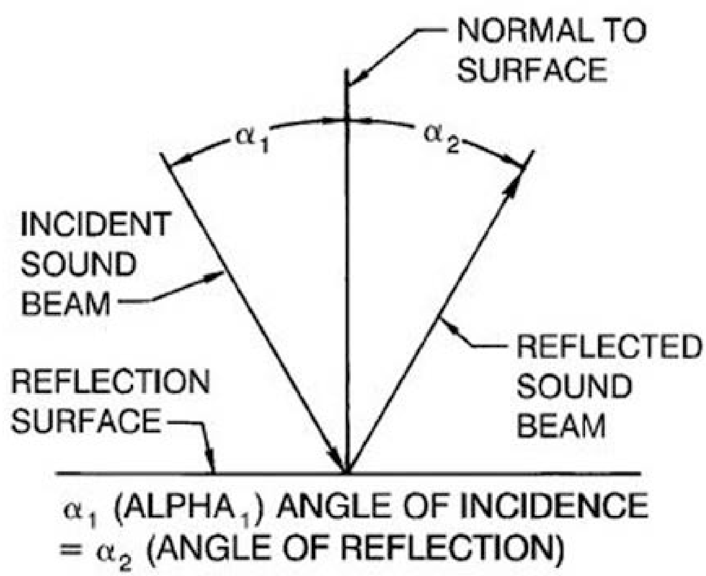


Figure 2–7. Reflection.

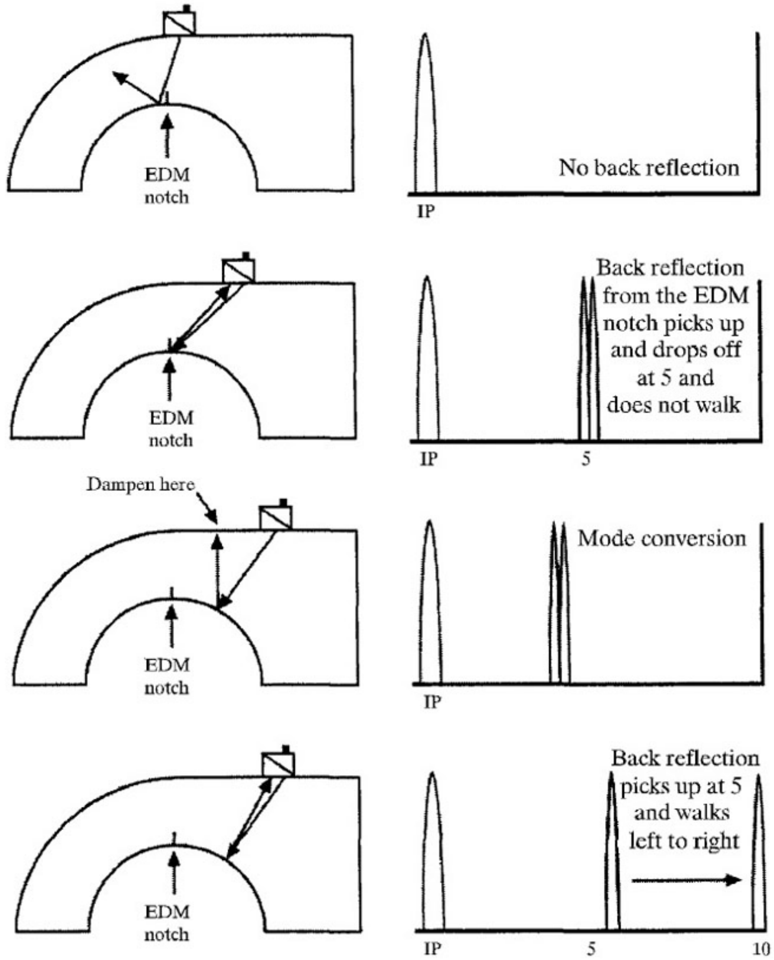


Figure 2–8. Mode conversion.

412. Sound beam characteristics

Sound beams do *not* propagate uniformly through the straight-sided projection of the transducer face. Side lobes exist along the outer edges of the beam near the transducer face and sound intensity is not uniform throughout the beam as discussed in this lesson. Eight characteristics of sound beams are listed below:

- Dead zone.
- Near field.
- Far field.
- Distance vs amplitude.
- Beam spread.
- Focused sound beams.
- Beam intensity.
- Attenuation.

Dead zone

During ultrasonic testing, there is test specimen thickness beneath the transducer in which no useful ultrasonic inspection can take place. This region defines as the dead zone. When a transducer is excited, it vibrates for a finite amount of time during which it cannot act as a receiver for a reflected echo. Reflected signals from defects located in the dead zone arrive back at the transducer while it is still transmitting.

A dead zone is inherent in all ultrasonic equipment. In some ultrasonic inspection equipment, the transmitted pulse length is electronically shortened, effectively making the dead zone shallower but not eliminated.

Near field

Extending from the face of the transducer is an area characterized by *wide* variations in sound beam intensity. These intensity variations are due to the interference effects of spherical wave fronts emanating from the periphery of the transducer crystal. The region where this interference occurs is called the near field (Fresnel Zone) illustrated in figure 2–9. The smaller the transducer element diameter or the lower the frequency, the shorter the near field will be. Due to inherent amplitude variations, inspection within the near field is not recommended without careful calibration on reference flaws within the near field.

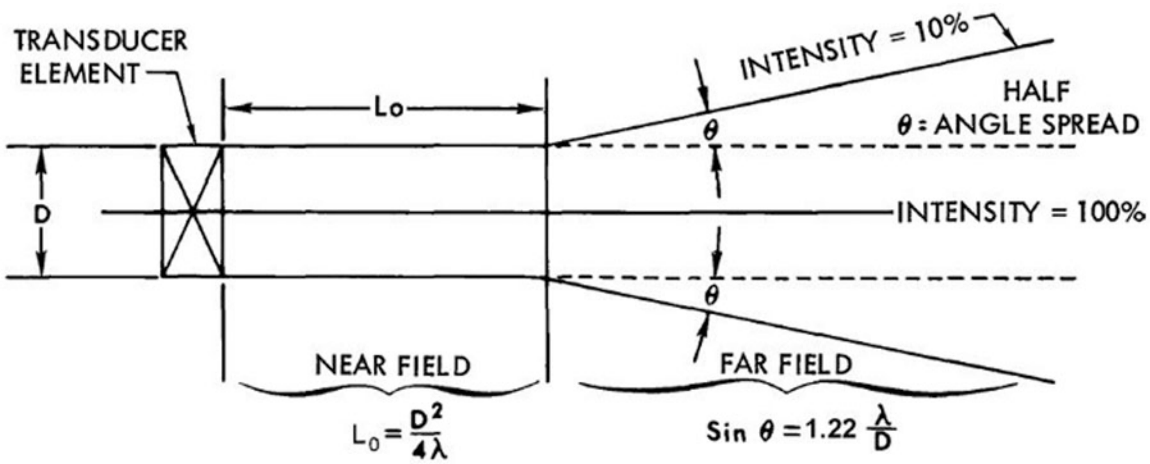


Figure 2–9. Near field.

The equation for calculating the length of the near field is located below.

$$N = \frac{D^2}{4\lambda} = \frac{D^2 f}{4v}$$

Where:

N = near field length (inches).

D = diameter of a transducer element in a round transducer, or maximum diagonal of transducer element in a rectangular or square transducer.

λ = wavelength of sound in the test material.

f = frequency (Hz).

v = velocity (in/sec).

Far field

At distances beyond the near field, there are no interfering effects. This region is called the far field (Fraunhofer Zone) illustrated in figure 2–9. Most ultrasonic inspection procedures occur in the far field. The intensity of the sound beam in the far field falls off exponentially as the distance from the face of the transducer increases.

Distance versus amplitude

It is always best to compare discontinuity signals with signals from reference standards, such as flat-bottom holes having the same metal travel distance as the discontinuity. A typical curve showing the amplitude response versus distance from the transducer face is shown in figure 2–10.

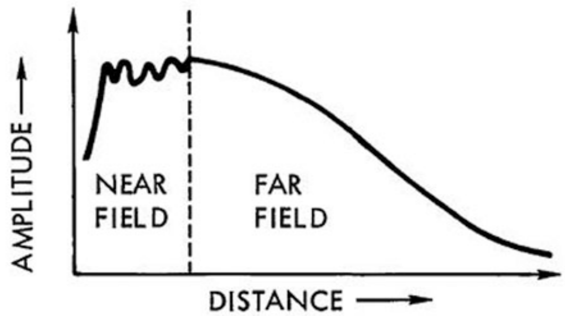


Figure 2–10. Amplitude response curve of typical transducer.

NOTE: Wide variations in amplitude from discontinuities can occur when inspecting in the near field.

Beam spread

In the near field, the sound beam essentially propagates straight out from the face of the transducer. In the far field, the sound beam spreads outward and *decreases* in intensity with *increasing* distance from the transducer face. Beam spread is an important consideration because in certain inspection applications, the spreading sound beam may result in erroneous or confusing presentations by reflecting off walls or edges as seen in figure 2–11.

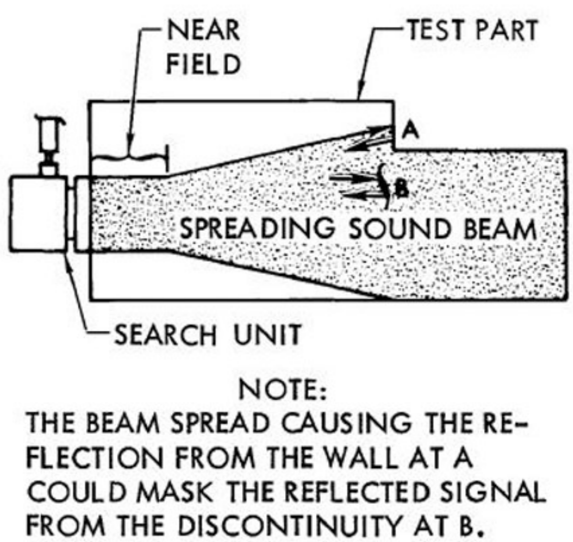


Figure 2–11. Example of beam spread causing confusing signals.

In addition to the main sound beam pattern discussed above, there is also a small amount of side lobe energy seen in figure 2–12. An adverse effect of side lobes, is a reduction in the efficiency of the transducer. Due to the interference created by the side lobes, the actual useable width of a sound beam near the face of the transducer is less than the actual width of the piezoelectric element.

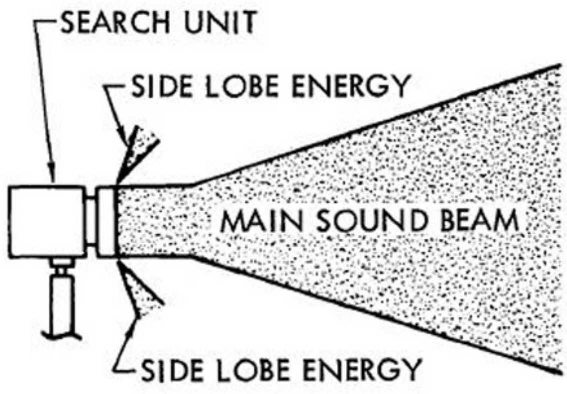


Figure 2–12. Main sound beam and side lobe energy.

The formula for calculating the half angle of the beam spread is located below:

$$\mathbf{Sin\theta = 1.22\ \lambda/D} \qquad \text{or} \qquad \mathbf{Sin\theta = 1.22v/fD}$$

Where:

θ = half-angle of spread

D = transducer diameter (inches)

λ = wavelength (inches)

f = frequency (Hz)

v = velocity (in/sec)

Example: Given 2014–T4 aluminum tested with a 1/4-inch diameter unit at 5 MHz, what is the half angle of the beam spread?

D = 1/4 inch (0.25 inch)

λ = 0.049 inch

$$\mathbf{Sin\theta = 1.22\ \lambda/D} \text{ then, } \mathbf{Sin\theta\ \frac{(1.22)(0.049)}{.25}} \text{ then, } \mathbf{Sin\theta = 0.2391} \text{ then } \mathbf{\theta = 14°}$$

Remember this is the half angle value; to get the full angle of the beam spread it is necessary to double the achieved value of the angle θ.

Focused sound beams

On some immersion inspections or special ultrasonic tests with a water delay column, a focused sound beam is used like in figure 2–13. In figure 2–14, the focusing produces a transducer containing a plastic acoustic lens on the face of the transducer element. The acoustic lens causes the sound beam to converge as the sound travels away from the transducer. Due to refraction at the plastic-water interface, a peak in amplitude is obtained at the focal point. The amplitude decreases rapidly on each side of this point.

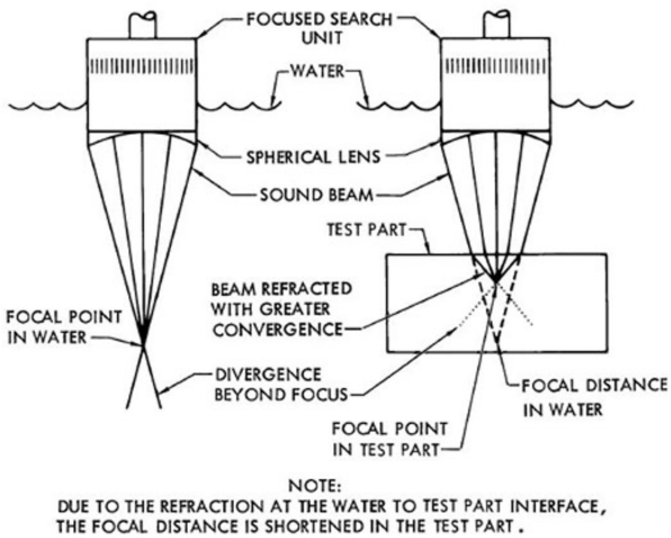


Figure 2–13. Focused sound beams.

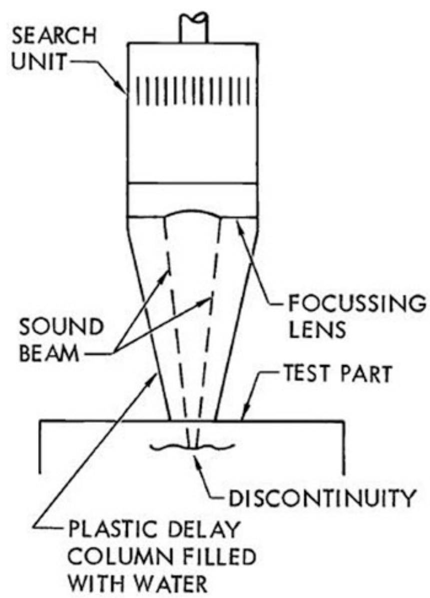


Figure 2–14. Water delay column transducers.

This type of transducer has a high sensitivity for discontinuities located at the focal point distance due to the concentration of energy at this focal point, but the depth of material inspected in any one scan is limited.

Beam intensity

Beam intensity is the sound wave energy transmitted through a unit cross-sectional area of the beam. The intensity is proportional to the square of the acoustic pressure applied in the material by the sound wave. The acoustic pressure *directly* relates to the *amplitude* of the material particle vibrations caused by the sound wave. Transducer elements sense the acoustic pressure of the reflected sound wave and convert it to an electrical voltage. Ultrasonic instrument receiver-amplifier circuits receive the input voltage from the transducer and produce an output voltage value proportional to the intensity of the reflected sound. This output voltage displays on the instrument as an A-scan signal.

Attenuation

Attenuation is the loss in acoustic energy that occurs between any two points of travel. The amount of loss is measured in decibels, but direct measurement of material attenuation can be very difficult. Beam attenuation occurs due to many factors that include absorption, scattering, diffraction, beam spread, geometry of the part, or other material characteristics.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

410. Theory of ultrasound

1. How is ultrasound used when detecting internal discontinuities like cracks and disbonds?

2. What is it called when a particle of sound displaces from its rest position by any applied stress and moves to a maximum distance away from its rest position?

3. What causes the vibrations in parts ultrasonically inspected that impose stresses low enough, so that there is no permanent effect to the part?

4. What is the distance traveled per unit time (second)?

5. What is the formula for wavelength?

6. When performing an ultrasonic inspection, energy transmits between the transducer and test part through what type of medium? Give examples.

7. What frequencies are used for flaw detection using the ultrasound contact method?

8. What should be the prime consideration when selecting inspection frequency?

411. Wave modes of ultrasonics

1. Ultrasonic waves consists of what two parts?

2. Into what four modes of vibration are ultrasonic waves classified?

3. Waves in particle motion that move in essentially the same direction as the sound wave are called?

4. What is a transverse wave mode?

5. What type of wave mode has a particle motion elliptical in a plane, parallel to the material direction, and perpendicular to the surface?

6. What type of waves are most suitable for detecting surface flaws, but may also be used to detect discontinuities lying up to one-half wavelength below the surface?

7. What type of waves propagate within thin plates, a few wavelengths thick?

8. What three terms address what happens to a sound beam as it travels from your transducer into the material you are inspecting?

9. What changes from one mode of vibration to another; caused by retraction at an interface?

10. Wave refraction at an interface is defined by what?

11. What is equal to the angle of reflection?

412. Sound beam characteristics

1. What exists along the outer edges of the sound beam near the transducer face and sound intensity is not uniform throughout the beam?

2. What is it called during ultrasonic testing when the test specimen thickness beneath the transducer is not useful?

3. Due to inherent amplitude variations, inspection within which sound beam characteristic is not recommended without careful calibration on reference flaws?

4. Which sound beam characteristic do most inspection procedures occur in?

5. What is always best to do when receiving a discontinuity signal during ultrasonic inspection?

6. Why is beam spread an important consideration in an ultrasonic inspection?

7. On some immersion inspections or special ultrasonic tests with a water delay column, which sound beam characteristic is used?

8. What is the sound wave energy transmitted through a unit’s cross-sectional area of the beam called?

9. How is attenuation loss in acoustic energy measured?

2–2. Ultrasonic Equipment and Hazards

Air Force NDI labs are normally equipped with a basic ultrasonic flaw detector to inspect parts. There are many types of ultrasonic flaw detectors available, and what is in your lab will depend on the equipment and aircraft inspections in your lab. The information covered in this section is general in nature and is not specific to any one unit.

In this section, we will discuss common operating controls of ultrasonic flaw detectors, operator safety, and maintenance practices within this method.

413. Ultrasonic inspection equipment and materials

Ultrasonic equipment performs functions for generating, receiving, and displaying pulses of electrical energy. All portable ultrasonic equipment consists of a power supply, a clock circuit, a pulser, a sweep circuit, a transducer, a receiver-amplifier circuit, and an instrument display. By properly adjusting an instrument, an operator can measure the amplitude of displayed pulse signals and determine the time/distance relationships of the received signals.

NOTE: Obtain detailed instructions for operation of individual models by consulting the operating and maintenance manual for the specific instruments.

Characteristics of instrument controls

The physical nature of instrument controls varies with the type and age of instruments. Older units have rotary knobs for fine adjustments, slide switches for coarse adjustments, and screwdriver rotary controls for infrequent adjustments, of waveform position and visibility. Newer units have push buttons or a sealed membrane keypad, both to select the desired control from a displayed menu and to make the respective adjustments. Alternatively, some menu driven instruments have a single rotary (“smart”) knob for making adjustments after selecting a control from the menu.

It is important to get to know, practice, and understand the unit that you will be using at your lab.

Unit display

An ultrasonic instrument may have one of several types of waveform displays, the following table describes each display.

Unit Display Types	
Display	**Description**
Cathode ray tube (CRT)	A vacuum tube that contains a screen that display signals.
Liquid crystal display (LCD)	Both LCD/EL displays the signal, menu sidebar, status bar, other indicators, and full screen text.
Electroluminescent display (EL)	

Waveform positioning controls

The events in an ultrasonic inspection relate to time referenced to the pulses produced by the instrument. Pulses or signals represent a horizontal line (typically called the sweep or baseline) at the bottom of the screen. Time starts at the left end of the sweep and progresses to the right. The sweep, included within the “frame” (fig. 2–15), is a visual presentation of a portion of the time base.

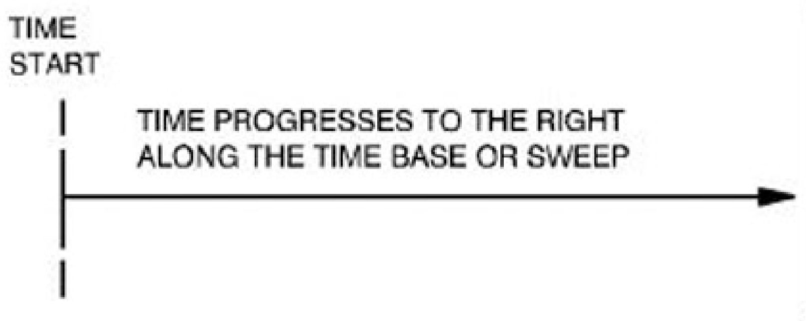


Figure 2–15. Time base.

The following typical controls align the baseline on the display screen.

- *Horizontal position* - adjust so that the horizontal baseline (sweep) begins at the left edge of the display.
- *Vertical position* - adjust so the horizontal time base is at zero position of the vertical scale.

Sweep delay

The sweep delay control determines the part of the time base viewed on the display. It is an area circled to frame the portion of the time base that an inspector wants to view on the instrument display. To adjust the sweep delay, move the frame to the desired portion of the time base. Figure 2–16 displays an example of a CRT screen before adjusting the sweep delay.

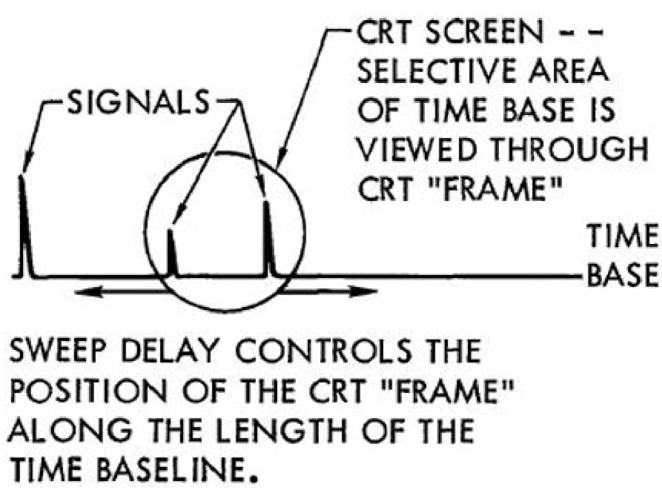


Figure 2–16. Relationship of CRT sweep to time base.

Sweep length (range)

The sweep length (*range*) control represents how much time/distance is on the display. If you adjust the range to decrease the time/distance represented, the spacing between the signals will increase. The range control calibrates the time base to specific distances for measurement purposes. If you adjust the range to decrease the time/distance represented, the spacing between the signals will increase. As shown in Figure 2–17, compare the left side original to the right side after the adjustment.”

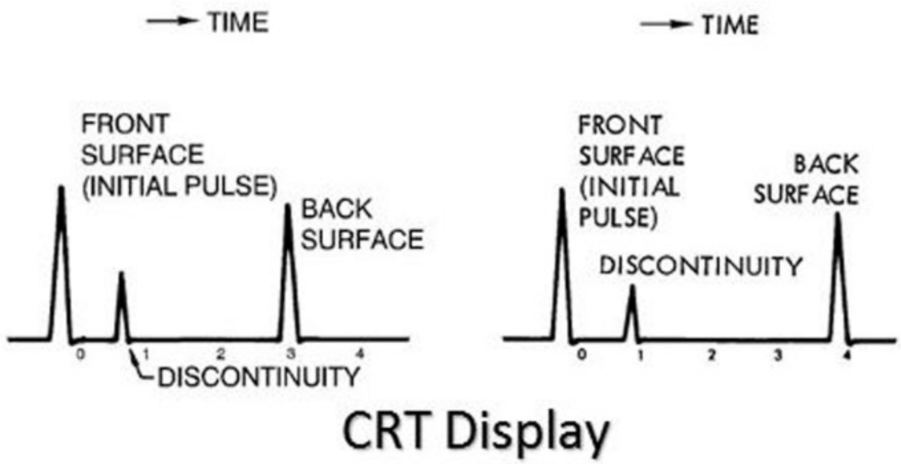


Figure 2–17. Screen display after adjusting sweep and the effect of sweep length.

