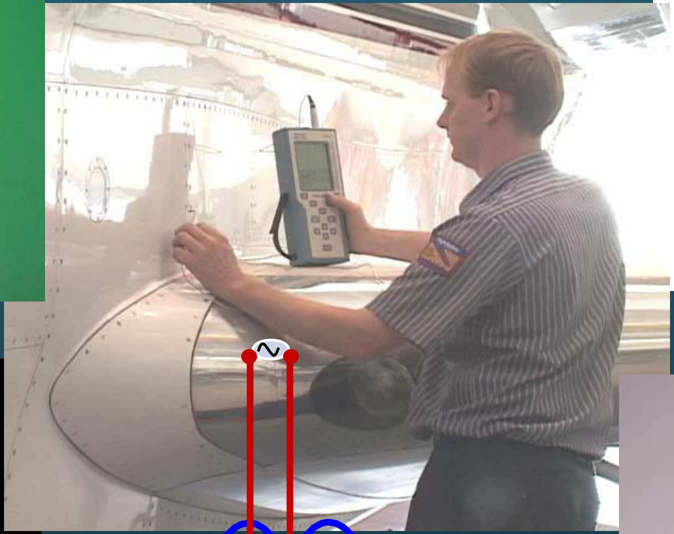
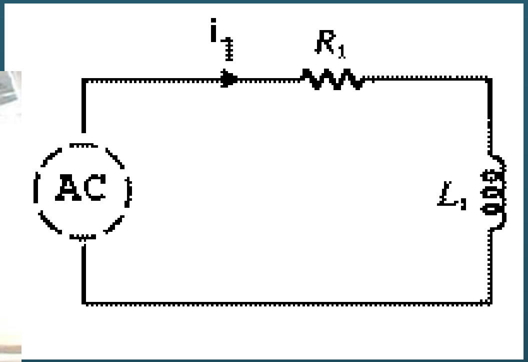
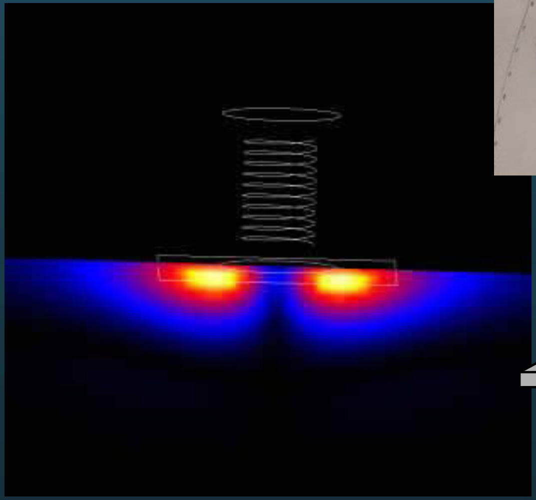
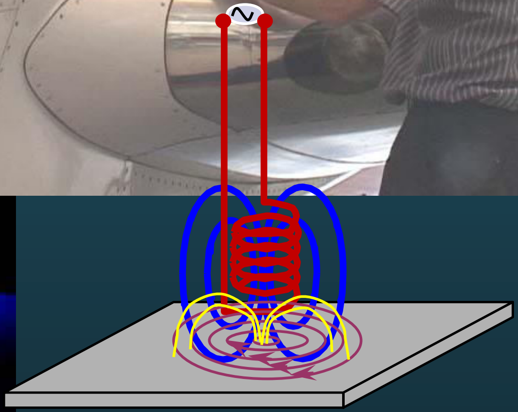
EDDY CURRENT TESTING









Introduction

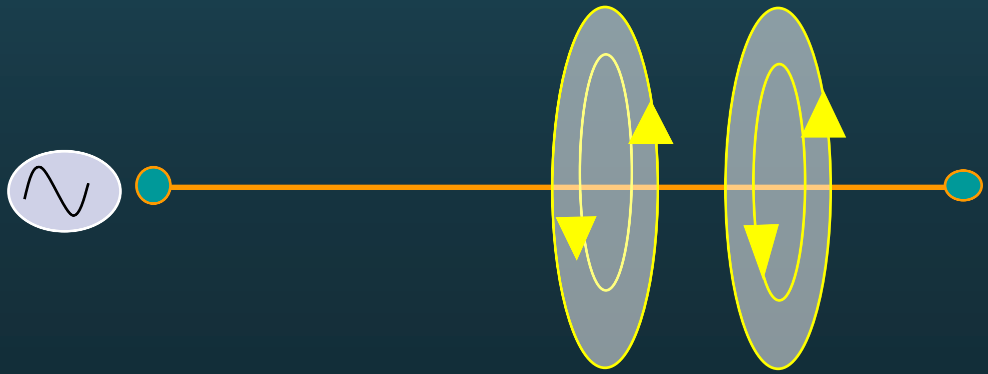
- This module is intended to present information on the NDT method of eddy current inspection.
- Eddy current inspection is one of several methods that use the principal of “electromagnetism” as the basis for conducting examinations. Several other methods such as Remote Field Testing (RFT), Flux Leakage and Barkhausen Noise also use this principle.

Outline

- Electromagnetic induction
- Generation of eddy currents
- Inspection applications
- Equipment utilized in eddy current inspection
  - Probes/Coils
  - Instrumentation
  - Reference standard
- Advantages and Limitations
- Glossary of Terms

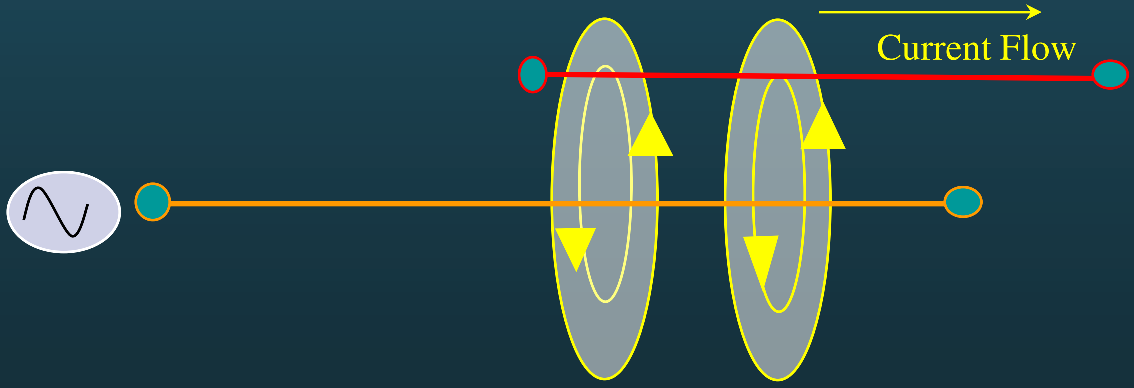
Electromagnetic Induction

- Eddy currents are created through a process called electromagnetic induction.
- When alternating current is applied to the conductor, such as copper wire, a magnetic field develops in and around the conductor.
- This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero.