Zero offset

A zero offset control is a *fine-delay* control used to compensate for transducer faceplate wear. In angle beam inspections with a wedge, or straight beam inspections with a delay line, this control can be used to compensate for the distance the sound beam travels in a plastic wedge or delay line. Essentially, it allows the inspector to set "time zero" for electronic distance calculations to the exact instant the sound pulse enters the part.

Velocity

The velocity control allows the inspector to enter the material velocity of the part under inspection. By entering the velocity in conjunction with proper range and delay settings, the horizontal scale of the display will be automatically calibrated to provide the depth of any discontinuity detected in that particular test part.

Pulser controls

When electronically triggered by the clock circuit, the pulser sends a high voltage spike to the transducer producing the initial pulse. Adjustments of the following pulser controls (if permitted by procedure) more clearly define the discontinuity indications.

Gain

The gain control adjusts the amplitude (height) of signals on the waveform display. A positive increase in the gain control will increase the amplitude of the signals. On most instruments, the gain control calibrates in decibels (dB). The dB expresses the relationship between two signal amplitudes.

For every 6dB increase, the amplitude of a signal doubles. Thus, with an 18dB increase, a signal would have eight times the original amplitude. Conversely, the signal amplitude is cut in half with a decrease of six db.

Reject

The reject control *reduces* irrelevant low-level signals and noise on the waveform display. This often permits easier interpretation of echo signals, but can also obscure wanted signals if applied inappropriately. Most new instruments have linear reject controls that eliminate the low-level signals without affecting the amplitude of the relevant echo signals. The effect of the linear reject control is illustrated in figure 2–18.

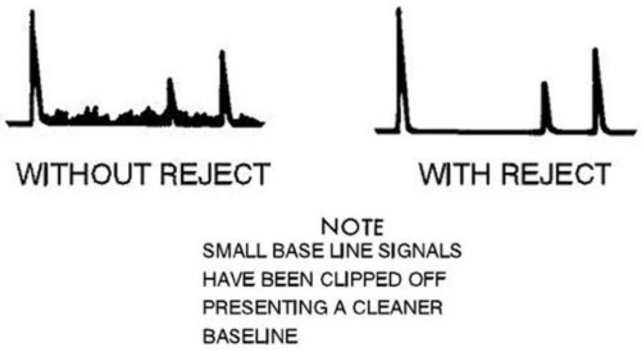


Figure 2–18. Reject control.

CAUTION: The reject control *should not* be set at or above the rejectable signal threshold because this will cause missed defects.

Frequency

The frequency control allows the inspector to select the frequency corresponding to a transducer or to select the broadband mode to cover all frequencies. The selection that gives the best echo signal is normally used.

Single/Dual Transducer

This control configures the transducer-cable receptacles for the following:

- Single-element transducer.
- Dual-element transducer.
- Two separate transducers (used for through-transmission, which is covered later in this section).

The dual position of the control uses both dual-element-transducer and two-transducer inspections. Some instruments specify one receptacle as transmitter and the other as receiver. For single-element-transducer inspections, only one receptacle is used. Consult the instrument manual or procedure for the appropriate use of the connectors.

Distance amplitude correction

Distance amplitude correction (DAC) electronically *compensates* for material attenuation. *Attenuation* is a loss of energy caused by scattering of the sound beam within a material or at an interface. It typically results in decreasing amplitude echoes from equal-size reflectors located at increasing travel distances from the transducer. After you apply a DAC over a particular thickness, all the echoes from reflectors of equal size and in the same orientation within that thickness will display at the same amplitude.

Flaw gates

A gate is an electronic feature that allows an inspector to monitor for discontinuities within specific zones of a test part. A gate appears on the display as a short horizontal sweep above the baseline. The gate can be adjusted so any signal that appears within the limits of the gate will energize an audible or visual alarm alerting the inspector to a possible flaw. Controls for the gate on the display are as follows:

- *Gate start* - used to adjust the location of the leading edge of the gate on the display.
- *Gate width/length* - used to adjust the width of the gate or the location of the trailing edge of the gate.

Threshold/Alarm level

This control adjusts the vertical position of the gate trigger level (accept/reject level).

- *A positive gate* – used when a signal triggers the gate as it *exceeds* the threshold level.
- *A negative gate* – used when a signal triggers the gate as it *falls below* the threshold level.

Negative gates are typically used in back wall procedures, following inspection techniques. Only signals that exceed the level of the gate cause an alarm.

414. Transducers

Transducers serve to convert electrical energy received from the ultrasonic instrument pulser into acoustic energy with piezoelectric elements. The acoustic energy enters the test piece and returns to the transducer where it converts back to electrical energy and returned to the ultrasonic instrument for display. Transducers are available in a great variety of shapes and sizes and discussed in more detail below.

Types of ultrasonic transducers

Contact transducers are typically hand-held and manually scanned in direct contact with the inspection piece. A couplant material is required to ensure sound transmission between the transducer and the test piece. There are two types of transducers discussed in this section, straight beam and angle beam.

Straight beam

Straight beam transducers launch longitudinal sound beams into a test piece and can be used for pulse-echo (one transducer), through-transmission (two transducers), and pitch-catch techniques (tandem). Typically straight beam transducers are used in a pulse-echo mode detecting laminar discontinuities with surfaces lying parallel with the inspection surface. The plastic wedge serves to transmit longitudinal waves to the test part surface where mode conversion produces a longitudinal wave. The basic parts of a typical straight beam transducer used for contact inspection are shown in figure 2–19.

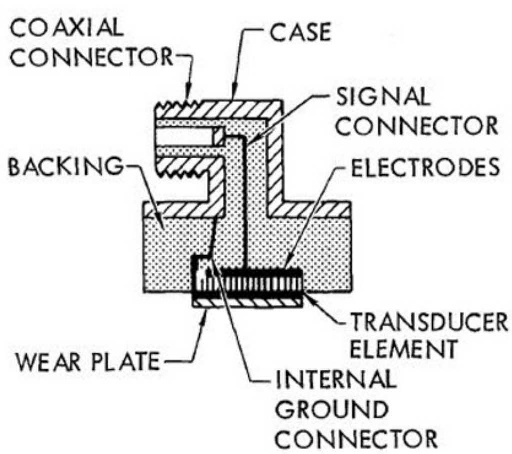


Figure 2–19. Straight beam transducer element.

Angle beam

Angle beam transducers launch shear wave sound beams into a test piece and are typically used for pulse-echo inspections. Typical uses for angle beam transducers include tube, plate, pipe welds, or anywhere there is a need to launch a sound wave at other than parallel to the test piece surface. An angle beam transducer shown in figure 2–20. The plastic wedge serves to transmit longitudinal waves to the test part surface where mode conversion produces a refracted shear or surface wave.

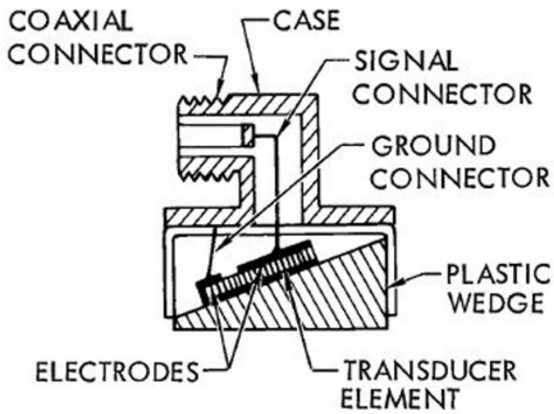


Figure 2–20. Angle beam transducer element.

Transducer sensitivity

Sensitivity is the ability of an inspection system to detect small discontinuities. It has the ability to detect a specified size and depth of a flat-bottom hole in a standard test block. Sensitivity is unique to each combination of transducer and test instrument. The ability to detect small discontinuities is typically increased by using a higher frequency (shorter wavelength).

Transducer resolution

Resolution refers to the ability of an inspection system to *separate* signals from two interfaces *close* together in depth. An example of two such signals is the front surface signal and the signal from a small discontinuity just beneath the surface. The damping or backing material affects the time required for the transducer to stop "ringing" after being excited by a pulse from the test instrument. Low damping causes high "ringing" resulting in a wide, high-amplitude front surface signal. This would cause a long dead zone and a subsequent loss of resolution. Generally, resolution improves with a higher frequency.

Dual transducers (through-transmission)

Dual transducers are used primarily in applications where good near-surface resolution is required. The operation of a typical dual transducer is shown in figure 2–21. The spaces under the transducer elements are usually filled with plastic material that serves as a delay line. Thus, the initial pulse does not interfere with any echoes from the near surface of the test piece. You may also use dual transducers in angle beam inspections.

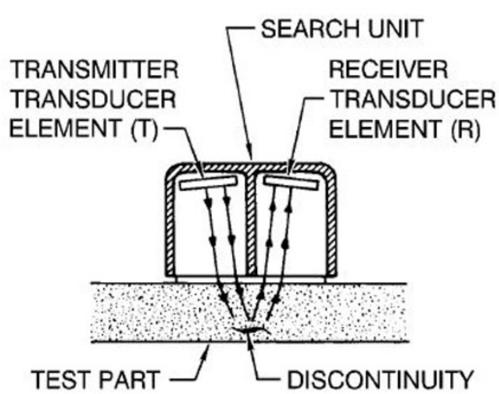


Figure 2–21. Dual transducer.

Delay lines

A transducer may have a solid or a fluid delay line. Delay lines move the part surface *out* of the dead zone, thereby improving near-surface resolution. Because of the increased resolution, delay lines are used extensively for thickness measurements and other applications (e.g., composites) that require a high degree of resolution.

415. Coupling and inspection standards

Couplant is a substance used between the search unit and specimen to permit or improve transmission of ultrasonic energy into the test part. Use any material effective at transmitting acoustic vibrations. Under normal conditions, a contact test cannot be successful without a suitable couplant between the search unit and material.

To ensure consistency of inspections from one inspector to another, many ultrasonic inspection techniques require the use of reference standards for setup and calibration. Both couplant and standards are a huge part of ultrasound inspection.

Couplants

Air is a poor transmitter of sound at the frequencies typically used for ultrasonic inspection. Therefore, to perform an ultrasonic contact inspection, the use of a couplant material is necessary to eliminate the air between the transducer and test piece interface.

NOTE: Do *not* use glycerin, silicones, and graphite greases as couplants unless authorized by specific engineering approval. Couplant materials should meet the following requirements:

- Be able to wet both the face of the transducer and the test part.
- Should not be corrosive or toxic.
- Easily removed.
- Be homogeneous and free of bubbles.
- Be viscous (adhere well) enough to prevent rapid flow off the test part. Typical couplant materials include water, oil, grease, or commercial gels.

NOTE: Avoid water on carbon steel components to prevent corrosion. Avoid petroleum base couplants on fibrous composite materials to prevent matrix degradation.

Inspection standards

Use of ultrasonic inspection standards allows the operator to adjust the instrument controls properly, ensuring that the combination of the instrument and transducer meets the specified sensitivity requirements. Ultrasonic standards can be locally manufactured to specific engineering instructions, an actual failed in-service component, or any one of numerous standard reference blocks.

Standard reference blocks hold dimensions that have been sanctioned and are required by professional organizations or commercial codes. The following paragraphs discuss only typically used standard reference blocks.

American Society of Testing and Materials Standard Reference Block Set

Each Air Force NDI laboratory possess an aluminum alloy American Society of Testing and Materials (ASTM) Standard Reference Block Set. The basic ASTM block set includes ten, 2.0 inch diameter blocks of the same material stock. Each block has a 0.75 inch deep flat-bottom hole (FBH) drilled in the center of the bottom surface.

- One block has a 3/64 inch diameter hole at a 3 inch metal travel distance.
- Seven blocks have 5/64 inch diameter holes at metal travel distances of 1/8, 1/4, 1/2, 3/4, 1.5, 3.0 and 6.0 inches.
- The remaining two blocks have 8/64 inch diameter holes at 3.0 and 6.0 inch metal travel distances.

Each block identifies by a *nine-digit code* (AAAA-B-CCCC). The *first* four digits identify the material alloy, the *center* digit is the diameter of the hole in 1/64 inch, and the *last* four digits are the metal travel distance from the top surface to the bottom of the hole. For example, the block marked (7075–8–0300) is 7075 aluminum and has an 8/64 inch diameter hole with a 3.0 inch metal travel distance.

Area-amplitude blocks

The area-amplitude blocks are intended to establish the correlation between the signal amplitude with the area of a flat bottom hole reflector. These sets of blocks contain flat-bottom holes of differing diameters all at the same distance from the sound entry surface.

There are three blocks with a 3.0-inch metal travel and a 3/64, 5/64 and 8/64 inch which are utilized as an area-amplitude set.

Distance-amplitude blocks

The distance-amplitude blocks are intended to establish the correlation between the signal amplitude with the corresponding distance to a flat bottom hole reflector. These sets of blocks contain flat-bottom holes of the same diameter all at varying distances from the sound entry surface. There are seven blocks with #5 (5/64-inch) flat-bottom holes used as a distance-amplitude set.

International Institute of Welding Blocks

Each Air Force NDI laboratory possess an aluminum alloy and steel, Type 2 International Institute of Welding (IIW) standard reference block. The IIW specifies the material and dimensional requirements of the IIW blocks. The Type 2 IIW blocks are primarily used for measuring the beam exit point and refracted angle of angle beam transducers and for calibrating angle beam metal path distances.

Ultrasonic tests typically used with IIW blocks used for certain know notches and block distances are listed below:

- Straight beam distance resolution.
- Distance calibration.
- Near and far surface resolution.

Miniature angle beam block

This block is a smaller and lighter version of the Type 2 IIW block and can be used for the same purpose; however, near and far surface resolution checks *cannot* be performed with the miniature angle beam block.

Thickness measurement reference standards

Reference standards are required to calibrate instruments prior to thickness inspections as well. The material and heat-treat condition of the reference standards are required to be the same as the test part. The sound velocity in the reference standard also needs to be the same. Thickness measurements of curved and radiuses parts may require standards with the same curvature.

416. Safety and operational maintenance

The laboratory supervisor on a continuing basis to ensure compliance contained in AFI 91–203 and other TO and manual provisions, should review safety requirements. Recommendations of the base bioenvironmental engineer and the manufacturer regarding necessary personnel protective equipment should be followed, as each lab is different.

Precautions when performing ultrasonic inspection include consideration of exposure to electrical current. The following safety requirements should be observed when performing ultrasonic inspections.

Safety precautions

Ultrasonic equipment can safely be used in and around aircraft as long as the following electrical safety guidelines are followed:

- Care should be taken when performing maintenance on *or* around the CRT of equipment.
- Ensure the CRT is electrically discharged according to applicable manufacturer's technical manuals *prior* to performing any maintenance on the equipment.
- Use care *not* to *break* the CRT, since a violent implosion can result.
- Hazards exist when ultrasonic equipment is *not* properly used in some hazardous environments. Consult the local safety office for guidance prior to performing ultrasonic inspections in a hazardous area.

Operational maintenance

Ultrasonic flaw detectors depend on sound preventive maintenance performed on a regular basis. There is no doubt that preventative maintenance *avoids* instrument failure and improves the reliability of ultrasonic instruments. The severity of the environment in which the instrument is used will determine the frequency of inspections and maintenance you perform on your equipment. There are three main aspects of operator maintenance:

- Cleaning the instrument.
- Making a visual inspection.
- Making an electrical inspection (operational check).

Cleaning the instrument

Always keep your equipment and all accessories clean. Following every inspection procedure, clean the ultrasonic unit, transducers, and cables to remove all couplant, grease, or contaminates.

Most new ultrasonic instruments have flush front control panels covered with a protective membrane and no protruding dials or switches. Never use any type of solvent to clean these membranes or any other plastic components. If you do, the membrane or plastic could fog, crack, or otherwise damage the components. Use only water or mild household detergent to clean the equipment.

Battery powered inspection units require additional maintenance to produce consistent, reliable power output. Consult your equipment manual for the specific requirements of your instrument.

Visual inspection

A thorough visual inspection of your equipment is performed to assess the unit for general appearance and cleanliness. When necessary, clean the outer case and CRT face with a mild soap and water solution to present a clean appearance and clear visual presentation. Always repair or replace any loose or broken controls as soon as practical. Replace any frayed cables, especially power cables, before the equipment can be used.

Electrical inspection

Perform operational checks as prescribed by the applicable operation and maintenance manual for your specific piece of equipment. Some electrical checks fall into the criteria of process control. Process control requirements are covered later in this unit of instruction.

If you find any malfunctions or discrepancies *not* covered in the current technical manual *or* the unit does not meet the acceptable criteria given *and* cannot make adjustments, refer to the precision measurement equipment laboratory (PMEL) for assistance. They will determine whether the problem can be fixed locally or if it is necessary to return it to the manufacturer.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

413. Ultrasonic inspection equipment and materials

1. What is used by some menu driven instruments for making adjustments after a control has been selected from the menu?

2. What type of unit display has a vacuum tube containing a screen upon which signals are shown?

3. What is the horizontal base line in which signals are represented?

4. What control on an ultrasonic unit determines what part of the time base is viewed on the display?

5. In straight beam inspections with a delay line, what control can be used to compensate for the distance sound beam travels in a delay line?

6. What ultrasonic unit control makes adjustments (if permitted by procedure) that clearly define discontinuity indications?

7. What is used to adjust the amplitude of signals on a waveform display?

8. What electronically compensates for material attenuation?

9. What is used to adjust the location of the leading edge of the gate on the display?

414. Transducers

1. What converts electrical energy received from the ultrasonic instrument pulser into acoustic energy with piezoelectric elements?

2. What are the two types of ultrasonic transducers?

3. What type of transducers are used in a pulse-echo mode and detect laminar discontinuities with surfaces lying parallel with the inspection surface?

4. What has the ability of an inspection system to detect small discontinuities?

5. What affects the time required for a transducer to stop "ringing" after being excited by a pulse from the test instrument?

6. What type of transducers are required for thickness measurement of thin materials?

415. Coupling and inspection standards

1. What should *not* be used as couplants unless authorized by specific engineering approval?

2. Why are ultrasonic inspection standards used?

3. How deep is an ASTM blocks flat-bottom hole?

4. What do the first four digits stand for on an ASTM standard block code?

5. How many blocks are used in an area-amplitude set?

6. Which ultrasonic tests are typically completed with the IIW block?

416. Safety and operational maintenance

1. What can happen if a CRT screen breaks?

2. What should you do after every ultrasonic inspection procedure?

2–3. Ultrasonic Inspection Application

There are many variables affecting the detection of defects in ultrasonic inspection. When preparing for ultrasonic technique, some factors about the testing situation will be beyond your control. For example, the sides of all parts aren't parallel with complex geometry involved in your sound transmission. If the part to be inspected happens to be a casting with a coarse grain structure, there is nothing you can do to alter this situation.

This section introduces a number of measures that can improve a technique and inspection interpretation to overcome physical limitations. As you study the next few topics, we present a variety of existing solutions to problems you may encounter in technique development.

417. Ultrasound inspection techniques

As with the other NDI disciplines, most ultrasonic techniques used in the field are established at the depot. In certain situations, it may be necessary to develop a technique in the field. If such a need arises, the following information will aid in developing the required techniques. The information may also lead to a better understanding of established techniques.

Familiarization with ultrasonic methods and equipment is obtained by the following:

- Performing familiarization tests included in the instrument manuals.
- Performing calibration procedures.
- Making DAC curves.
- Surface wave familiarization.

Data presentation methods

Data presentation methods are different types of ways to read ultrasonic indications and depend on the type of unit used. Use these three methods for data presentation in ultrasonic inspection:

- A-scan.
- B-scan.
- C-scan.

A-scan

A-scan presentations is a plot of time versus amplitude and is displayed on an ultrasonic instrument in the form of a horizontal baseline that indicates time or distance as seen in figure 2–22. A-scan signals deflect vertically from the baseline to indicate the amplitude of electrical pulses (echoes) received from the transducer. On a calibrated ultrasonic instrument, flaw depth can be determined from the horizontal position of the echo on the baseline. A-scan presentations are the most utilized ultrasonic data presentation method and are also referred to as distance-amplitude presentations.

B-scan

B-scan presentations provide a cross-sectional view of the test piece. This requires a device encoder that plots the time of arrival of the pulse, as a function of the physical location of the transducer. B-scans are typically generated by scanning the transducer at a uniform rate, in a straight line across the surface of the test piece. B-scans may be displayed in real-time on the ultrasonic instrument, an external monitor, or an x-y plotter. An example is shown in figure 2–22.

C-scan

C-scan presentations provide a view of the material and discontinuities therein. This is accomplished by collecting an electronically gated output of an A-scan presentation. The C-scan is generated as the part is scanned in a raster pattern with a manual or automated two-axis scanner. Discontinuities are indicated at positions corresponding to the actual x-y locations of the discontinuities in the part illustrated in figure 2–22. Device encoders to track and relay transducer positions to the recorder or display are required. Typically, video displays are produced after the analog signal is converted to digital data. The display can be adjusted so different colors or shades of gray represent different depths or thickness. C-scan can also display signal amplitudes in various color schemes. Numerous image processing tools may be available to the operator depending on system capabilities. Figure 2–22 shows presentations of all three scans.

Figure 2–22. A-scan, B-scan, and C-scan.

Pulse-echo technique

Pulse-echo testing uses a straight beam to transmit and receive longitudinal sound waves. Two limitations are known to interfere with pulse echo method.

- Dead zone.
- High attenuation.

Dead zone limitations

The dead zone *interferes* with ultrasonic inspection of *near-surface* regions of parts. When required, the coverage of a straight beam inspection in near-surface regions extend by several different techniques, such as the following:

- Inspect the part from opposite sides. You cannot inspect the surface area because of the dead zone from the first side. You will need to inspect both sides of the part to ensure to avoid the dead zone area as shown in figure 2–23.
- Use a dual-element transducer.
- Use a delay line transducer.
- Use an immersion inspection method.

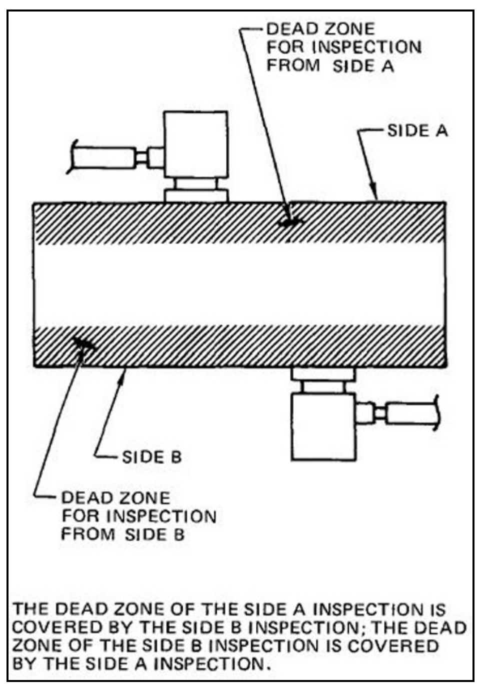


Figure 2–23. Dead zone limitations.

High attenuation

In some cases, when inspecting thick sections, the sound energy in the part drops below usable levels. If this happens, inspecting from opposite sides can help since only half the section thickness needs to be covered in a single inspection. If inspecting from two sides, the zones must overlap by a minimum of 1/2 inch. The through transmission technique may also help alleviate high attenuation limitations.

Through-transmission technique

Through-transmission also uses the straight beam method, but this method requires two transducers, one to transmit the signal, and one to receive the signal. In through-transmission inspection, a transmitting transducer is placed on one surface and the receiving transducer is placed on the opposite surface of the test piece. In this technique, discontinuities block the passage of sound resulting in a reduction of the received signal (fig. 2–24). Since the echoes from the discontinuities are *not* received, the depth of information *cannot* be determined.

Through-transmission encounters two problems:

- Beam alignment.
- Part geometry.

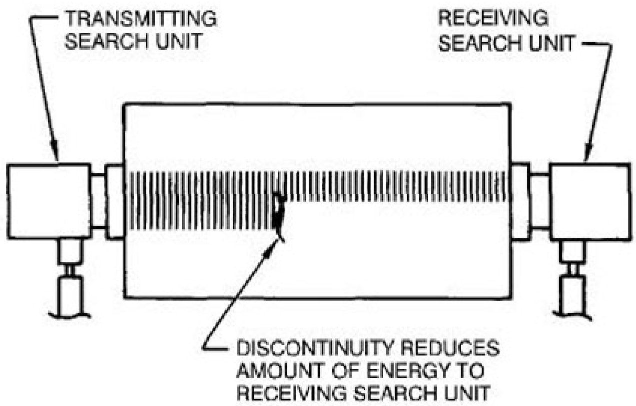


Figure 2–24. Through-transmission inspection.

Beam alignment

A major problem encountered with through-transmission testing is maintaining alignment of transducers. Misalignment can reduce the amplitude of the received signal. Anything causing the received energy to drop suddenly can be misinterpreted as a defect. The through-transmission technique is useful when insufficient energy is obtained with the pulse-echo method and can be applied to inspect thick materials (distances up to 80 feet have been inspected). The through-transmission technique also inspects *thin* test parts when the dead zone *prevents* an inspection with the pulse-echo method.

Part geometry

The straight beam technique is used to detect discontinuities with at least one surface oriented parallel to the test surface. Typical discontinuity examples are laminations, corrosion, high-and low-density inclusions, porosity, forging bursts, and cracks. Applications of the straight beam technique depend upon the test part geometry.

Angle beam technique

This method generally uses shear waves refracted in the test part at angles of 30°–70°. It is used extensively in field nondestructive inspections and can provide for inspection of areas with complex geometries or limited access. This is because angle beams can travel through a material by bouncing from surface to surface. Useful inspection information can be obtained at great distances from the transducer.

Angle beam inspections are particularly applicable to inspections around fastener holes, inspection of cylindrical components, examination of skins for cracks, and inspection of welds. Figure 2–25 shows a typical angle beam inspection.

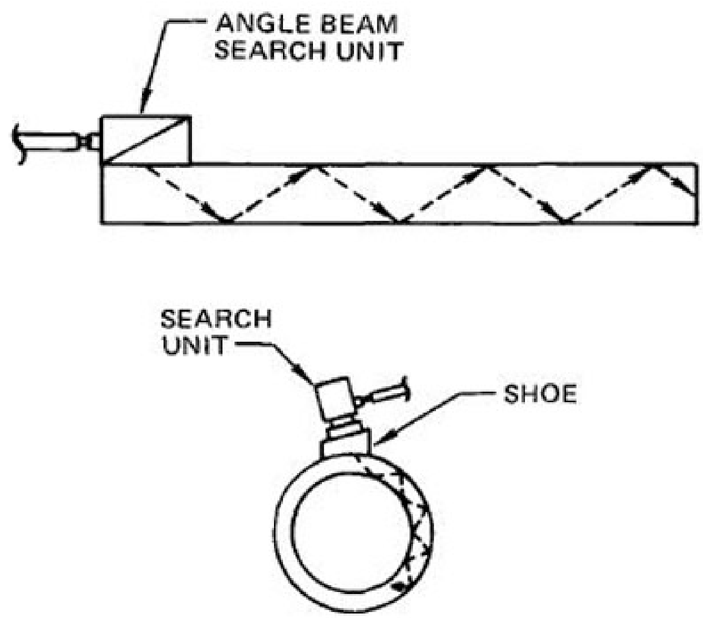


Figure 2–25. Angle beam inspection.

Surface wave technique

This technique uses surface waves refracted in the test part at an angle of 90°. These waves propagate such that they must be bound by air along the surface of the test specimen as seen in figure 2–26.

Surface wave inspections are utilized in many NDI applications involving surface cracks or slightly subsurface discontinuities. On smooth surfaces, sound energy can travel long distances with little energy loss. Surface waves travel around curved surfaces. They reflect at sharp edges. Complete reflection does not occur even at sharp edges.

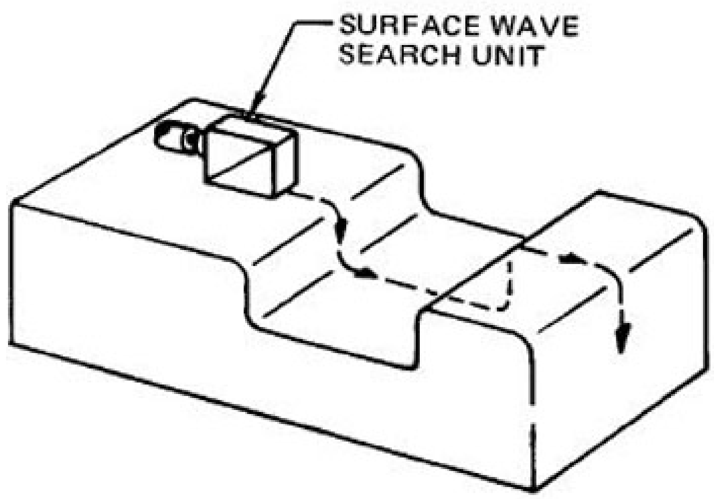


Figure 2–26. Surface wave inspection.

Lamb wave technique

If the thickness of a test part is less than one wavelength of the sound introduced at the appropriate incident angle, lamb waves travel between the two parallel surfaces of the part. This is a special technique not widely used.

Distance amplitude correction curve

DAC is not a process control, but is used when it is necessary to compensate for sound attenuation with increasing metal travel distance. Many instruments have built-in DAC features, in these cases; follow the instructions in the operator's manual for establishing a DAC curve.

A DAC curve is usually not necessary for surface wave inspections, because the transducer can generally be moved back and forth from a discontinuity to maximize the signal. If a DAC curve is needed for a surface wave inspection, it can be easily established. The transducer is placed at a few points at different distances from the reference standard reflector. At each point, the peak amplitude is measured and marked on the display. A smooth curve is then drawn through the points as in the straight beam and angle beam procedures as seen in figure 2–27.

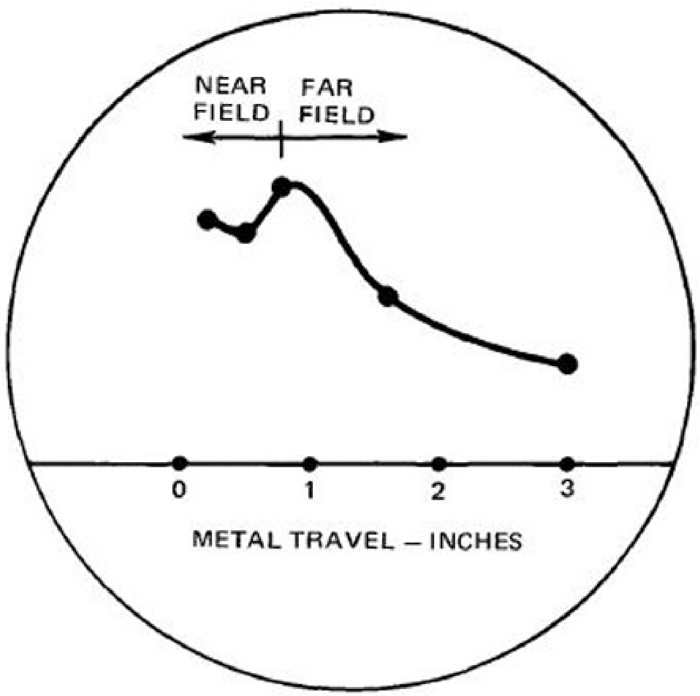


Figure 2–27. DAC curve.

418. Inspection interpretation

When a discontinuity indication is found, it is desirable to learn as much as possible about the discontinuity (or discontinuities). Information on the following helps determine the seriousness of a discontinuity.

- Location.
- Size.
- Orientation.
- Spacing.

Discontinuity location

An indication on the waveform display determines the location of a discontinuity and compares it to the positions of indications from known reflectors, such as the front and back surface. For angle beam inspections, the position is determined by first finding the angle of the refracted beam and then performing a distance calibration as shown in figure 2–28. With this information, the beam path and distance to the discontinuity in the test part is determined. It is often helpful to use a cross-sectional sketch of the test part and draw the beam path on the sketch.

For surface wave inspections, the location of a discontinuity is easily determined by wetting a finger with couplant, and then moving the finger along the test part surface away from the transducer. The wet finger will damp the surface waves (called *damping*), and the discontinuity signal will be reduced in amplitude until the finger moves just past the discontinuity. By noting when the discontinuity signal first starts to increase in amplitude, the location of the discontinuity is determined. A distance calibration can also be easily set up for surface waves.

To see the angle beam location, place a transducer on a test part at a known distance away from a reflector (such as an edge of the test part) or at a known distance from a reflector on the IIW block. Watch the screen display for the signal location.

Discontinuity size

The size of a small discontinuity is measured by the maximum signal amplitude produced by the discontinuity. The amplitude from a small discontinuity is proportional to the cross-sectional area of the discontinuity, if the discontinuity is oriented normal to the sound beam. Since natural discontinuities usually have irregular shapes and rough surfaces, determination of the actual size of small discontinuities may not be possible with ultrasonics; therefore, estimating the size of small discontinuities by comparing their signal amplitude with the signal amplitude of reference standard discontinuities is subject to errors.

Estimating the size of discontinuities larger than the sound beam is done by moving the transducer over the discontinuity, and mapping the extremities of the discontinuity. The *outer* edges of discontinuities can be assessed by noting the positions of the center of the transducer when the signal amplitude from the discontinuity is *reduced* to ½ its peak value. This procedure estimates the projected area of discontinuities in a plane perpendicular to the incident sound beam.

Discontinuity orientation

In evaluating discontinuities, it is helpful, to evaluate the discontinuities from several different directions. This can be accomplished by using a combination of angle, and straight beam methods, or sound entry from different surfaces. Inspecting in these various directions reveals more about the discontinuity. The direction where the highest amplitude signal is obtained is most nearly perpendicular to the plane of the discontinuity for equivalent distances. If the discontinuity signal changes very little with changing direction, the discontinuity is probably rounded. The sound scattered from a rounded discontinuity is independent of the incident direction. A flat discontinuity gives a maximum reflection when the incident sound beam is perpendicular to the discontinuity.

Loss of back reflection and multiple indications

Close small discontinuities can produce multiple indications often accompanied by the loss of back reflection. An example of how large grain size or porosity can produce multiple indications and reduce the amplitudes of back-reflection multiples are shown in figure 2–29. It is necessary to change the A-scan settings to check for both the effects, because the back surface signal saturates the display at the gain setting that shows the multiple indications. By lowering the gain and lengthening the sweep range, the decreasing amplitude of multiple back reflections is observed. The rate of amplitude decrease of the back reflection signal will be greater than an area with no discontinuities.

A number of factors can cause loss of back reflection with no other indications:

- Large grain size.
- Porosity.
- Dispersion of precipitated particles in the material.
- Overheated structure.

Lowering the frequency will generally reduce multiple indications when shown on a display. The rate of decrease in the amplitudes of the back reflection signals will be greater for an area with no discontinuities. When either multiple indications or loss of back reflection is noted, compare the test part with the reference standard.

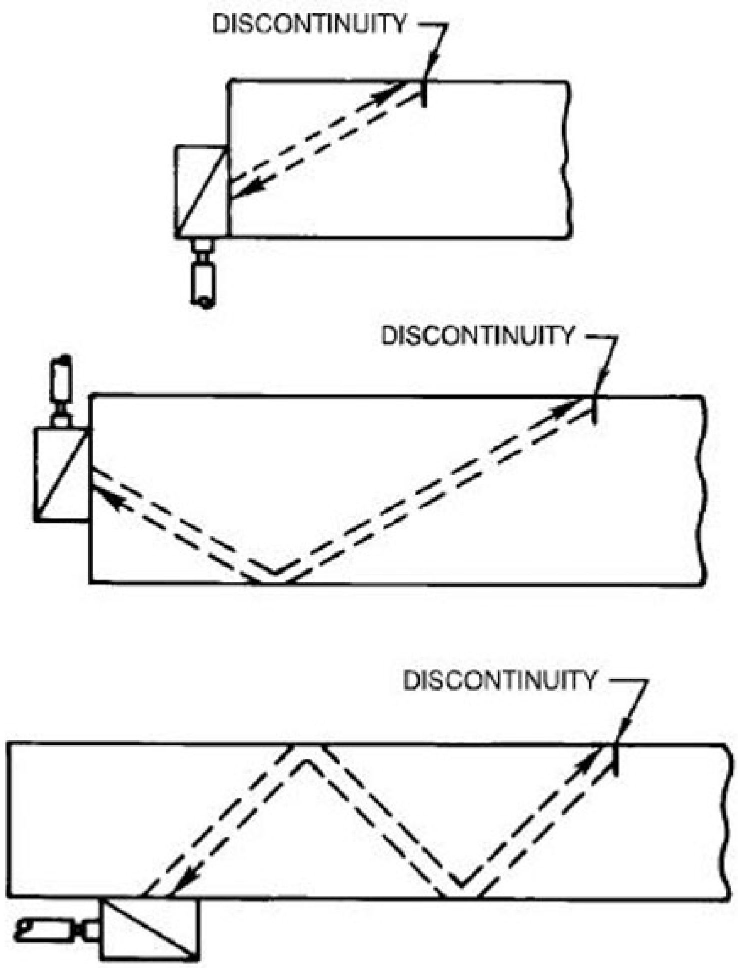


Figure 2–28. Angle beam discontinuity location.

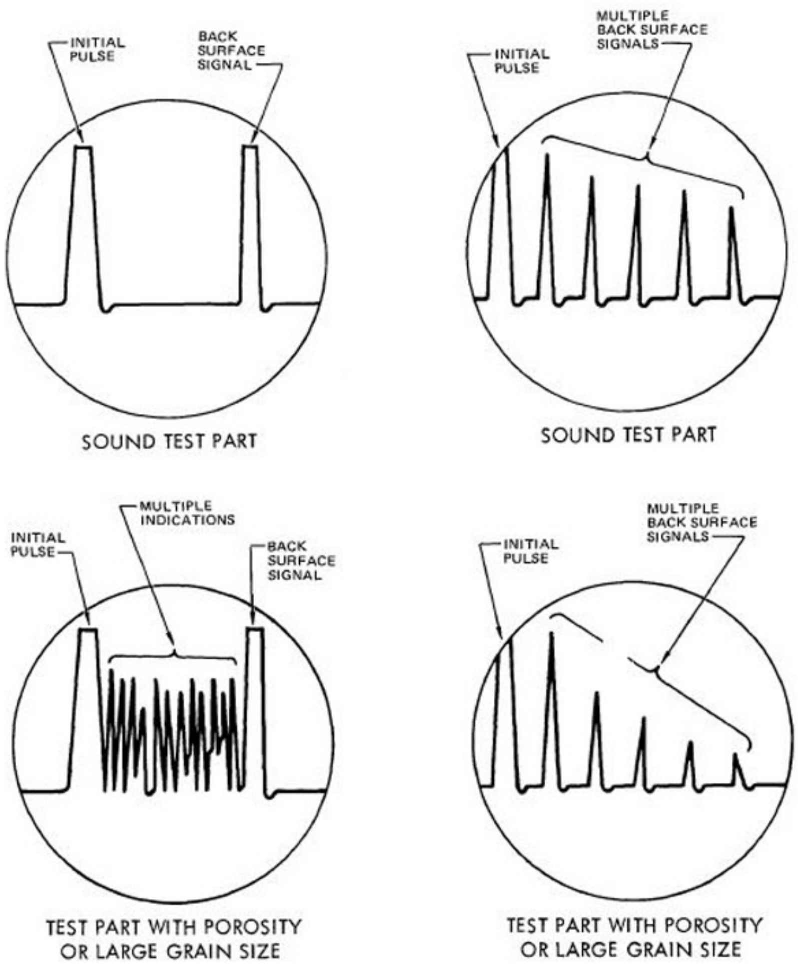


Figure 2–29. Multiple indications and decrease in multiple back reflections caused by large grain size or porosity.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

417. Ultrasound inspection techniques

1. What are the three data presentation methods in ultrasonic inspection?

2. Which data presentation is a plot of time versus amplitude and is displayed on an ultrasonic instrument in the form of a horizontal baseline that indicates time or distance?

3. Which data presentation may be displayed in real-time on the ultrasonic instrument, an external monitor, or an x-y plotter?

4. Which data presentation uses encoders to track and relay transducer positions to a recorder or display?

5. What two limitations are known to interfere with the pulse echo method?

6. Which ultrasound technique uses the straight beam method and requires two transducers to transmit and receive signals?

7. What reduces the amplitude of the received signal making inspection difficult during through-transmission technique?

8. Angle beam technique uses shear waves refracted in the test part at what angles?

9. Complete reflection *does not* occur even at sharp edges in this ultrasonic technique.

10. What is usually not necessary for surface wave inspections, because the transducer can generally be moved back and forth from a discontinuity to maximize the signal?

418. Inspection interpretation

1. When you wet a finger with couplant and move it along the test part surface away from the transducer making the discontinuity signal reduce amplitude, you are doing what?

2. What measures the maximum signal amplitude produced by a discontinuity?

3. If the discontinuity signal changes very little with changing direction, the discontinuity is probably?

4. What factors can cause loss of back reflection with no other indication during your inspection?

2–4. Ultrasonic process controls

Ultrasonic process control checks concentrate on ensuring the equipment used can properly detect and display signals from defects sought. Effective process control relies on the use of ultrasonic standards to isolate any potential problems with the ultrasonic instrument or transducers. All of the information in this section is designed to help ensure accuracy and repeatability of ultrasonic inspections.

All ultrasound tests and procedures will be followed in detail by new inspectors. It is recommended that the procedures be run through several times. The inspector should experiment with various combinations of specimens and transducers to become familiar with different ultrasonic inspection procedures and equipment.

419. System process controls

In the ultrasonic inspection process, like all other processes, you must know your equipment is functioning properly. The frequency of process control checks on equipment should come from the system operations manual or technical data. The operator is the critical link in this process. Even if all the equipment is working properly, the inspector must follow the written procedure and use the correct standard. Deviations *will not* be made without proper engineering authority.

NOTE: TO 33B–1–2 *Nondestructive Inspection General Procedures and Process Controls.* WP 105 00 states the *minimum* interval frequencies for process control checks on equipment and transducers.

All inspections include the use of one or more reference standards for setting up an inspection. In addition, compare all discontinuity indications to reference standards by comparing the signal amplitude of the discontinuity with the signal amplitude of the reference standard. According to TO 33B–1–2 *Nondestructive Inspection General Procedures and Process Controls all* ultrasound process controls are completed *quarterly*. Ensure you use the appropriate TO and manual for specific unit set up for specific inspections.

System (equipment) checks

The *most* important system check is the calibration or standardization of each inspection setup with applicable reference standards. An ultrasonic system consists of the instrument, search unit (transducer) and the coaxial cable. It is critical to calibrate or standardize your equipment before each inspection. Additionally, general calibration procedures ensure the system is within the parameters required to perform ultrasonic inspections. Perform system checks and document results when an operator suspects a problem with equipment as well as at specific intervals as directed. The three system process controls include the following:

1. System linearity.
    a. Vertical linearity.
    b. Horizontal linearity.
2. System sensitivity.
3. System resolution.
    a. Entry surface resolution.
    b. Back surface resolution.

System linearity limits

The *upper linearity limit* is the level of vertical deflection defining the greater limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of a known size.

The *lower linearity limit* is the level of vertical deflection defining the lesser limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of known size.

The *horizontal limit* is the *maximum readable* length of horizontal deflection determined either by an electrical or physical limit in the A-scan presentation of an ultrasonic testing instrument. Horizontal limit is expressed as the maximum observed deflection in inches from the left side or the start of the horizontal line representing the time base.

Vertical linearity (ASTM blocks)

The following table outlines general procedures for vertical linearity.

Vertical Linearity	
Step	**Description**
a	Use three ASTM blocks with 3 inch metal travel distance, one each with a 3/64, 5/64, and 8/64 inch diameter FBH.
b	Move the search unit over the surface of the 5/64 FBH block until a maximum response is obtained.
c	Leave the gain fixed; maximize the FBH signal on the 3/64 and 8/64 FBH blocks. Record the FBH signal amplitudes. If the instrument is linear, the signals from the 3/64 and 8/64 FBH's will be 13% ±3% and 90% ±5% of saturation.
d	Replace or repair instruments not linear (within the above limits).

Horizontal Linearity (Type 2 IIW Block)

The horizontal linearity range is the range of horizontal deflection in which a constant relationship exists between the incremental horizontal displacement of vertical indications on the A-scan presentation and the time required for reflected waves to pass through a known length in a standard.

The following table outlines general procedures for horizontal linearity.

Horizontal Linearity	
Step	**Description**
a	Use the IIW block and a straight beam transducer. Place the transducer on the IIW block shown in figure 2–30.
b	Adjust the gain so that the second back reflection achieves 95% FSH (Figure 2–30) and the range to obtain six back reflections on the display screen. The first back reflection should be located at the left side of the screen (the initial pulse should be off the screen), and the 6th back reflection should be located at the right side of the base line.
c	Measure the distance between the leading edge of adjacent back reflections by moving the first gate to the next back reflection. The second gate will move with first gate if the instrument settings are entered correctly. *Ideal* horizontal linearity indicates an equal distance between the leading edges of subsequent back reflections. If *all* the values are *equal* within 3.0% of the FSW, the instrument is *horizontally linear*. Given a 5 inch range, 3% of FSW is 0.150 in; therefore, the acceptable range is 0.85–1.15.

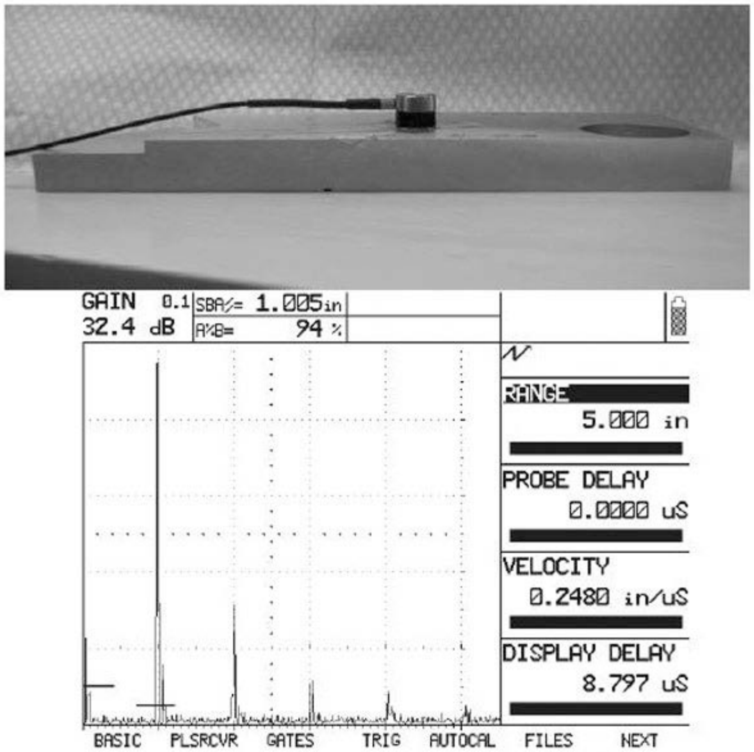


Figure 2–30. Horizontal linearity with IIW block.

System sensitivity (ASTM blocks) (5MHz and below)

Sensitivity is a measure of the ability of the inspection system (e.g., instrument and transducer) to detect discontinuities producing relatively low-amplitude signals because of the size, geometry, or location of the discontinuities. Noise can limit the ability to detect discontinuities by masking their indications.

The following table outlines general procedures for system sensitivity.

System Sensitivity	
Step	**Description**
a	Use the ASTM 0300 reference blocks with FBH.
b	Select the 0300 ASTM block with the appropriate FBH. Obtain a peak signal from the appropriate FBH.
c	Adjust the gain control of the instrument until the discontinuity indication is 60 percent of FSH, then add the dB (Gain) compensation as required.
d	The noise should be no higher than 20 percent of FSH. The noise threshold does not change when using ASTM blocks requiring additional gain.

System resolution

Resolution is the *minimum* spacing between discontinuities for which separate and distinct ultrasonic echo signals are obtained. Spatial resolution refers to the lateral separation of discontinuities. Depth resolution refers to depth separation between internal discontinuities or a discontinuity and a boundary surface. The following procedures are concerned only with entry and back surface resolutions, which are defined as the inspectable distances nearest to the respective surfaces of the test material.

Entry surface resolution (dead zone) (Type 2 IIW block)

The following table outlines general procedures for entry surface resolution or dead zone check.

<table>
<tr><th colspan="2">Entry Surface Resolution</th></tr>
<tr><th>Step</th><th>Description</th></tr>
<tr><td>a</td><td>Position the transducer on a Type 2 IIW block at P–1 or P–2 as shown in figure 2–31.

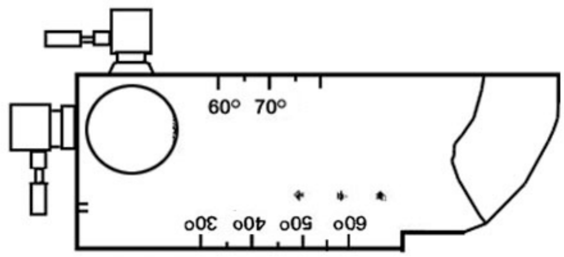
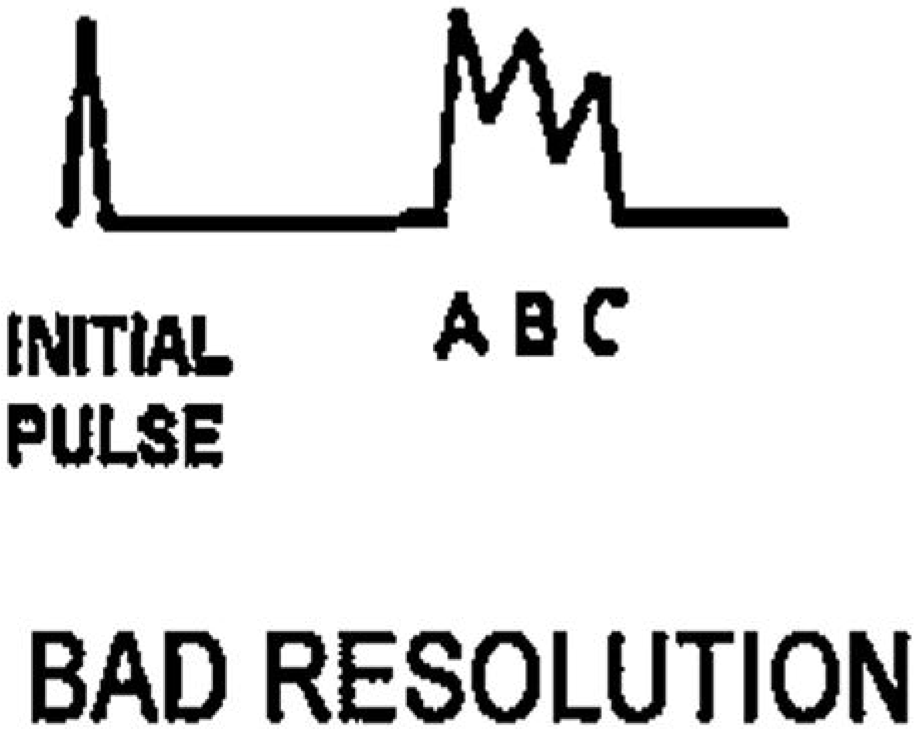


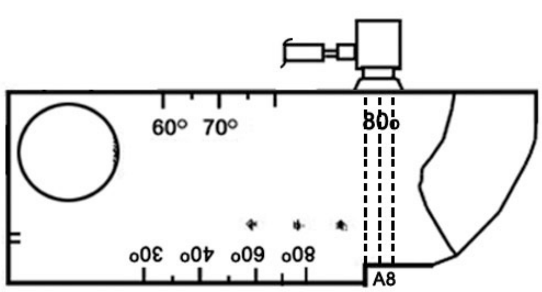
Figure 2–31. Entry surface resolution with Type 2 IIW block.</td></tr>
<tr><td>b</td><td>Adjust the gain, so that the first back reflection is 90%– 95% FSH, to display the separation between the initial pulse and the hole signal. Evaluate the signal pattern according to the criteria given in Figures 2–32 and 2–33.

Figure 2–32. Good entry surface resolution.</td></tr>
</table>

Entry Surface Resolution	
Step	**Description**
	 **Figure 2–33. Bad entry surface resolution.**
c	The first echo from the edge of the hole should be completely separate from the initial pulse. The initial pulse should return to the baseline, as shown in the good example above in figure 2–33.

Back Surface Resolution (2.25 MHz and above) (Type 2 IIW Block)

The following table outlines general procedures for *back* surface resolution used *with* a 2.25MHz transducer *or above*.

Back Surface Resolution	
Step	**Description**
a	Use Type 2 IIW block and maximize the separation of the signals from the reflectors A, B, and C (fig. 2–34).  **Figure 2–34. Back surface resolution check with the Type 2 IIW block.**

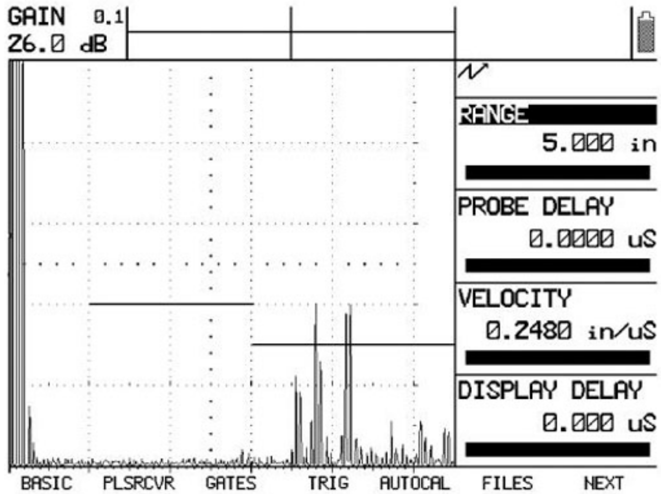
<table>
<tr><th colspan="2">Back Surface Resolution</th></tr>
<tr><th>Step</th><th>Description</th></tr>
<tr><td>b</td><td>Evaluate the resolution by matching the signal patterns. Good resolution is indicated by the respective signals returning to the baseline shown in figures 2–35 and 2–36.


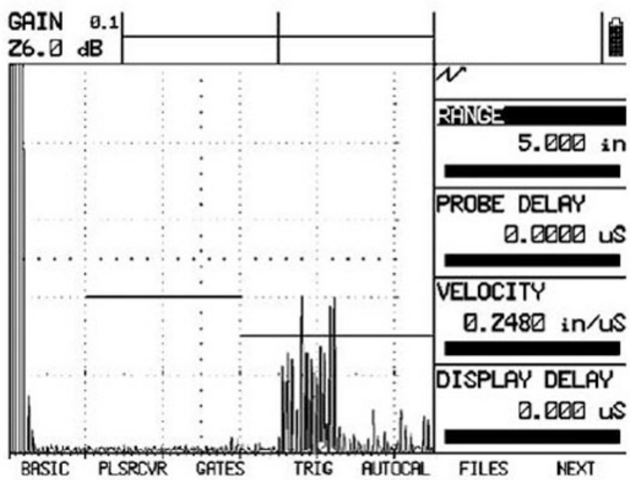
Figure 2–35. Good back surface resolution.


Figure 2–36. Bad back surface resolution.</td></tr>
</table>

420. Transducer process controls

It is also important to verify that your daily transducers are working correctly. Frequency of transducer inspections are determined by the amount of use. It will save you a lot of time in the end by doing process controls in the specified time. You do not want to be called out to do a flightline inspection and find out that the transducers do not work.

Transducer checks

The angle of new and used ultrasonic transducers should be maintained *within 2 degrees* of what is *required* to perform an ultrasonic inspection. Transducers that do not fall within this parameter should not be used to perform ultrasonic inspections. If possible, transducers out of tolerance shall be reworked within parameters to extend their usefulness. The rework procedure consists of wet sanding the wear plate/wedge very slowly using 600 grit or finer sandpaper, or equivalent emery cloth.

Transducer verification process control checks include the following:

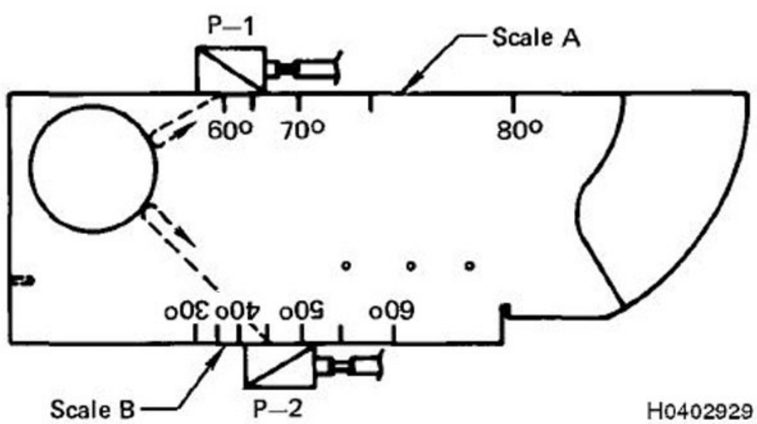
1. Angle beam checks.
    a. Angle beam angle determination (Type 2 IIW block).
    b. Angle beam angle determination (miniature angle beam block).
2. Point of incidence (POI).
    a. Angle beam POI (Type 2 IIW block).
    b. Angle beam POI (miniature angel beam block).
3. Angle beam misalignment (Skew angle).

Angle beam checks

Accomplish calibration prior to angle beam inspection with the use of Type 2 IIW standard block or the miniature angle beam block.

Angle beam angle determination (Type 2 IIW block)

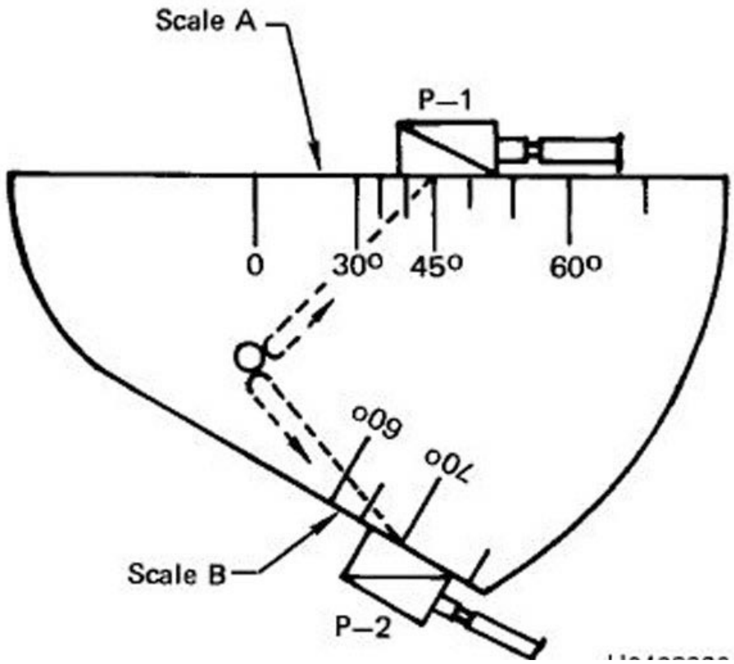
The following table outlines general procedures for angle beam, angle determination with the Type 2 IIW block.

Angle Beam Angle Determination (Type 2 IIW Block)	
Step	**Description**
a	Position the transducer on scale A or B, as appropriate and as shown in figure 2–37. Move the transducer back and forth until the peak signal from the hole is obtained.  **Figure 2–37. Angle determination with Type 2 IIW block.**
b	Read the refracted angle from the position on scale A or B coinciding with the point-of-incidence. The refracted angle should be + or –2-degrees of the angle identified on the wedge or transducer.

Angle beam angle determination (miniature angle beam block).

The following table outlines general procedures for angle beam determination with the miniature angle beam block.

Angle Beam Angle Determination (Miniature Angle Beam Block)	
Step	**Description**
a	Position the transducer on scale A or B as shown in figure 2–38. Move the transducer back and forth until the peak signal from the hole is obtained.

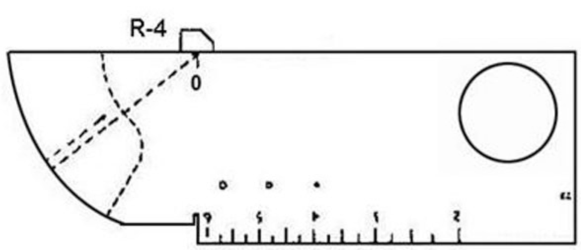
Angle Beam Angle Determination (Miniature Angle Beam Block)	
Step	**Description**
	 **Figure 2–38. Angle determination with miniature block.**
b	Read the refracted angle from the position on scale A or B coinciding with the point-of-incidence of figure 2–38 and P–2 shows 70° P–1 shows 45°. The refracted angle should be + or – 2 degrees of the angle identified on the wedge or transducer.

Angle beam point of incidence

The POI is defined as the center point of the sound beam exiting the transducer wedge. A *mark* on the side of the transducer indicates the point where an imaginary line through the exit point of the beam *intersects* the side of the wedge.

Angle beam point of incidence (Type 2 IIW block)

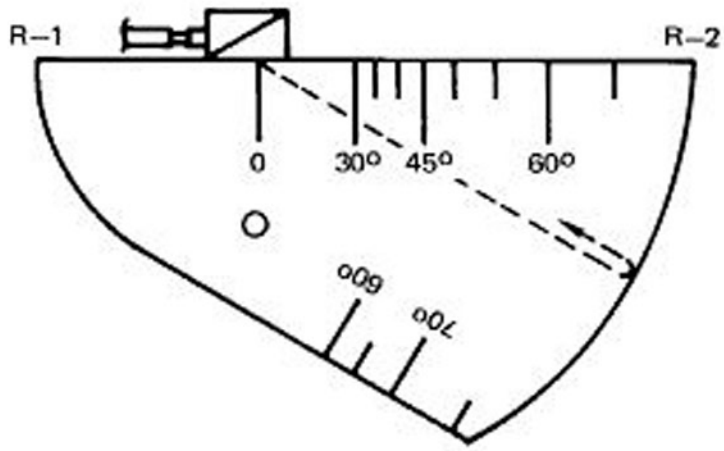
The following table outlines general procedures for angle beam POI with the Type 2 IIW block.

Angle Beam POI (Type 2 IIW Block)	
Step	**Description**
a	Move the transducer back and forth from the curved surface at R–4 (see figure 2–39) until the peak signal is obtained.  POINT OF INCIDENCE **Figure 2–39. POI determination with IIW Block.**
b	Mark the transducer on the side corresponding to the line marked 0 on the block. This is the POI.

NOTE: Use the steel Type 2 IIW block or steel miniature block for testing POI on all shear wave transducers over 45° intended for aluminum inspections.

Angle beam Point-of-Incidence (miniature angle beam block)

The following table outlines general procedures for angle beam POI with the miniature angle beam block.

Angle Beam POI (Miniature Angle Beam Block)	
Step	**Description**
a	Move the transducer back and forth from the curved surface at R–2 (fig. 2–40) until the peak signal is obtained.  **Figure 2–40. POI determination with miniature angle beam block.**
b	Mark the transducer on the side corresponding to the line marked 0 on the block. This is the POI.

Angle beam misalignment (skew sngle) (Type 2 IIW block)

Skew angle is a measure of the misalignment angle between the ultrasonic beam and the search units' axis of symmetry.

The following table outlines general procedures for angle beam misalignment or commonly called the skew angle.

Angle Beam Misalignment (Miniature Angle Beam Block)	
Step	**Description**
a	Lay the Type 2 IIW block flat on the side and adjust the transducer to maximize the echo from the bottom corner of the block (Figure 2–41). The corner of the block where there are no scale engravings should be used.

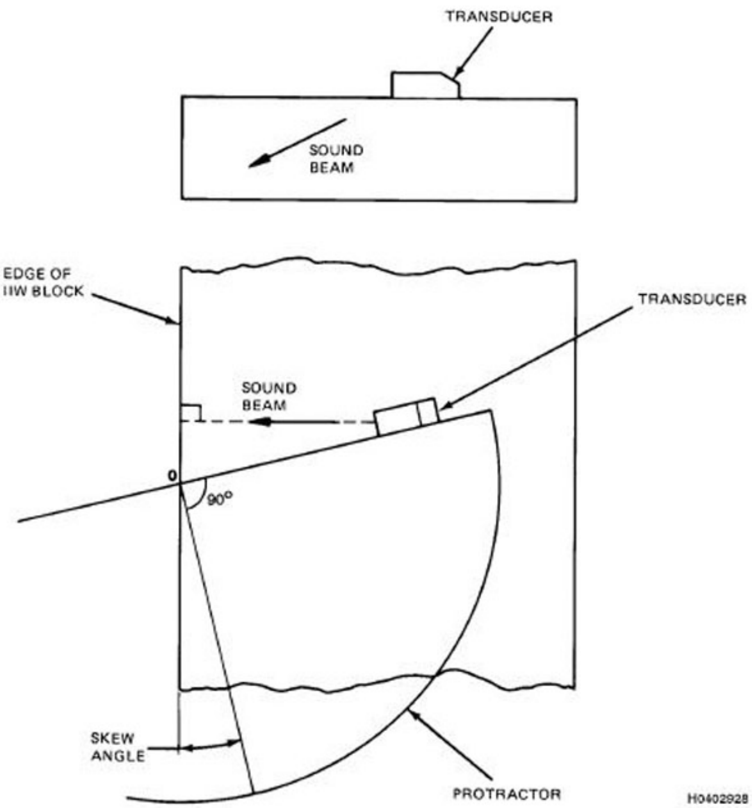
<table>
<tr><th colspan="2">Angle Beam Misalignment (Miniature Angle Beam Block)</th></tr>
<tr><th>Step</th><th>Description</th></tr>
<tr><td></td><td>


Figure 2–41. Skew angle measurement.
</td></tr>
<tr><td>b</td><td>
Place a protractor on the block, as shown in figure 2–42, and measure the skew angle. The skew angle of new and used ultrasonic transducers should be maintained within 2 degrees of the probe symmetry axis.

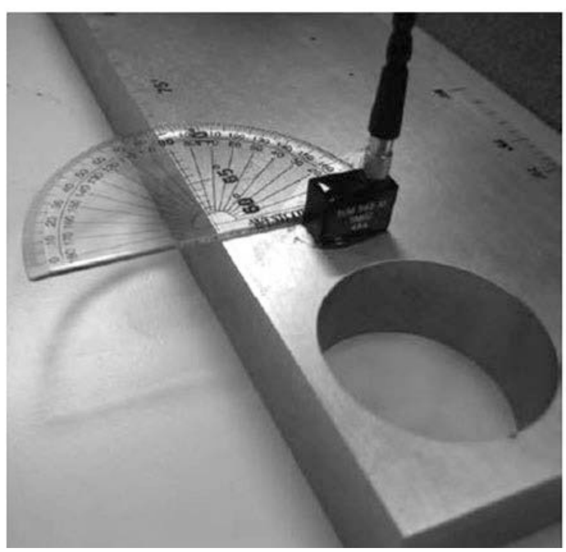


Figure 2–42. Skew angle measurement positioning.
</td></tr>
</table>

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

419. System process controls

1. What tells you the frequency of process control checks on ultrasound equipment?

2. What is the most important part of the system check?

3. What are the ultrasonic system process control checks?

4. What is the level of vertical deflection that defines the greater limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of a known size?

5. Which process control uses three ASTM blocks with 3 inch metal travel distance, one each with a 3/64, 5/64, and 8/94 inch diameter FBH?

6. When adjusting the gain during horizontal linearity check, what percent of FSH is the second back reflection?

7. What refers to the lateral separation of discontinuities?

420. Transducer process controls

1. What tells the frequency of your transducer process control inspections?

2. What are the transducer verification process controls?

3. What should the refracted angle be during the angle beam angle determination (Type 2 IIW block) check?

4. What is usually indicated by a mark on the side of the wedge at the area where an imaginary line through the exit point of the beam intersects the side of the wedge?

5. Which standard uses POI on all shear wave transducers over 45° for aluminum inspections?

6. What is a measure of the misalignment angle between the ultrasonic beam and the search units' axis of symmetry?

Answers to Self-Test Questions

410

1. To inspect almost any material, to locate discontinuities from large disbonds, down to the smallest defects, to measure the overall thickness of a material, and to find a specific depth of a defect.
2. Maximum displacement.
3. The amplitudes.
4. Velocity.
5. λ (lambda) = v/f.
6. A coupling medium (e.g., oil, grease, or water).
7. 2.25 MHz and 10 MHz.
8. The size of the defect detected.

411

1. Compression and rarefaction.
2. Longitudinal, transverse, shear, and lamb.
3. Longitudinal.
4. The motion of waves in which the particle motion is perpendicular to the direction of a part.
5. Surface or rayleigh waves.
6. Surface waves.
7. Lamb waves.
8. Refraction, reflection, and mode conversion.
9. Mode conversion.
10. Snell's Law.
11. The angle of incidence.

412

1. Side lobes.
2. Dead zone.
3. Near field.
4. Far field.
5. Compare discontinuity signals with signals from reference standards.
6. Because in certain inspection applications, the spreading sound beam may result in erroneous or confusing presentations by reflecting off of walls or edges.
7. Focused sound beam.
8. Beam intensity.
9. Decibels.

413

1. A single rotary ("smart") knob.

2. Cathode ray tube (CRT).
3. Sweep.
4. The sweep delay.
5. Zero offset control.
6. Pulser controls.
7. Gain control.
8. Distance amplitude correction (DAC).
9. Gate start.

414

1. Transducers.
2. Straight beam and angle beam.
3. Straight beam.
4. Sensitivity.
5. Damping.
6. Transducers with a narrow dead zone and superior near surface resolution.

415

1. Glycerin, silicones, and graphite greases.
2. To allow the operator to adjust the instrument controls properly, ensuring that the combination of the instrument and transducer meets the specified sensitivity requirements.
3. 0.75 inch deep.
4. The material alloy.
5. Three blocks.
6. Straight beam distance resolution, distance calibration, and near and far surface resolution.

416

1. A violent implosion can occur.
2. Clean the ultrasonic unit, transducers, and cables to remove all couplant, grease, or contaminates.

417

1. A-scan, B-scan, and C-scan.
2. A-scan.
3. B-scan.
4. C-scan.
5. Dead zone and high attenuation.
6. Through-transmission.
7. Misalignment.
8. 30°– 70.
9. Surface wave.
10. A DAC curve.

418

1. Dampening.
2. The size of a small discontinuity.
3. rounded.
4. Large grain size, porosity, dispersion of precipitated particles in the material, and overheated structure.

419

1. System operations manual or technical data.

2. The calibration or standardization of each inspection setup with applicable reference standards.
3. System linearity (vertical linearity and horizontal linearity), System sensitivity, and System resolution (entry surface resolution and back surface resolution).
4. The upper linearity limit.
5. Vertical linearity.
6. 95%.
7. Spatial resolution.

420

1. Determined by the amount of use.
2. Angle beam checks, (angle beam angle determination using Type 2 IIW block and miniature angle beam block), Point of Incidence (POI) (angle beam POI using Type 2 IIW block and miniature angle beam block), and Angle beam misalignment (Skew angle).
3. + or –2 degrees of the angle identified on the wedge or transducer.
4. Point of Incidence (POI).
5. A steel Type 2 IIW block or the steel miniature block.
6. Skew angle.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

27. (410) What is the advancement of a wave through a medium by transferring energy from one molecule to another?
    a. Period.
    b. Velocity.
    c. Frequency.
    d. Propagation.

28. (410) Ultrasonic vibrations generate by applying electrical energy to what part of the transducer?
    a. Piezoelectric element.
    b. Test part.
    c. Vacuum.
    d. Wedge.

29. (411) Which wave mode is used extensively for thickness inspections, corrosion thinning, and for the detection of other defects parallel to the inspection surface?
    a. Lamb.
    b. Shear.
    c. Surface.
    d. Longitudinal.

30. (411) What is the angle between an incident longitudinal wave and a line normal to the surface called?
    a. Elastic modulus.
    b. Incident angle.
    c. Reflection.
    d. Refraction.

31. (411) What changes direction of an ultrasonic beam as it passes through the interface between two materials with different acoustic velocity?
    a. Reflection.
    b. Refraction.
    c. Rarefaction.
    d. Mode conversion.

32. (412) Extending from the face of the transducer is an area characterized by wide variations in sound beam intensity known as
    a. far field.
    b. near field.
    c. dead zone.
    d. beam spread.

33. (412) During beam spread, sound extends outward from the transducer and does what to intensity and distance?
    a. Increases in intensity with increasing distance.
    b. Increases in intensity with decreasing distance.
    c. Decreases in intensity with increasing distance.
    d. Decreases in intensity with decreasing distance.

34. (412) Acoustic pressure directly relates to what in the material particle vibrations caused by sound waves?
    a. Intensity.
    b. Frequency.
    c. Amplitude.
    d. Attenuation.

35. (413) What is a fine-delay control used to compensate for transducer faceplate wear?
    a. Range.
    b. Delay.
    c. Velocity.
    d. Zero offset.

36. (413) What *reduces* irrelevant low-level signals and noise on the waveform display?
    a. Gain.
    b. Pulse.
    c. Reject.
    d. Frequency.

37. (413) What electronically compensates for material attenuation?
    a. Distance amplitude correction (DAC).
    b. Single/Dual transducer.
    c. Gate trigger lever.
    d. Reject.

38. (414) What moves the part surface out of the dead zone, thereby improving near-surface resolution?
    a. Reject.
    b. Resolution.
    c. Delay lines.
    d. Contact transducers.

39. (415) Which couplant is authorized for use?
    a. Gel.
    b. Glycerin.
    c. Silicones.
    d. Graphite greases.

40. (415) Which American Society of Testing and Materials (ASTM) block would you use if you have a 7075 aluminum block with a 3/64 inch diameter hole and a 3.0 inch metal travel distance?
    a. 0300−3−7075.
    b. 7075−3−0003.
    c. 0003−3−7075.
    d. 7075−3−0300.

41. (416) What do you do with ultrasonic instruments if you find malfunctions or discrepancies *not* covered in the current technical manual or the unit does *not* meet acceptable criteria and you cannot make adjustments?
    a. Take the unit to precision measurement equipment laboratory (PMEL).
    b. Send the unit back to the manufacturer.
    c. Give it to your supervisor.
    d. Turn the unit into supply.

42. (417) Which data presentation displays signal amplitudes in various color schemes?
    a. A-scan.
    b. B-scan.
    c. C-scan.
    d. D-scan.

43. (417) What ultrasonic technique *inspects thin* test parts *when* the dead zone *prevents* an inspection with another method?
    a. Lamb.
    b. Pulse-echo.
    c. Angle beam.
    d. Through-transmission.

44. (417) Which inspection technique will you use when inspecting around fastener holes, cylindrical components, skins, and welds?
    a. Lamb wave.
    b. Angle beam.
    c. Surface wave.
    d. Through-transmission.

45. (418) Indications on an ultrasonic waveform display determine the
    a. location of a discontinuity.
    b. location of beam spread.
    c. refracted beam angle.
    d. size of a defect.

46. (418) Assess the outer edges of discontinuities by noting the positions of the center of the transducer when the signal amplitude from the discontinuity *reduces* to the value of
    a. ¾ its peak.
    b. ½ its peak.
    c. ¼ its peak.
    d. 1/8 its peak.

47. (419) According to TO 33B−1−2 *Nondestructive Inspection General Procedures and Process Controls*, when do you complete all ultrasonic process controls?
    a. Weekly.
    b. Monthly.
    c. Quarterly.
    d. Semi-annually.

48. (419) What are the three system process controls required for ultrasonics?
    a. Linearity, sensitivity, and resolution.
    b. Sensitivity, angle beam, and linearity.
    c. Skew angle, resolution, and angle beam.
    d. Angle beam, point of incidence (POI), and skew angle.

49. (419) What is the *maximum* readable length of deflection determined either by an electrical or physical limit in the A-scan presentation of an ultrasonic testing instrument?
    a. Time base.
    b. Horizontal limit.
    c. Lower linearity limit.
    d. Upper linearity limit.

50. (419) Instruments are horizontally linear if all the values are equal within
    a. 3.0 percent of the full-scale width.
    b. 5.0 percent of the full-scale width.
    c. 3.0 percent of the full-scale height.
    d. 5.0 percent of the full-scale height.

51. (419) Which reference blocks are used for the system sensitivity check?
    a. Distance-area blocks.
    b. Miniature angle beam block.
    c. International Institute of Welding (IIW) block.
    d. American Society of Testing and Materials (ASTM) Standard Reference Blocks.

52. (419) Which type of frequency transducers are used for the *back* surface resolution control checks?
    a. 1.0MHz or above.
    b. 1.0MHz or below.
    c. 2.25MHz or above.
    d. 2.25MHz or below.

53. (420) The angle of new and used ultrasonic transducers should be maintained within how many degrees of what is required to perform an ultrasonic inspection?
    a. Two.
    b. Four.
    c. Six.
    d. Eight.

54. (420) Which process control has a mark on the side of the transducer indicating an imaginary line through the exit point of the beam that intersects the side of the wedge?
    a. Angle beam point of incidence (POI).
    b. Angle beam angle determination.
    c. Angle resolution.
    d. Skew angle.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Bond Testing

AN ADHESIVE IS A SUBSTANCE that adheres to two materials and bonds them together. Forms of adhesive bonding have been around for centuries. For example, adhesives obtained from bitumen (a type of asphalt) and from tar pits were used as a type of mortar by the builders of the Tower of Babel. In another application, the ancient Egyptians used adhesives made from eggs and tree resin.

Metal bonding was slow to progress and there were few advances in adhesive metal bonding technology until World War II. At that time, military needs resulted in great technological progress. Following World War II, lightweight aircraft designs using metal and honeycomb construction required the development of new methods to join and fasten structural members. One of the first developments was the formulation of adhesive from phenolic resin and neoprene rubber. Today, these adhesives join load-bearing components on aircraft. This has a great advantage of reducing concentrated stress, such as around rivets. Fatigue crack formation around conventional fasteners has been eliminated and adhesives have replaced fasteners.

The use of adhesives is now common in the manufacture of everything from toys to residential building materials to modern spacecraft.

NDI focuses on inspection of the adhesive bond itself, usually after the part has been in service for some time. The purpose of this unit of instruction is to introduce you to bonded structures, familiarize you with the various NDI bond-testing methods, and provide you with knowledge regarding the equipment you will use to perform bond inspection methods.

3–1. Principles and Standards of Bond/Composite Testing

A composite or bonded structure is one consisting of two or more material components adhesively bonded together. The individual components may be metallic or nonmetallic and contain honeycomb or other lightweight core material. Carbon/epoxy composites are bonded structures although the layers are only a few thousandths of an inch thick and lose their individual identity as the materials cure together. Delaminations or separations between individual layers can occur and be detected ultrasonically.

In this section, we will present the terminology and principles involved in bonding and bond testing, use of standards and typical defects. We will also introduce a new NDI technique called shearography used for inspecting bonded structures. Your understanding of the material we present could directly affect your ability to perform bond testing correctly.

421. Bonded structures

There are vast numbers of bonded structures and configurations used in the Air Force today. To enable you to describe disbonds, delaminations, or other discontinuities to repair technicians, you will need to understand each part of the bonded structure.

NOTE: It is beyond the scope of this career development course (CDC) to cover every known method of bond testing. Because of this, we only cover the general and specific tests you are likely to use.

Bonded structures

A bonded structure is one consisting of two or more components adhesively bonded together. The structure can be all metallic or nonmetallic, or it can consist of both types of material. A bonded structure can contain honeycomb or other type of lightweight core. Sheets of metal or nonmetal can be bonded together to provide the appropriate thickness. Carbon/epoxy composites are bonded structures although the individual layers are only a few thousands of an inch thick, and essentially lose their individual identity in the curing process. Delaminations do occur between these layers because of external impacts with foreign objects. We present some of the common bonded structural features in the following paragraphs. The features you will look at are as follows:

- Lap joint.
- Multiple laminate.
- Honeycomb sandwich.
- Composite materials.
- Doubler.

Lap joint

The lap joint is the simplest structure that uses an adhesive application. As figure 3–1 shows, the lap joint consists of two materials held together by an adhesive. The adhesive in any assembly is *normally* referred to as the *glue line* or *bond line*. Lap joints are structures used in edge treatment for sandwich panel construction, doubler installation, laminations, and other applications where the objective is to bond two or more flat surfaces together.

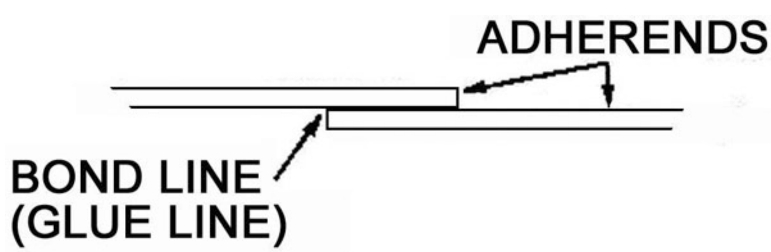


Figure 3–1. Lap joint.

Multiple laminate

Laminate structures may be in the form of a sheet or bar, composed of two or more metal layers bonded together using heat, adhesive, and pressure. The laminated metals form a structural member. This is demonstrated in figure 3–2. A good example of a multiple laminate is plywood. However, by modern aircraft standards, the strength to weight ratio of plywood is *not* very good and you will *not* likely encounter plywood as part of an aircraft.

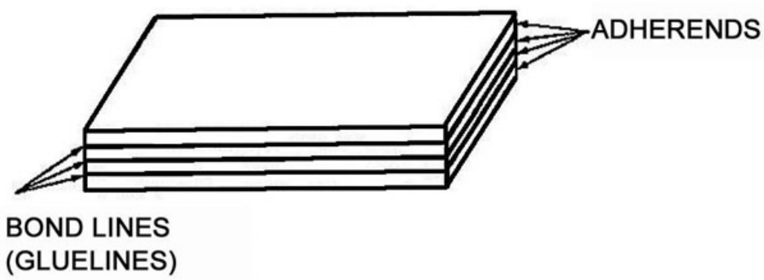


Figure 3–2. Aluminum and adhesive multiple laminate.

As you might expect, a laminate is a stack of lamina or plies built up using precise ply orientation. A better example of a multiple laminate is fiberglass. Many modern aircraft use fiberglass for the construction of radomes. In this type of construction, fiberglass is molded in multiple layers with the glass cloth strands in each adjoining layer running in different directions for added strength. Multiple laminates are normally used as face sheets, or the outside portions or skins of sandwich construction.

Honeycomb sandwich

By far, the *most common* application of bonded structures in aircraft construction is honeycomb panels. These panels provide a light, rigid structure often found in wing, empennage, and control surface components. Honeycomb construction is used in just about any section of the aircraft.

A typical honeycomb sandwich cross-section is shown in figure 3–3. The face and back sheets are *normally* aluminum or composite materials. The core can be made of balsa, foam, wood or almost any lightweight material with good compressive strength. Most aircraft panels are constructed with aluminum or phenolic honeycomb cores.

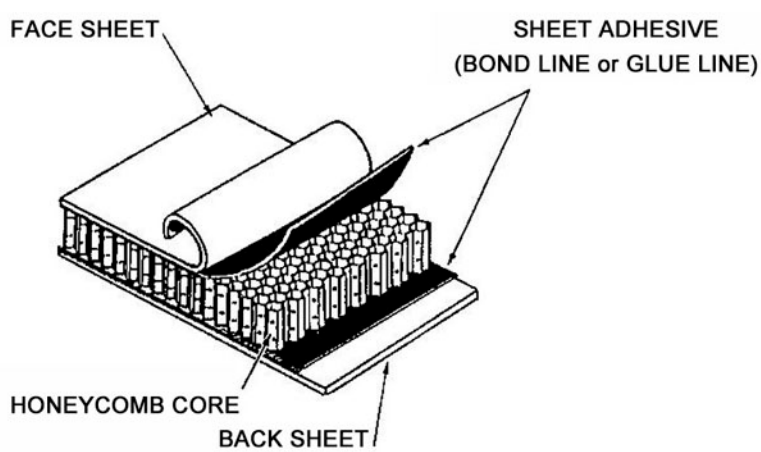


Figure 3–3. Honeycomb sandwich.

Honeycomb skins carry loads from one structure to the other substructures and the core transfers loads from one skin to the other skin. This distributes the stresses throughout the structure.

Composite materials

An advanced composite material is made of a fibrous material *embedded* in a resin matrix, generally laminated with fibers oriented in alternating directions to give the material strength and stiffness. The next lesson describes advanced composites more in detail.

Doubler

A doubler is a reinforcement structure and can be part of an original bonded structure, as shown in figure 3–4. When you are inspecting an original bonded structure, you will normally experience a doubler. By being aware of it, your testing will not produce confusing inspection results.

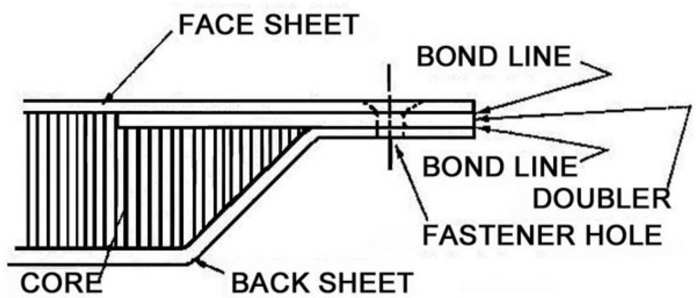


Figure 3–4. Honeycomb panel edge close out doubler.

The repair of a severe dent or a puncture involves the removal and replacement of the damaged material. Often, the repair involves adding a doubler to the structure to ensure that the strength of the honeycomb sandwich is not compromised. Adding a doubler may affect the continuity of the part and will produce varying indications when inspected. For this reason, you need to ask the aircraft structural repair technician if they know if alterations have been made to the part. This will prevent confusing inspection results, especially if a doubler is in the repair of a components back surface. Figure 3–5 shows a doubler not visible to the inspector.

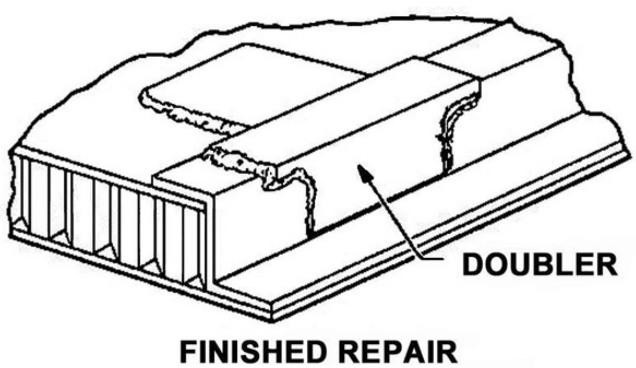


Figure 3–5. Honeycomb panel edge close out doubler.

422. Advanced composite materials

As stated before, an advanced composite is made of fibrous material embedded in a matrix. The term “advanced” applies to composites using fibers of superior stiffness and strength. Plies of this fibrous material are generally oriented in various directions to give the structure strength and stiffness superior to the fibers or matrix alone; however, fibers are chopped and spread throughout a matrix without a pattern or orientation. A good example of this is castings or moldings.

Advanced composites can present some unique problems to the NDI technician. They are a combination of two or more materials acting as one unit, but the materials retain their separate identities. It is common that the heterogeneous mass of an advanced composite is harder to inspect than a homogeneous part. In this lesson, you will study the following advanced composite subjects:

- Matrix.
- Fibers.

- Advantages of advanced composites.
- Disadvantages of advanced composites.

Matrix

Bonding the fibers together in an advance composite is the job of the matrix. The matrix is the adhesive (glue) that bonds the fibers to each other *and* gives side-to-side support. It maintains fiber position and helps keep the fibers from buckling. It also resists crack development and expansion. Matrix systems transfer and distribute the load from fiber to fiber and ply to ply. They are also improving along with hybrid fiber combinations and three dimensional fiber layouts.

There are three general matrix groups:

- Metal – usually aluminum or titanium.
- Ceramic – used for very high temperature applications, but too brittle for most uses.
- Polymers – the most commonly used material and the only matrix we discuss.

Polymer matrix material is broken down into two groups:

- Thermoplastics.
- Thermosets.

Thermoplastics

These are an upgraded version of the same type of plastics you can find around any house. They are very easy to form, very tough, and take strain well. Thermoplastics get their name from the heating process used to form the matrix around fibers. An advantage of thermoplastics is that they can be heated *and* reformed into *different* shapes. Thermoplastics have evolved from basic plastic to a polymer capable of withstanding temperature applications as high as 500° F; however, they are seldom used in any primary structures of an aircraft and are usually found in secondary, nonweight bearing structures. Thermoplastics are just one example of the push for new and better materials.

Thermosets

Unlike thermoplastics, thermosets cannot be heated and reformed. They get their name from the heat necessary to cause the polymer to set or cure into its final form. Epoxy resin, commonly used as a household adhesive or bonding agent, is an example of a thermoset polymer. Epoxy resins generate heat by chemical reaction, causing the epoxy to cure. Thermosets can use heat from a chemical reaction or artificially applied heat to cause the polymer to cure.

Thermosets are the typical matrix you see on the flight line. They form a crosslinked molecular structure when properly cured. While strong, they tend to be brittle or lack toughness. For this reason, advanced composites with thermoset matrix material are susceptible to impact damage. Primary aircraft structures such as flight control surfaces, empennage structures, and wings use thermoset composites.

NOTE: About 90 percent of all impact damage to advanced composite structures occurs on the ground, not in the air! You need to be careful around these materials to avoid damaging them.

Fibers

Fibers give advanced composites some structural properties that are superior in many ways to the metal alloys they have replaced. The fibers act as reinforcing agents, contributing strength, stiffness, and impact resistance to the composite material. They are the *principle* load-carrying components. You will look at the following types of fiber used in advanced composite construction:

- Boron.
- Carbon and graphite.
- Aramid.

Boron

Boron was the first high-performance fiber used in aerospace construction. Boron fiber is produced by depositing vaporized boron on a thin filament of tungsten or carbon. The finished fiber is about 0.004 of an inch in diameter. Boron fiber is extremely hard, with excellent compressive strength and stiffness. Boron has a high tensile and compression strength and a lack of galvanic corrosion potential, which makes it *popular* for repairs.

The disadvantage of boron is the high cost and its difficulty to form into odd and curved shapes. Boron is so stiff that it is not capable of woving into fabric or forming a tight radius without snapping.

Carbon and graphite

Carbon and graphite fibers are made from organic filaments, such as rayon and other polymers. They can heat to high temperatures. While the terms *carbon* and *graphite* are often used interchangeably, graphite is heated to a higher temperature than carbon in a process called graphitizing. The resulting fibers are only a few microns in diameter, very strong, stiff, and brittle. Fibers with different properties, such as higher strength or stiffness, can be manufactured by controlling the heating process. Carbon and graphite are the most commonly used advanced fibers. They are easy to mold or shape and have very high tensile strength.

The disadvantage of carbon fiber or graphite is that it has a high potential for causing galvanic corrosion when used with metallic fasteners and structures.

Aramid

Aramid fibers, better known by the trade name Kevlar, are organic fibers spun from a process tightly controlled by Dupont. Produced as yarn or fabric, aramid fibers have many advantages over other organic fibers. Aramid fibers have great tensile strength, are easy to mold, and have a natural resistance to solvents, lubricants, fuels, heat, and flame.

Aramid fibers' disadvantages include a low compressive strength and high expense. It is also known for moisture absorption, which will break down the matrix.

Advantages and disadvantages of advanced composites

The following table indicates some of the reasons why aircraft builders are using composite materials more often.

Advantages and Disadvantages of Advanced Composites

Advantages	Disadvantages
• Higher strength-to-density ratio (saves weight). • Higher stiffness-to-density ratio. • Better fatigue resistance than aluminum skin. • Lower thermal coefficient of expansion. • Mechanical properties are more tailored. • Better vibration dampening characteristics. • Less sensitive to repeated tensile loads. • Better tolerance for small flaws or holes. • Fewer design constraints. • Inherently corrosion resistant. • Inherent stealth benefits.	• They tend to be more brittle and are prone to low velocity impact damage. • They are more expensive than the metal components they replace. • Repair procedures are complex, lengthy, and require strict process control. • Most repair materials have a short shelf life and require refrigeration or special controls. • Advanced composites are more sensitive to repeated compressive loads.

423. Bond testing standards and indications

All NDI techniques are comparative which means you must compare an indication from one area to indications from known good and bad areas of a standard. Bond testing techniques require you to take care when interpreting indications. Changes in the structure, such as a splice, tapered core, differing skin thickness, or excess adhesive, can produce indications easily confused with a defect condition. You must be familiar with the internal construction of the part to distinguish between defects and legitimate structural changes. In this lesson, you will study the following subjects:

- Reference standards.
- Inspection without standards.
- Defects.

Reference standards

A bonded reference standard may be a duplicate of the test part except for the controlled areas of unbond. As an option, simple test specimens, which represent the respective different areas of the test part and contain controlled areas of unbonds may be used.

It is essential to use standards to calibrate and standardize your bond testing equipment. These standards check equipment operation and compare indications of possible defects in the structure you are inspecting. We will now break down bond testing reference standards by the following:

- Configuration of standards.
- Types of defects.
- Fabrication of bond testing standards.

Configuration of standards

A reference standard may be a duplicate of a test part *except* for the controlled disbonded areas. As an option, you may use simple test specimens that represent the varied areas of the test part and contain controlled areas of disbonds. These areas correspond to defects you may find in the test part. Advanced composite standards complicate inspections because they add factors such as number of plies making it difficult to configure these standards.

Reference *standards* will be similar to the test part with respect to material, geometry, and thickness. (This includes closure members, core splices, stepped skins, and internal ribs that are similar to the test part).

- Standards should contain bonds of good quality except for controlled areas of unbond fabricated.
- Standards should be bonded using the adhesive and cure cycle prescribed for the test part.

Types of defects

Disbonds or unbonds are separated into five general types to represent the various areas of bonded sandwich and laminate structures. The five general types are:

- Type I: Unbonds or voids in an outer skin-to-adhesive interface.
- Type II: Unbonds or voids at the adhesive-to-core interface.
- Type III: Delaminations or voids between layers of a laminate.
- Type IV: Voids in foam adhesive *or* unbonds between the adhesive *and* a closure member at core-closure member joints.
- Type V: Water in the core.

Figure 3–6 demonstrates the location of type I–IV. type V (water) is not shown.

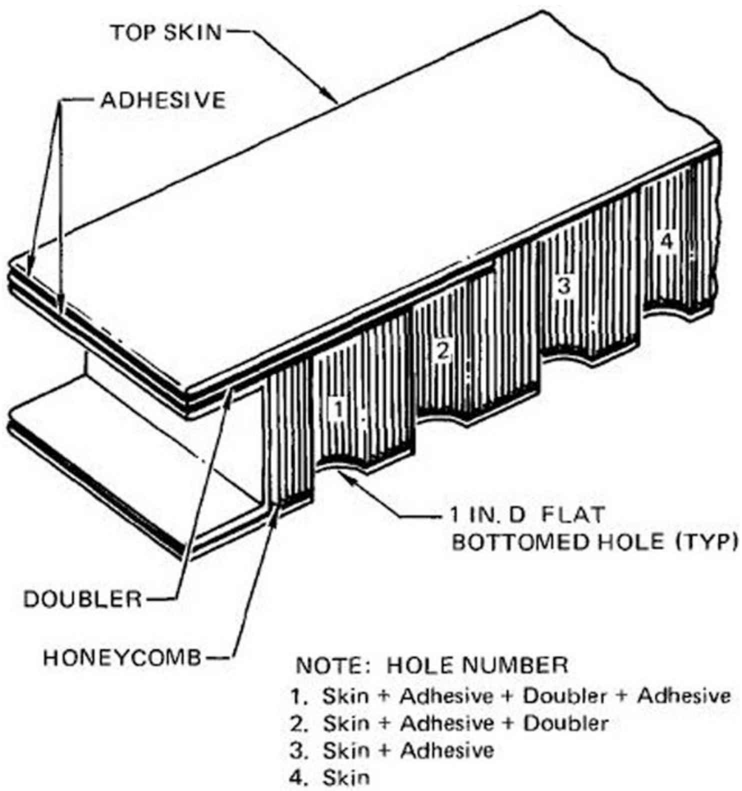


Figure 3–6. Bonded structure.

Fabrication of bond testing standards

The reference standard will contain disbonded areas equal to the sizes of the minimum rejectable disbonds for the test part. Obtain information on minimum rejectable disbond sizes for test parts from the technical manual or from the prime depot-level engineering activity.

Producing disbond standards using grease, vinyl, and other foreign material not specified in the list below is prohibited. One or more of the techniques below illustrate reference defects manufactured in standards. Since materials vary, some methods may not always work.

- Standards for type I, II, III, and IV disbonds are prepared by placing discs of 0.006 inch thick Teflon sheets over the adhesive in areas selected for disbonds. In type II disbond standards, the Teflon is placed between the core and adhesive. Assemble the components and cure the assembly the same as the test piece.
- Type I, II, and III standards are manufactured by cutting flat bottom holes the same diameter as the desired disbond. The holes are cut from the backsides of the bonded specimens and their depth is controlled to produce air gaps at the applicable interfaces. When using this method, bond the patch plates to the rear of the reference standards to cover each hole and seal the standard.
- Type II standards are produced locally by undercutting the surface of the core to the desired disbond size. The depth of the undercut is sufficient to prevent adhesive to flow, causing bonds between the undercut core and the face skin.
- Type IV standards are produced by removing the adhesive in selected areas prior to assembly.
- Type V standards are produced by drilling small holes in the back of the standard and injecting varying amounts of water into the cells with a hypodermic needle. Seal the small holes with a small amount of water-resistant glue or adhesive.

The following table describes specific inspection techniques with bonded structure configurations.

Scan Plane Number	Defects Sought	Applicable Techniques
1	Near-side skin-to-core	• Pitch/catch • MIA • Resonance • Eddy-sonic • Through-transmission • Pulse-echo • Ringing
	Core damage	• MIA • Through-transmission • Pulse-echo
	Far-side skin-to-core	• MIA • Through-transmission
2	Near-side skin-to-core	• Resonance • MIA • Through-transmission • Ringing
	Core damage	• MIA • Through-transmission
	Far-side skin-to-core	• MIA • Through-transmission
3	Any	• Resonance • MIA • Ringing
4	Any	• Resonance • Ringing • Through-transmission • Damping
5	Any	• Resonance • Ringing
6	Any	• Through-transmission (with delay lines)
7	Any	• Resonance • MIA • Through-transmission • Ringing

Inspection without standards

When standards are not available for a required inspection, some inspection techniques will require you to calibrate equipment on a known undamaged area of the test part. Inspect a repaired or damaged area, and compare it to indications from an unrepaired or undamaged area; however, only perform these inspections as a last resort.

Defects

Defects that are undiscovered could prevent parts from fulfilling their desired functions or leave a hazardous condition undetected. For this reason, bond-testing inspection are concentrated on defect detection. Types of *defects* associated with bond testing are:

Disbond - a *separation* at an adhesive bond line in a bonded joint.

Unbond - an area within a bonded interface between two adherents in which the intended bonding action *failed* to take place.

Delaminations can be *confused* with disbonds or unbonds and it is important to know the differences when describing your defects. You will also inspect areas that have injected adhesive or repairs in the material.

Delaminations

A delamination will be indicated by a new response on screen and a complete loss of the back surface response (fig. 3–7, display two and three). While scanning over delamination, the screen presentation will display a decrease in the back surface response and an increase in response. For delaminations located at certain depths, multiples of the response may appear on the screen. A delamination smaller than the transducer diameter may not cause complete loss of back surface response.

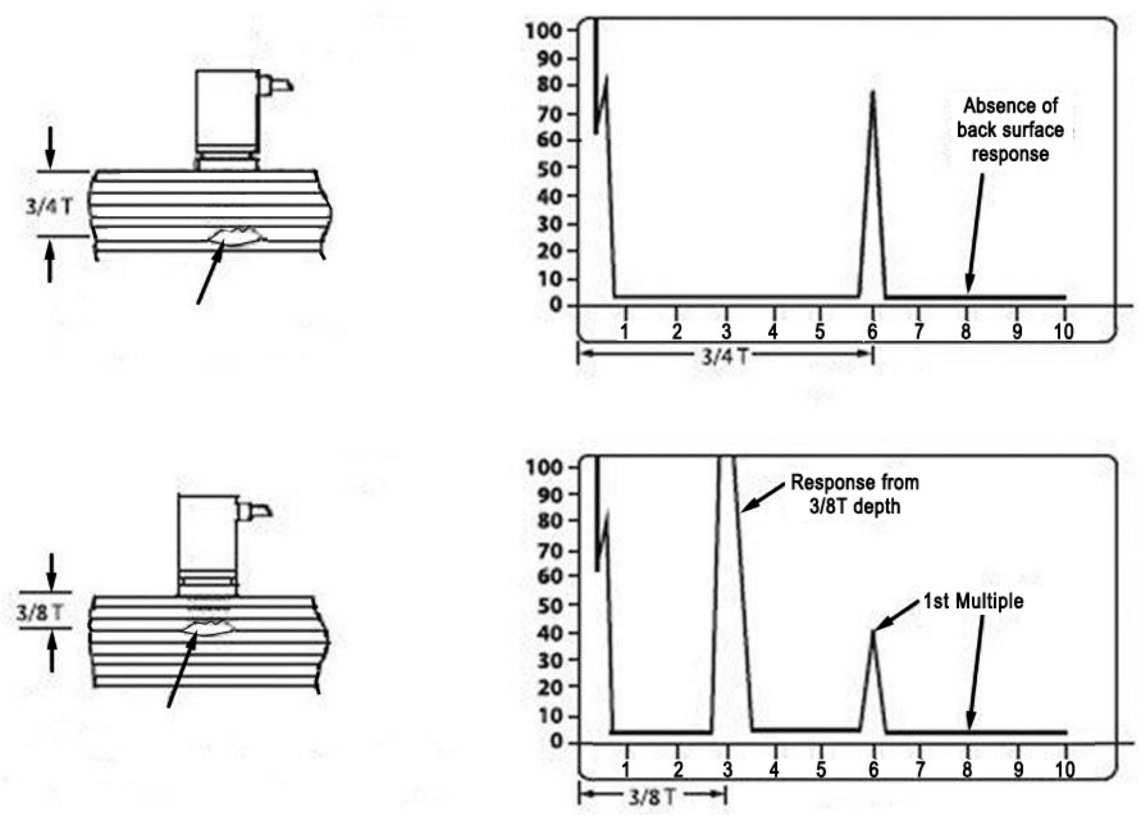
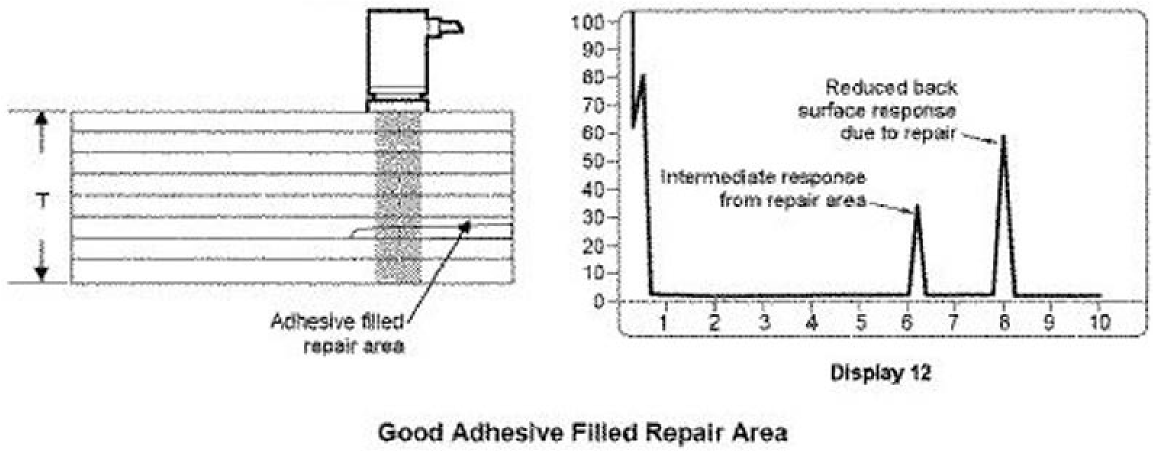


Figure 3–7. Example of single level delamination.

Injection and edge repair

Adhesive filled edge repair areas may result in intermediate responses from the repair area, and a reduction in the back surface response amplitude due to attenuation from the repair area (fig. 3–8). A repaired area containing an adhesive void will indicate an intermediate response and an absence of the back surface reflection. In addition, the amplitude of intermediate responses may increase compared to a flaw free repair area, but not always as also seen in figure 3–10.



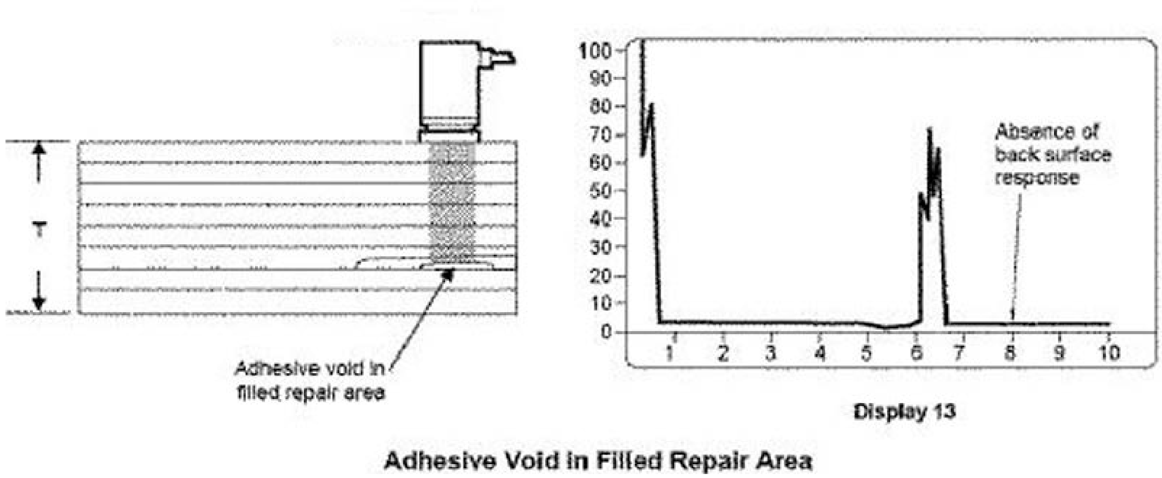


Figure 3–8. Example of response from repair.

424. Introduction to laser shearography

The electronic image shearing interferometer was pioneered in the early 1980s by three researchers, Dr. John Butters at Loughborough University in the United Kingdom, Dr. S. Nakadate in Japan, and Dr. Mike Hung at Oakland University in the USA. The commercial development of the shearography camera as a tool for nondestructive testing led to the delivery of the world's first production shearography system in 1987 for select aircraft production programs. The introduction of the first portable shearography systems occurred in 1989 to fill a need for fast, large-area field inspection of aircraft honeycomb structures.

In this lesson, you will study the basic principles of laser shearography even though it is not yet used in the Air Force. You need to be familiar of different NDI techniques used for future development.

Principles of shearography

Shearography *interferometry* NDI *use* laser-based imaging to detect, measure, and analyze surface and subsurface irregularities in materials or structures. This is done by imaging submicroscopic changes to a test part surface when an appropriate stress is applied.

Shearography methods are mature and effective solutions for wide ranges of aerospace NDI applications. They include the following:

- Composite aircraft panels.
- Aircraft tires.
- Control surfaces.
- Metal honeycomb.
- Foam core panels with metal or composite face sheets.
- Elastomer or cork bonds.
- Composite over-wrap pressure vessels (COPVs).
- Spray on foam insulation (SOFI) and solid composite laminates.

Shearography inspection

Shearography systems consist of a laser light source, a shearing image interferometer, an image-processing computer, a display monitor, and a means to provide a controlled and repeatable stress to the test object. The shearography optical system has a common path imaging interferometer. Shearography cameras create images showing the *first* derivative of the out-of-plane deformation of the test part surface in response to a change in load. It is relatively insensitive to test objects because of bending or deformation from applied stress. Yet it is still highly sensitive to local deformation caused by a defect.

Shearography cameras are sensitive to changes in the distance from the object surface to the camera. In practice, zaxis surface deformations may be as small as 2–20 nanometers depending on the environmental noise. Inspection on large test parts with a small number of images using a large field of view (FOV) or a large number of images with a smaller FOV that automatically stitches together. The FOV for a shearography camera depends on the following:

- Maximum allowable defect size.
- Camera resolution.
- Laser illumination power.
- Ability to uniformly apply a stress change.
- Amount of background noise.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

421. Bonded structures

1. What is a bonded structure?

2. What are two good examples of multiple laminates?

3. What are normally used as face sheets, or the outside portions, or skins of sandwich construction?

4. What is the most common application of bonded structures in aircraft construction?

5. Adding a doubler may affect the continuity of the part and do what to your inspection?

422. Advanced composite materials

1. How does the term “advanced” apply to composites?

2. What bonds the fibers together in an advance composite?

3. What are the three general matrix groups?

4. What type of matrix material is very easy to form, very tough, and holds strain well?

5. What type of matrix material cannot be heated and reformed?

6. What acts as reinforcing agents, contributing strength, stiffness, and impacts resistance to a composite material?

7. What type of fiber produces depositing vaporized boron on a thin filament of tungsten or carbon?

8. What are the most commonly used advanced fibers?

9. What fibers have great tensile strength, are easy to mold, and have a natural resistance to solvents, lubricants, fuels, heat, and flame?

423. Bond testing standards and indications

1. Reference standards may be duplicates of the test part *except* for?

2. What is a type II defect of a bonded structure?

3. How are type IV standards produced?

4. What sort of inspection is to only be performed as a last resort?

5. What is a separation of an adhesive bond line in a bonded joint called?

6. How does a delamination appear on an instrument display?

7. What may result in intermediate responses from an area, and a reduction in the back surface response amplitude due to attenuation from a repair?

424. Introduction to laser shearography

1. What is shearography interferometry NDI?

2. What type of aerospace applications are used with shearography NDI methods?

3. What does a shearography NDI system consists of?

3–2. Bond Test Inspection Techniques

Bond testing techniques, like other NDI techniques, prescribe a definite way of accomplishing an inspection by specifying equipment and materials used. Every technique is based on a standard. In this section, we will look at understanding each bond testing technique and the display received from either ultrasonic or bond testing units and variables that you may encounter.

NOTE: The aircraft **–**36 series TOs provide NDI instructions and techniques for the inspection of aircraft structures. Any deviation from these documents for a specific aircraft must be approved by the responsible engineering agency. We will also look at maintaining the equipment assigned to your lab.

425. General bond testing and variables

From previous sections, you are already familiar with some of the methods discussed here. Most of your attention will be directed toward ultrasonic techniques not covered previously. First, we will look at two general bond-testing methods:

- Visual.
- Tap test.

These two methods are normally only used to determine whether a more extensive inspection involving NDI is required. Both of these are seldom used without confirmation by another technique.

Understanding different variables associated with bonded structures are also important when interpreting where the defect is located.

Visual

Visual inspections are the oldest and most economical means of performing nondestructive evaluations. It is routinely used for damage assessment and during all stages of repair.

When assessing the integrity of bonds in honeycomb panels, buckling or dents in the face or back sheet could indicate delamination between these sheets and core material. Crushed core material may indicate dents especially if they are large or deep.

Use visual inspection aids, such as mirrors, borescopes, and magnifiers to increase access or detectability. Usually visual inspection is limited to surface defects and also degraded by human factors such as, surface coatings and contaminates. *Never* use this method of inspection as the sole means of determining whether a bond is good.

Tap test

During tap testing, the acoustic response of a good part can vary dramatically with changes in geometry. Tap testing using a hammer like the one in figure 3–9 is useful for locating large voids or disbonds. Normally, you can easily detect *voids* of $1^1/_2$–inch diameter *or* larger in metal-to-metal, composite-to-metal, *or* thin facing-sheet honeycomb assemblies using this method; however, tap testing is limited to detection of upper facing sheet to adhesive disbonds or voids. It will not detect voids or disbonds at second, third, or deeper layers. Additionally, this test method is subjective and yields varying test results.

Perform tap testing over a suspected area by tapping with a special mallet, coin, or tap hammer. The inspector produces a continuous sound with an established tapping rate. With practice, a trained ear can detect subtle differences in sound tone. Note the following when using tap test:

- The surface should be dry and free of oil, grease, and dirt.
- Tap test is limited to finding shallow defects in skins.
- It is portable, and easy to use.

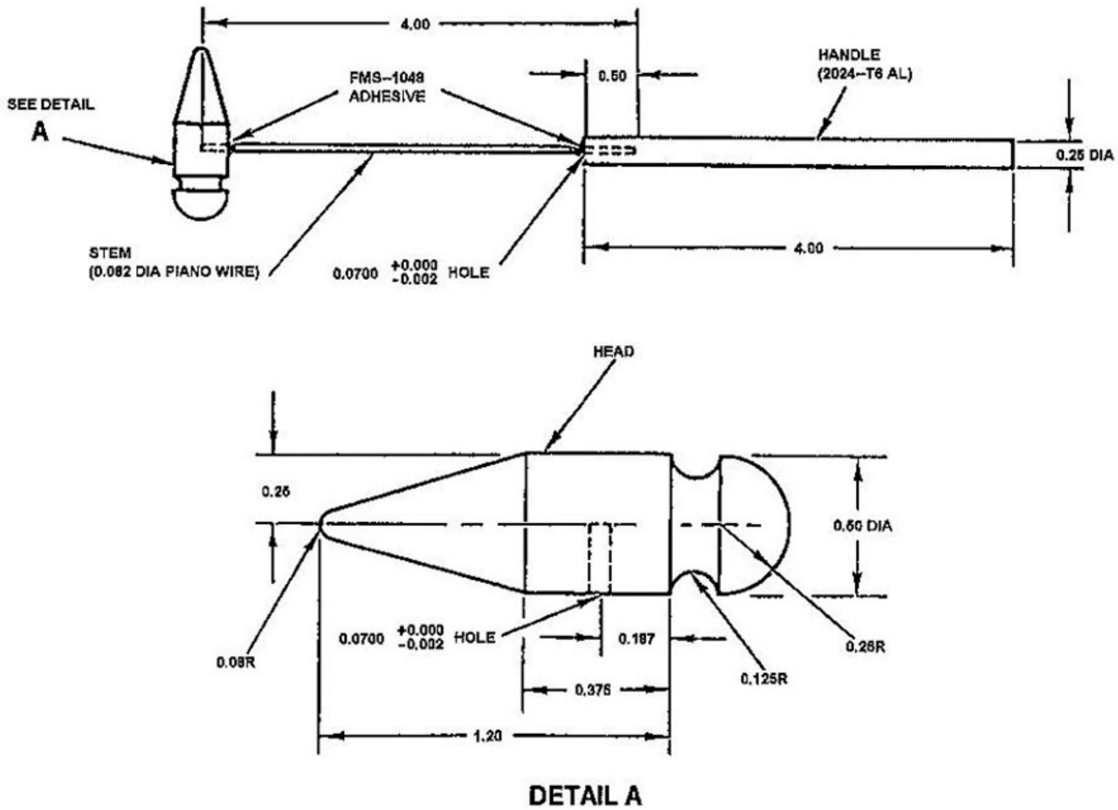


Figure 3–9. Tap test hammer.

Variables of bonded structures

There are many configurations and types of bonded structures, thus, there are many variables to consider when performing NDI. It is thus important to know the many locations of possible defect configurations.

- Probe-side skin material and thickness.
- Adhesive type and thickness.
- Structure under the skin.
- Accessibility to one skin or both skins.

All of these variations complicate the application of ultrasonic inspection. A method, which works well on one part or in one area of the part, may not be applicable for different parts or different areas of the same part.

The examples in figure 3–10 suggest ultrasonic bond testing to the area of *numbered* coverage. Due to access limitations, it will not be possible in many cases to apply the inspections in all the areas shown. These coverage's and associated methods are guidelines only. Details of inspection coverage and methods for a particular assembly shall be obtained from the applicable NDI manual or the depot engineering activity. In figure 3–10, note the following:

- The numbered lines surrounding each view indicate the scan planes. The number on each line is used to determine the acceptable inspection methods.
- Where surfaces are symmetrical, the coverage illustrated shall be considered typical for both sides.
- When the same methods are specified in more than one scan plane, calibration shall be verified for each plane.

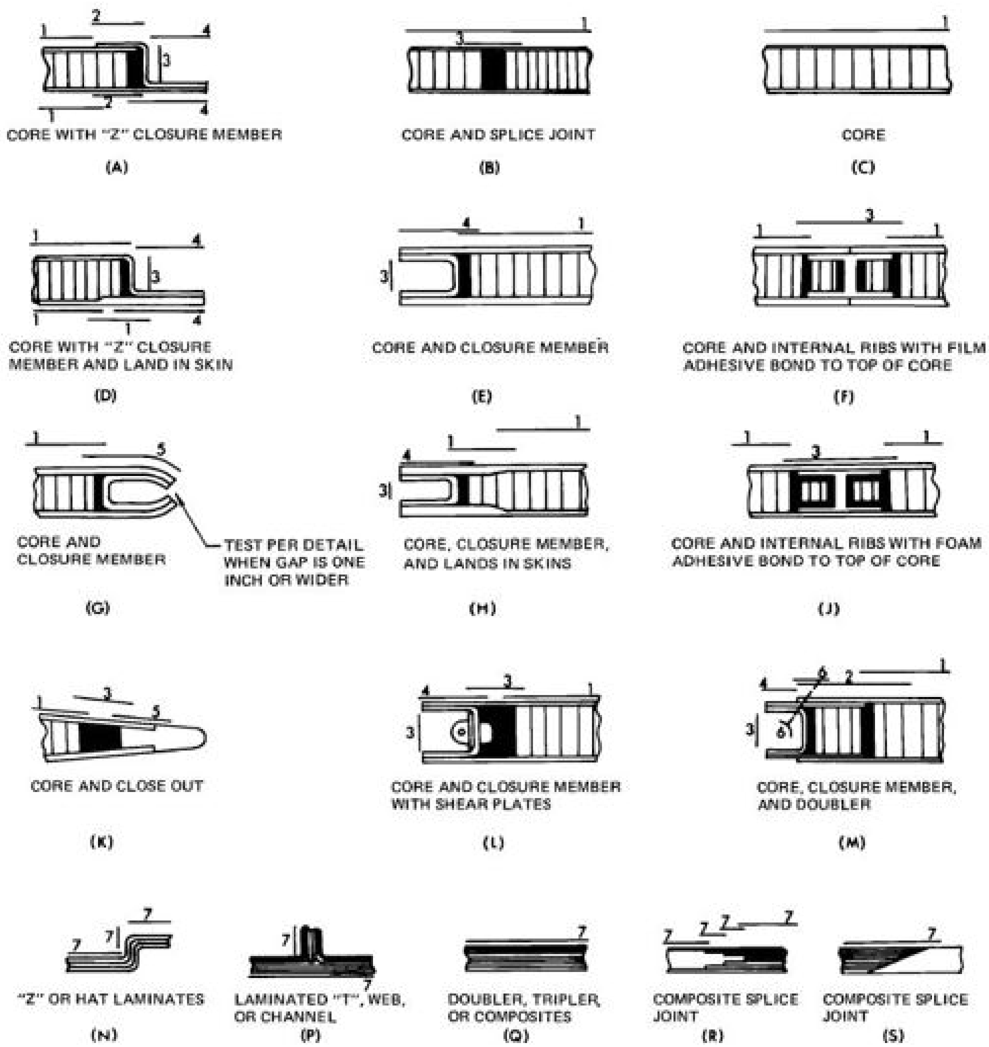


Figure 3–10. Bonded structure configurations and suggested inspection coverages.

426. Bond testing techniques using ultrasonic units

This lesson looks at various aspects of bonded inspections utilizing an ultrasonic unit. The subjects you will study include variables affecting bonded structures and the following inspection techniques:

- Through-transmission.
- Pulse-echo.
- Ringing.
- Damping.

Inspections can reveal differences in physical characteristics between good and bad bonded structures. For example, a good laminated structure conducts sound and heat and is rigid. Bad bonds or damaged structures, on the other hand, tend to distort sound, conduct heat poorly, lose their rigidity, and rattle when they vibrate.

Through-transmission technique

Delaminations in either skin, unbonds between skin and core, and core damage prevents the transmission of sound to the receiving transducer. The *minimum* size flaw detected is *proportional* to the *size* of the *receiving* transducers. The received signal does not have to disappear completely to indicate a flaw. Detection is noticeable by any flaw large enough to lower the received signal. Figure 3–11 shows the principle of this technique.

NOTE: Move both transducers in tandem; otherwise, misaligned transducers will generate false indications.

Through-transmission requires the following factors:

- Frequencies used are normally 2.25 or 5 MHz.
- Applicable to structures with multiple layers, with or without honeycomb.
- When sound energy travels through homogeneous materials with no appreciable loss discontinuities can be found.
- Minimum size flaw is dependent upon the diameter of the receiving search unit.
- Cannot find both the presence of a defect and its location relative to the surface of the part.
- Requires two search units (one to transmit and one to receive).
- Access to both sides of the part is required.
- Alignment of search units is critical.
- Inspection rate is slow.

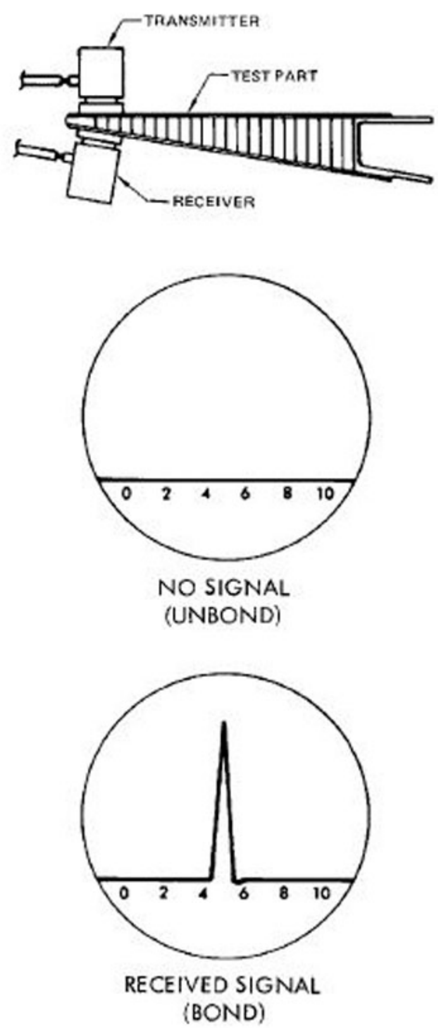


Figure 3–11. Through-transmission technique.

Through-transmission provides a definitive method of detecting discontinuities throughout the depth of multilayer bonded structures. Voids, delaminations, crushed core, lack of adhesive, and other discontinuities in the structure attenuate the transmitted signal and are detectable by this method.

Pulse-echo technique

Pulse-echo employs an angle beam transducer because straight beam transducers can produce multiple echo signals from the layers that would interfere with echo signals from the core. This method is applicable only to honeycomb structures with single-layer skins when you cannot use through-transmission. Straight beam transducers could provide better results on structures with multi-layer skins as well. Use pulse-echo as a backup for techniques associated with bond inspection instruments.

Use angle beam transducers producing refracted angles of 30°–90° for this inspection. The angle selected should be the one that produces the maximum signal response from the back of the core. The basic principle of pulse-echo technique is shown in figure 3–12.

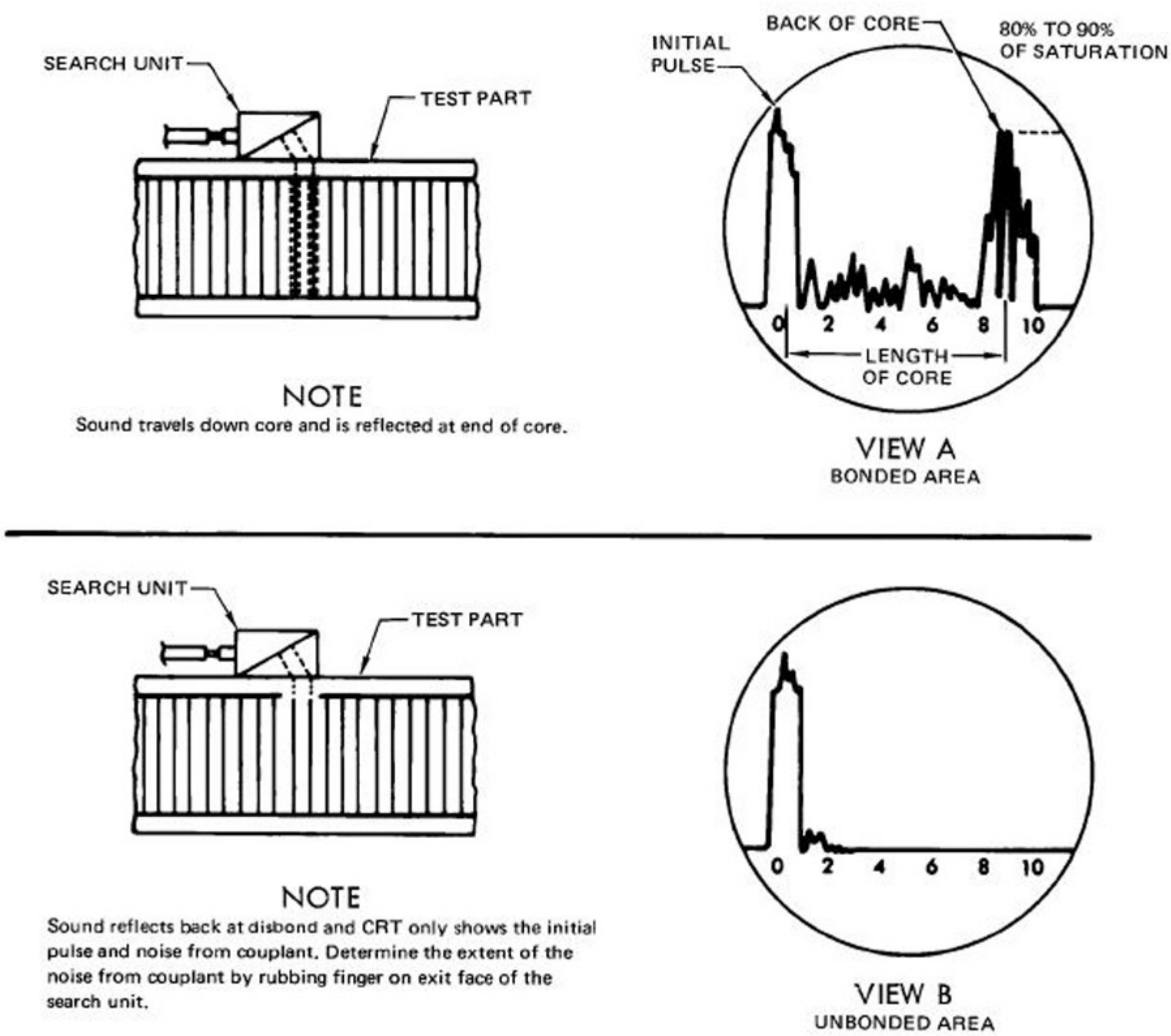


Figure 3–12. Pulse-echo technique.

The following can be used with the pulse-echo technique:

- High frequency transducer (10 MHz).
- Thickness measurement (ranges from 0.005 inch to several feet depending on the instrument and material under test).
- A delay line is used for better near surface resolution.
- Graphite face sheets (type III defects).

Ringing technique

This technique is a variation of the pulse echo method because of how it absorbs energy *loss* in the bond line *and* core material. Ringing techniques have the *best* sensitivity for disbonds between a single top skin *and* the adhesive layer. Disbonds between the adhesive and core or lower sheet in the structure *may not* produce a ringing signal because the adhesive bonded to the top sheet dampens the signal. A good application for this method is inspection of core-to-closure member areas for disbonds. The display shown in figure 3–13 represents the outline of multiple echo signals from the skin that cannot be individually resolved. Apply this technique only when one of the other techniques is not applicable.

Use the following inspection criteria with the ringing technique:

- Uses a high frequency transducer (1–10 MHz).
- Most sensitive to unbonds between a single layer of skin and the adhesive layer (type I).
- An unbond between the adhesive and the core, or another layer of skin or a doubler, will often not produce a ringing signal, because the adhesive bonded to the top sheet dampens the signal (type II).
- Another application for this technique is the inspection of core-to-closure-member bonds (type IV).

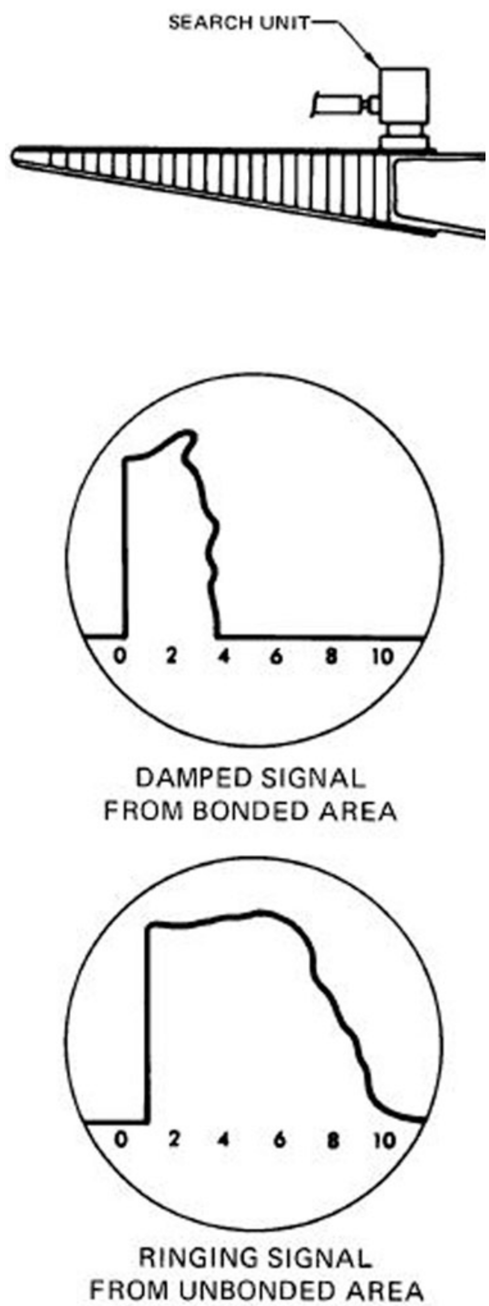


Figure 3–13. Ringing technique.

Damping technique

This technique, illustrated in figure 3–14, is effective for laminate, doubler, and skin-to-closure member bonds when access to the backside is available. This principle is similar as previously discussed in ultrasonics. If the inspector can dampen the multiple echoes from the far side of the bonded structure with a wet finger, then the bond is good. Otherwise, the sound may reflect from a disbond, which will not reach the far surface, and cannot be damped. Unbonds equal to or larger than the size of the transducer are easily detected.

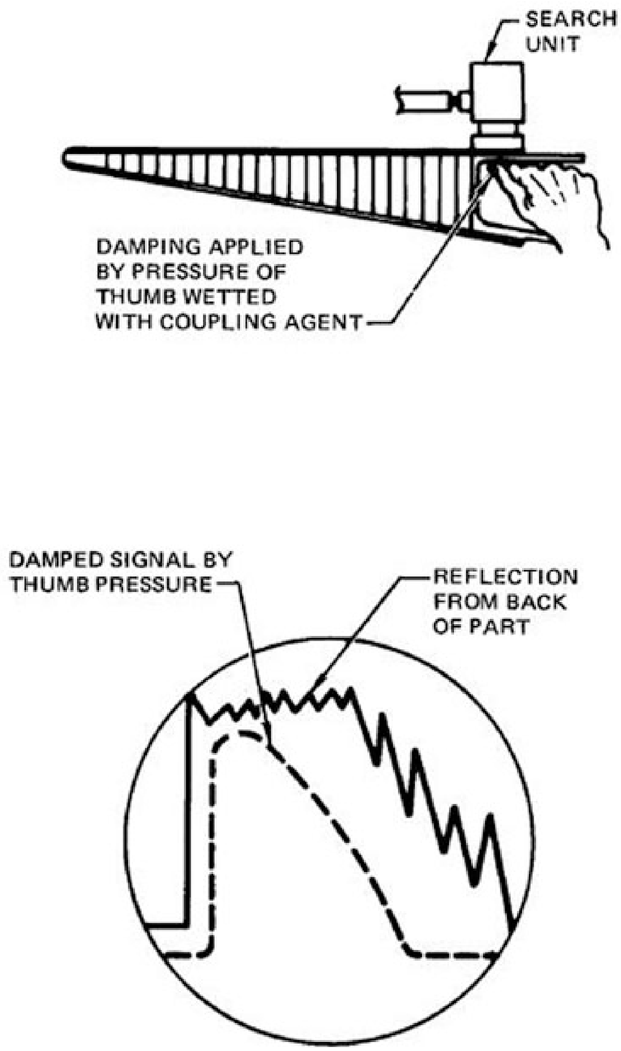


Figure 3–14. Damping technique.

Advantages and limitations of bond methods (ultrasonics)

The following table outlines ultrasonic bond inspection techniques, along with advantages and limitations of each.

Advantages and Limitations of Bond Methods				
	Through-Transmission	**Pulse-echo**	**Ringing**	**Damping**
Advantages	• Applicable to structures with multiple layers, with or without honeycomb.	• Applicable to honeycomb structures with thick or thin skins.	• Applicable to complex shapes.	• Applicable to multilayered structures with thick or thin sheets.

Advantages and Limitations of Bond Methods				
	Through-Transmission	**Pulse-echo**	**Ringing**	**Damping**
	• Defects unbonds between any layers or in honeycomb. • Detects small defects larger than the diameter of receiving search unit.	• Detects small unbonds within the search unit diameter and smaller.	• Detects small near surface unbonds larger than the diameter of the search unit.	• Detects unbonds between any layers. • Detects small unbonds larger than diameter of search unit.
Limitations	• Access to both sides of part required. • Does not determine layer position of unbonds. • Alignment of search units is critical. • Couplant is required. Inspection rate is slow.	• Inspection from both sides required. • Does not detect far side unbonds. • Applicable only to honeycomb sandwich structures, usually those with single-layer skins. • Couplant is required.	• Applicable only to near surface unbonds. • Works best on unbonds between top sheet and adhesive layer, may miss unbonds on other side of adhesive. • Works best on metals. • Couplant is required.	• Applicable only to laminated non-honeycomb structures. • Access to both sides is required. • Does not determine layer position of unbond. • Couplant is required.

427. Bond testing techniques using bondmaster units

The Sonic BondMaster® is the current, most advanced bond testing equipment used in the Air Force. It is a portable, lightweight, digitally controlled piece of NDI equipment. The BondMaster® can test components made from any combination of advanced composites and metallic structures. It is capable of performing tests using these four methods:

- Resonance.
- Pitch/Catch swept.
- Pitch/Catch impulse (pulsed).
- Mechanical impedance analysis (MIA)

Resonance technique

When an ultrasonic transducer is placed on a test sample, with couplant, an oscillator in the instrument drives it at its resonance frequency. The detector in the instrument measures the phase and amplitude components of the electrical impedance of the probe, which affect changes in the acoustic impedance of the test part. The acoustic impedance of a part alters by a lack of bond, commonly referred to as a delamination.

The resonance mode works very well for the following:

- Detecting disbonds at metal-to-metal, metal-to-composite, and composite-to-composite interfaces, for finding delaminations within composite materials, and for detecting skin-to-core disbonds in honeycomb sandwich structures.
- Applies continuous (as opposed to pulsed) electrical energy to the transducer *producing* standing waves within the material which cause it to vibrate or resonate.
- The acoustic impedance of the material and its thickness determines resonant frequency.

- Internal flaws and discontinuities are observed as changes in the strength and location of the resonance indications.
- Used to locate layer position of delaminations within composite face sheets.
- Signal-phase rotation estimates the depth of delaminations.

Bonded laminates act like a thin plate, which vibrates and generates a standing wave. Changes in the effective thickness caused by the delaminations will significantly affect the phase and amplitude of the acoustic wave in the part. With the resonance technique, the instrument indicates the probe's impedance with a 'flying spot" on an ultrasonic impedance plane display. Amplitude changes in impedance are indicated by the radial distance of the spot from the center of the display (null reference point), and changes in the phase are indicated by the rotation of the spot around the center null point.

Figure 3–15 shows an example of the ultrasonic impedance plane display. Position "A" shows the spot positions corresponding to different depths of unbonds (delaminations). In the bonded laminate shown in position "B", the laminate is an example of a typical reference standard used for calibration.

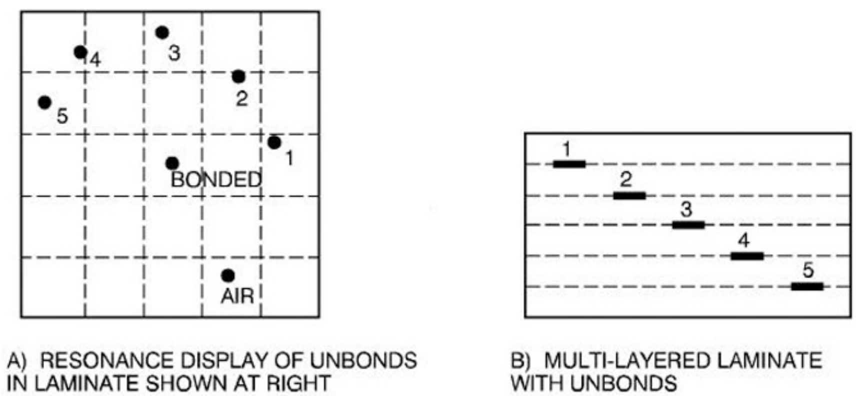


Figure 3–15. Resonance technique.

Setting a gate for an audible alarm for a disbonded area is recommend. Monitor the display to determine between which layers disbonds occur.

The following is an example of a resonance technique setup. We will already assume that all probes are connected and the unit is defaulted.

Basic Resonance Technique	
Step	**Description**
a	Apply couplant to the reference standard. Couple the transducer to a *known* GOOD area of the *reference standard* as defined by the part-specific procedure, representing the number of plies or thickness inspected. Press NULL. The dot should move to 20% vertical and 50% horizontal. Lift the probe off the standard. The dot should move to the right and remain within the lower right quadrant (>50% horizontal, <50% vertical). Adjust the ANGLE to achieve this approximate position.
b	Verify the null point and readjust the ANGLE until the null and lift-off.
c	Couple the transducer on the BAD region.
d	Adjust the instrument horizontal GAIN and vertical GAIN and ANGLE as required to place the BAD response within the alarm box.
e	Repeat steps a through d to achieve the required response from both the GOOD the BAD and lift-off response.
f	Verify the signal from both BAD areas trigger the alarm.

NOTE: These are general procedures based off TO 33B–1–2, *Nondestructive Inspection General Procedures and Process Controls* using the Olympus Bondmaster 1000e+. Ensure you use the correct TO and reference manual for your equipment.

Pitch/Catch impulse method

The dual transducer, pitch and catch method uses a *pair* of transducers *displaced* from each other by a *fixed* distance. Place the transducers on the same or opposite sides of the part. A single ultrasonic frequency transmits into the part by one transducer; a second transducer in the same probe assembly receives the returned signal. Contact with the part is made through nylon wear tips on spring-loaded metal rods attached to the respective transducers. The ultrasound travels through the material between the two probe tips.

Use the following for Pitch/Catch impulse:

- Uses a low frequency range of 2.5 kHz–70 kHz.
- Permit the operator to select a single frequency providing the largest received signal, due to maximum flexure in the layer being tested is chosen for the inspection.
- Lower frequencies eliminate the need for couplant.

Depending on the instrument, received signals display in various ways. The amplitude and phase components can be displayed on separate meters or the resultant signal activates a light-emitting-diode (LED) display. The phase and amplitude components can also be combined to position a "flying spot" on an impedance plane display.

The display in figure 3–16 shows a box in the middle of the display, which is the gate that sets off an alarm if the spot lands inside, indicating a disbond.

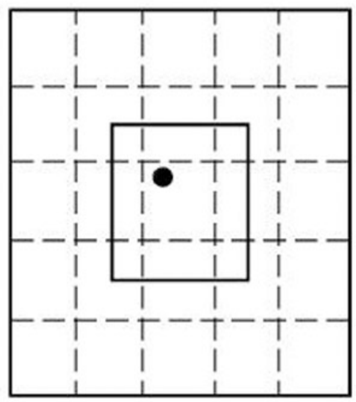


Figure 3–16. Pitch/Catch impulse technique.

Pitch/Catch swept frequency technique

Instead of a single frequency, each pulse contains a range of frequencies generating ultrasonic lamb waves within the part. These waves attenuate by coupling into the second layer in well-bonded joints. In an unbond region, the waves travel with very little attenuation or leakage into the second layer and produce larger indications. Use Pitch/Catch swept technique in the following ways:

- Each pulse contains a range of frequencies (e.g., 20–40 kHz or 30–50 kHz), generating ultrasonic Lamb (plate) waves within the part. Use transducers with these frequency ranges only.
- Both the swept and impulse modes find similar types of defects but interpretation of indications is easier with the swept mode because both phase and amplitude are simultaneously displayed in the form of circular patterns on one x-y screen.

Instrument displays corresponding to three situations detected with the Pitch/Catch swept-frequency technique, are shown in figure 3–17.

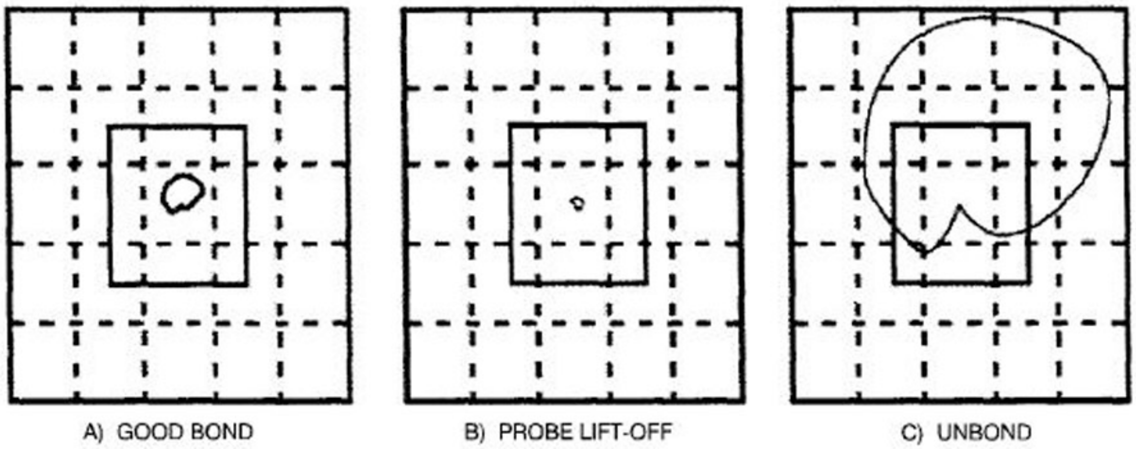


Figure 3–17. Pitch/Catch swept technique.

The following is an example of a Pitch/Catch Swept technique setup. We will already assume that all probes are connected and the unit is defaulted.

<table>
<tr><th colspan="2">Basic Pitch/Catch Swept Technique</th></tr>
<tr><th>Step</th><th>Description</th></tr>
<tr><td>a</td><td>Place probe over good area of calibration standard and press NULL.</td></tr>
<tr><td>b</td><td>Center the probe over the defect in the calibration standard. See position 2 of figure 3–18. The size of the signal loop should increase. Adjust GAIN such that the majority of the signal loop is beyond one major division outside of the alarm box if possible.

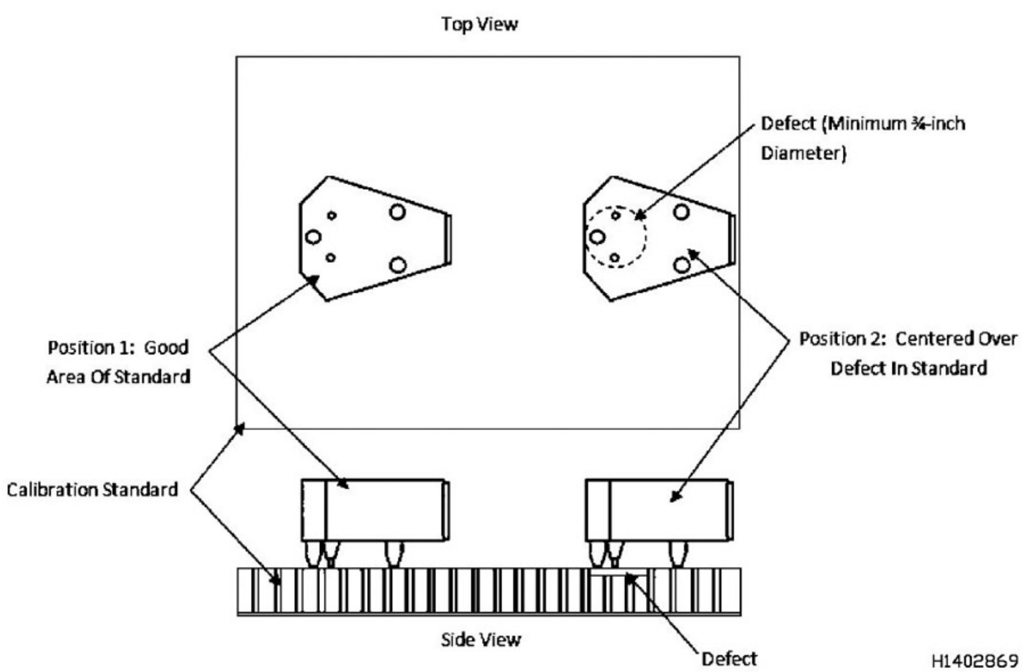


Figure 3–18. Pitch/Catch swept calibration.</td></tr>
<tr><td>c</td><td>Scan good area of calibration standard to ensure that good area signals do not exceed the alarm box. If these signals do exceed the alarm box, reduce the GAIN as necessary to contain the good area signals within the box. After adjusting the GAIN, rescan the defect on the reference standard to ensure that at least half of the signal still exceeds the alarm box.</td></tr>
<tr><td>d</td><td>Press the RUN function key. The instrument is now calibrated and ready for inspection.</td></tr>
</table>

NOTE: These are general procedures based off TO 33B–1–2, *Nondestructive Inspection General Procedures and Process Controls* using the Olympus Bondmaster 1000e+. Ensure you use the correct TO and reference manual for your equipment.

Mechanical impedance analysis technique

The driver portion of a single-tip dual-element probe generates low-frequency sound waves that transfer to mechanical movements in the test material. The stiffness and mass of the material measures the receiving sensor, and displays both phase and amplitude values. The *receiver* element at the bottom of the probe affects part stiffness. This changes from very high over bonded regions to low over unbonded regions. Since the measurements are a comparison of stiffness, results are better on stiff structures. Flexible composites would not have much change in stiffness from bonded to unbonded areas.

The MIA mode does not require couplant, and has a small contact area so it can be used on irregular or curved surfaces. The MIA technique seems most suitable for detecting damage associated with honeycomb core such as:

- Detecting skin-to-core disbonds, severely corroded aluminum core, and buckled or crushed core along with disbonds and delaminations. Typical positions of indications produced with the MIA technique are shown in figure 3–19.
- Containing a range of frequencies (e.g., 20–40 kHz or 30–50 kHz), generating ultrasonic Lamb (plate) waves within the part.
- Both the swept and impulse modes find similar types of defects but interpretation of indications is easier with the swept mode because both phase and amplitude simultaneously display the form of circular patterns on one x-y screen.
- Using on irregular or curved surfaces because of its small contact area.

During an inspection, only the "flying spot" would be present on the display as seen in figure 3–19. The gate box can be positioned anywhere on the display; the appropriate position is determined during calibration. Place the inspection area into grids to keep the inspection area down to a manageable size and to help solve your alignment problem. If the area is very large, special fixtures are normally manufactured to hold both transducers and keep them aligned.

The following is an example of the MIA technique setup. We will already assume that all probes are connected and the unit is defaulted.

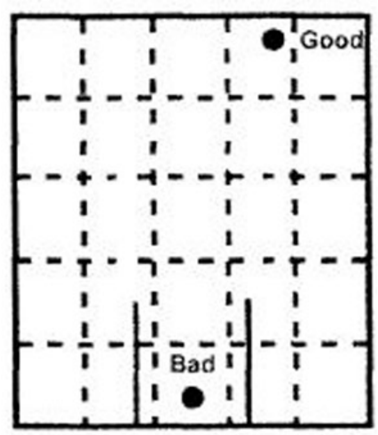


Figure 3–19. MIA technique.

Basic MIA technique	
Step	**Description**
a	Place the probe on good area of applicable reference standard as defined by the part-specific procedure, representing the number of plies or thickness inspected. Press GOOD PART soft key several times to ensure a consistent amplitude is obtained.
b	Place the probe on the defect area of the applicable reference standard as defined by the part-specific procedure, representing the number of plies or thickness inspected. Press BAD PART soft key several times to ensure a consistent amplitude trace is obtained.
c	Set the positive alarm.
d	Press RUN function key. Place probe on good area of reference standard and press the NULL function key.

<table>
<tr><th colspan="2">Basic MIA technique</th></tr>
<tr><th>Step</th><th>Description</th></tr>
<tr><td>e</td><td>Use vertical GAIN to set the good area of the dot at 90% FSH, which is 10% below the top of the screen.</td></tr>
<tr><td>f</td><td>Scan over the artificial defect and note the downward vertical deflection of the dot. If the dot does not remain within the alarm box when on the artificial defect, place probes on the artificial defect where the maximum deflection occurs. Hold probe firmly and increase the vertical GAIN setting to place the dot at 10% FSH (see figure 3–20). Place probe over good area and press NULL function key.

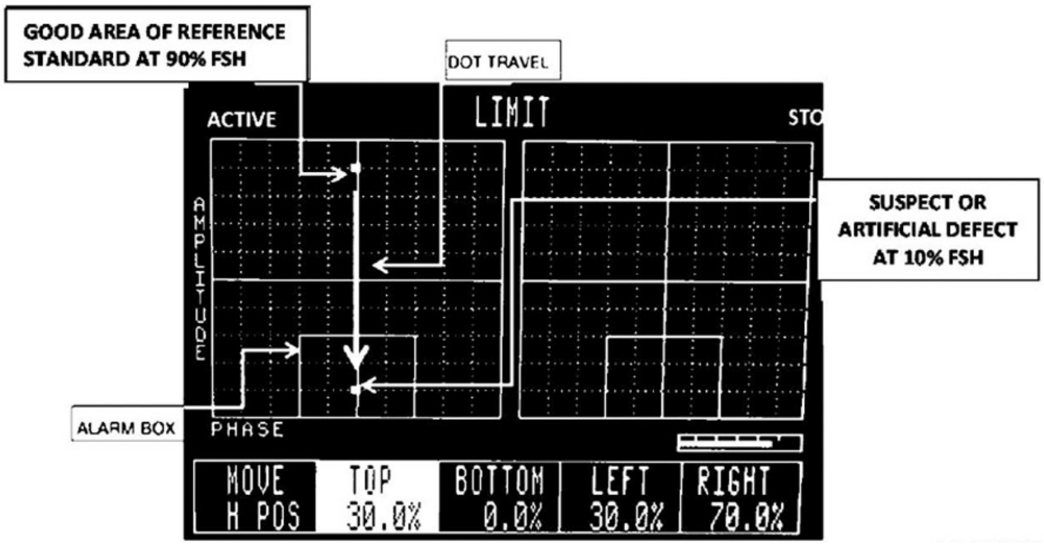


Figure 3–20. Good area nulled at 90% FSH (Defect signal at 10% FSH).</td></tr>
<tr><td>g</td><td>Scan the reference standard again, noting deflection of dot over the artificial defect. If the dot does not enter and remain within the alarm box.</td></tr>
<tr><td>h</td><td>Set up negative alarm and repeat steps d-g.</td></tr>
<tr><td>i</td><td>Scan around the good area of the reference standard several times. If the dot noise is less than 30 percent of the screen then proceed to inspection.</td></tr>
</table>

NOTE: These are general procedures based off TO 33B–1–2, *Nondestructive Inspection General Procedures and Process Controls* using the Olympus Bondmaster 1000e+. Ensure you use the correct TO and reference manual for your equipment.

Eddy-sonic method

Since this method is based on the generation of eddy currents in the test part, it will work only on metal structures. The instrument sends electrical pulses with frequencies in the low kHz range to a coil in the probe. Unbonds cause changes in the vibrations of the part. The resultant pulsating magnetic field produces eddy currents in the part; the eddy currents cause the part to vibrate, and a microphone on the axis of the coil detects the sonic vibrations. The detected changes produce an indication on a meter or an LED array.

Use eddy-sonic technique by the following:

- Use on metallic honeycomb structures with thin skins.
- Each probe usually has a mechanical lift-off adjustment that sets the air gap between the coil and the test surface to *minimize* the noise produced by probe scanning.

Other methods do as well on such configurations, because the eddy-sonic is rather limited in its application, it is not commonly used.

Advantages and limitations of bond method (bondmaster)

The following table outlines bondmaster inspection techniques, along with advantages and limitations of each.

	Resonance	Pitch-Catch	MIA	Eddy-Sonic
Advantages	• Locates layer position of unbonds. • Applicable to laminate or honeycomb structures. • Applicable to complex shapes.	• Applicable to honeycomb structures with thick or thin skins. • Detects small unbonds within the search unit diameter and smaller.	• Applicable to complex shapes. • Detects small near surface unbonds larger than diameter of search unit.	• Applicable to multilayered structures with thick or thin sheets. • Detects unbonds between any layers. • Detects small unbonds larger than diameter of search unit.
Limitations	• Inspection required from both sides of honeycomb structures. • Couplant required.	• Reduced effectiveness for unbonds greater than 0.80 inch below inspection surface. Access to both sides of honeycomb required. • Probe is directional with respect to locating boundaries of unbonds.	• Reduced effectiveness on purely laminated structures.	• Works only on metals. • Reduced effectiveness for unbonds farther from inspection surface and for low conductivity metals (titanium).

428. Operator maintenance

Preventive maintenance of the inspection unit is a regularly scheduled inspection that detects conditions leading to equipment malfunction. The frequency of your inspections will depend on your particular laboratory's practices, operator's manual, and technical data.

Preventive maintenance

When your unit has been out of service for an extended period or is due for a periodic inspection, perform a visual and electrical check before using the instrument. Inspect the entire exterior of the BondMaster® for damage, wear, and missing components. If an inspector drops or abuses the instrument, perform a 100 percent operational, electrical, and performance check in accordance with the BondMaster® equipment manual.

A visual inspection involves checking these items as a minimum:

1. Ensure all parts are installed and not missing.
2. Check all seams and joints for proper fit – look for exposed gasket material.
3. Make sure all connectors are undamaged and secure.
4. Ensure the SmartKnob is secure and rotates freely.
5. Carefully rotate the instrument and listen for any loose internal components.
6. Ensure the handle and all latches are firmly attached.
7. Tighten any loose connections and replace any missing parts as soon as possible.

Cleaning bondmaster instruments

Clean the outside of your unit using mild, general-purpose detergent. When the front panel becomes soiled, clean it with nonabrasive paper towels and isopropyl alcohol as follows:

1. Saturate a tissue with alcohol.
2. Wipe the entire panel surface.
3. Dispose of the tissue.
4. Saturate a second tissue.
5. Wipe the entire panel again.
6. Dispose of the second tissue.
7. Using a clean, dry tissue, wipe the entire panel until dry.
8. Inspect the panel for any residue and repeat steps one through seven as needed.

NOTE: Failure to use isopropyl alcohol when cleaning the front panel could result in permanent damage.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

425. General bond testing and variables

1. What are two general bond-testing methods?

2. What are visual inspection aids?

3. What is limited to the detection of upper facing sheets to adhesive disbonds or voids?

4. What are the locations of posable defect configurations?

426. Bond testing techniques using ultrasonic units

1. Through-transmission delaminations in either skin, unbonds between skin and core, and core damage prevent the transmission of sound to?

2. To prevent the generation of false indications due to misalignment you are required to move both transducers in tandem during which inspection technique?

3. What type of transducer is used for pulse-echo technique?

4. Which bond testing method measures thickness?

5. Which bond testing method inspects core-to-closure-member bonds (type IV)?

6. How do you know if a bond is good during the dampening technique?

7. What are the limitations of using through-transmission method?

8. What are the advantages of the rining method?

427. Bond testing techniques using bondmaster units

1. What four test methods are capable of the Sonic BondMaster?

2. Which bond testing technique has a detector in the instrument that measures phase and amplitude components of electrical impedance of the probe?

3. Depth of delaminations in the resonance technique can be estimated by using what?

4. Which bond testing technique uses a single ultrasonic frequency transmitted into a part by one transducer and a second transducer in the same probe assembly that receives the returned signal?

5. Which bond testing technique has a pulse containing a range of frequencies generating ultrasonic lamb waves within the part?

6. What bond testing technique uses a driver portion of a single-tip dual-element probe that generates low-frequency sound waves and transfers them to mechanical movements in the test material?

7. Why does the MIA mode have a small contact area?

8. What bond testing technique will work only on metal structures?

428. Operator maintenance

1. What is done to a bond-testing unit when it is out of service or has not been used for an extended period?

2. What should you do if a testing instrument has been dropped or abused?

3. What could result in permanent damage if not used?

Answers to Self-Test Questions

421

1. Two or more components adhesively bonded together.
2. Plywood or fiberglass.
3. Multiple laminates.
4. Honeycomb panels.
5. Produce varying indications.

422

1. It uses fibers of superior stiffness and strength.
2. The matrix.
3. Metal, ceramic, and polymers.
4. Thermoplastics.
5. Thermosets.
6. Fibers.
7. Boron fiber.
8. Carbon and graphite.
9. Aramid fibers.

423

1. The controlled disbonded areas.
2. Type II: Unbonds or voids at the adhesive-to-core interface.
3. By removing the adhesive in selected areas prior to assembly.
4. Inspection without standards.
5. Disbond.
6. It is indicated by a new response on the screen and a complete loss of the back surface response.
7. Adhesive filled edge repair areas.

424

1. Uses laser-based imaging interferometers to detect, measure, and analyze surface and subsurface anomalies in materials or structures by imaging submicroscopic changes to a test part surface when an appropriate stress is applied.
2. Composite aircraft panels, aircraft tires, control surfaces, metal honeycomb or foam core panels with metal or composite face sheets, elastomer or cork bonds, composite over-wrap pressure vessels (COPVs), spray on foam insulation (SOFI), and solid composite laminates.

3. A laser light source, a shearing image interferometer, an image-processing computer, display monitor, and a means to provide a controlled and repeatable stress to the test object.

425

1. Visual and tap test.
2. Mirrors, borescopes, and magnifiers.
3. Tap testing.
4. Probe-side skin material and thickness, adhesive type and thickness, structure under the skin, accessibility to one skin or both skins.

426

1. The receiving transducer.
2. Through-transmission.
3. Angle beam transducer.
4. Pulse-echo.
5. Ringing.
6. If the inspector can dampen multiple echoes from the far side of the bonded structure with a wet finger.
7. Access to both sides of part required, does not determine layer position of unbonds, alignment of search units is critical, couplant is required, and inspection rate is slow.
8. Applicable to complex shapes, and detects small near surface unbonds larger than diameter of search unit.

427

1. Resonance, Pitch/Catch swept, Pitch/Catch impulse (pulsed), and MIA.
2. Resonance.
3. The signal-phase rotation.
4. Pitch/Catch impulse.
5. Pitch/Catch sweep.
6. MIA.
7. It can be used on irregular or curved surfaces.
8. Eddy Sonic.

428

1. A visual and electrical inspection.
2. Perform a 100 percent operational, electrical, and performance check in accordance with the operator's manual.
3. Isopropyl alcohol when cleaning the front panel.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

55. (421) What is the adhesive in any lap joint assembly called?
    a. Sandwich panel.
    b. Bond line.
    c. Joint line.
    d. Doubler.

56. (421) Honeycomb core can be made of all of these *except*
    a. Balsa.
    b. Foam.
    c. Wood.
    d. Aluminum.

57. (421) What material is made of a fibrous material embedded in a resin matrix?
    a. Doubler.
    b. Honeycomb.
    c. Multiple laminate.
    d. Composite materials.

58. (422) What is an adhesive that bonds fibers to each other and gives side-to-side support?
    a. Glue.
    b. Matrix.
    c. Cement.
    d. Bond line.

59. (422) What are the principle load-carrying components in bonded or composite structures?
    a. Fibers.
    b. Aramid.
    c. Thermosets.
    d. Thermoplastics.

60. (422) Which fiber has high tensile and compression strength and a lack of galvanic corrosion potential, which makes it popular for repairs?
    a. Boron.
    b. Aramid.
    c. Carbon.
    d. Graphite.

61. (423) Which of the following is true regarding reference standards?
    a. Should not duplicate the test part.
    b. Fabricated using any adhesive and cure cycle.
    c. Must be similar to the test part with respect to material, size, and adhesive.
    d. Contain bonds of good quality except for controlled areas of unbond fabricated.

62. (423) How thick are the discs of Teflon sheets that are placed over the adhesive areas of bonded standards for type I, II, III, and IV disbonds?
   a. 0.003 inch.
   b. 0.006 inch.
   c. 0.009 inch.
   d. 0.012 inch.

63. (423) Which inspection technique(s) are used for far side skin to core disbonds?
   a. Mechanical impedance analysis (MIA) only.
   b. Ringing, through-transmission, and resonance.
   c. Through-transmission and mechanical impedance analysis (MIA).
   d. Resonance, ringing, through-transmission, and mechanical impedance analysis (MIA).

64. (423) What is an area within a bonded interface between two adherents in which the intended bonding action failed to take place called?
   a. Unbond.
   b. Disbond.
   c. Discontinuity.
   d. Delamination.

65. (424) What uses laser-based imaging to detect, measure, and analyze surface and subsurface irregularities in materials or structures?
   a. Bond testing.
   b. Shearography interferometry.
   c. Spray on foam insulation (SOFI) inspection.
   d. Composite over-wrap pressure vessels (COPVs) inspection.

66. (424) Shearography creates images showing the first derivative of the out-of-plane deformation of the test part surface in response to a change in load by using
   a. Lasers.
   b. Cameras.
   c. Interferometer.
   d. Image-processing computer.

67. (425) When visually assessing the integrity of bonds in honeycomb panels, what could indicate a delamination between sheets and core material?
   a. Holes or other defects.
   b. Scratches on the part surface.
   c. Signals from the bond-testing unit.
   d. Buckling or dents in the face or back sheet.

68. (425) Which bond testing method finds voids of 1 ½ inch diameter or larger in metal-to-metal, composite-to-metal, or thin facing-sheet honeycomb assemblies?
   a. Resonance.
   b. Pulse-echo.
   c. Tap testing.
   d. Through-transmission.

69. (426) All of these inspections utilize bond testing with an ultrasonic unit *except*
   a. damping.
   b. resonance.
   c. pulse-echo.
   d. through-transmission.

70. (426) Which bond testing method uses a delay line for better near surface resolution?
    a. Ringing.
    b. Resonance.
    c. Pulse-echo.
    d. Through-transmission.

71. (426) Which bond testing technique is based on absorption or energy loss in the bond line and core material?
    a. Ringing.
    b. Damping.
    c. Pulse-echo.
    d. Through-transmission.

72. (427) Which bond testing technique applies continuous electrical energy to the transducer *producing* standing waves within the material that cause it to vibrate?
    a. Ringing.
    b. Resonance.
    c. Pulse-echo.
    d. Through-transmission.

73. (427) Which bond testing method has a probe having mechanical lift-off adjustments that sets the air gap between the coil and the test surface to *minimize* the noise produced by probe scanning?
    a. Resonance.
    b. Eddy sonic.
    c. Pitch and catch.
    d. Mechanical impedance analysis (MIA).

74. (428) How do you clean your bondmaster when the front panel becomes soiled?
    a. Clean it with nonabrasive paper towels and isopropyl alcohol.
    b. Wipe the entire surface with soap and water.
    c. Use a lint free towel and solvent.
    d. Never clean a bondmaster unit.

Student Notes

Glossary of Abbreviations and Acronyms

AC	alternating current
ASTM	American Society of Testing and Materials
CDC	career development course
COPV	composite over-wrap pressure vessels
CRT	cathode ray tube
DAC	distance amplitude correction
dB	decibels
DC	direct current
E	Voltage
EDM	electro-discharge-machining
EL	electroluminescent
EMF	electromotive force
FBH	flat-bottom hole
FOV	field of view
FSH	full screen height
FSW	full screen width
HCF	high cycle fatigue
HPF	high pass filter
Hz	hertz
I	current
IACS	International Annealed Copper Standard
ID	inside diameter
IIW	International Institute of Welding
kHz	Kilohertz

L	inductance
Lbs	pounds
LCD	liquid crystal display
LCF	low cycle fatigue
LED	light-emitting-diode
LPF	low pass filter
MIA	Mechanical Impedance Analysis
MOI	Magneto-optic imaging
MHz	megahertz
NDI	nondestructive inspection
NIST	National Institute of Standards and Technology
OD	outside diameter
PMEL	Precision Measurement Equipment Laboratory
POI	point of incidence
PTP	peak to peak
R	Resistance
SAE	Society of Automotive Engineers
SOFI	spray on foam insulation
TMDE	Test and Measurement Diagnostic Equipment
TCTO	time compliance technical orders
TO	technical order
WP	work package

Student Notes

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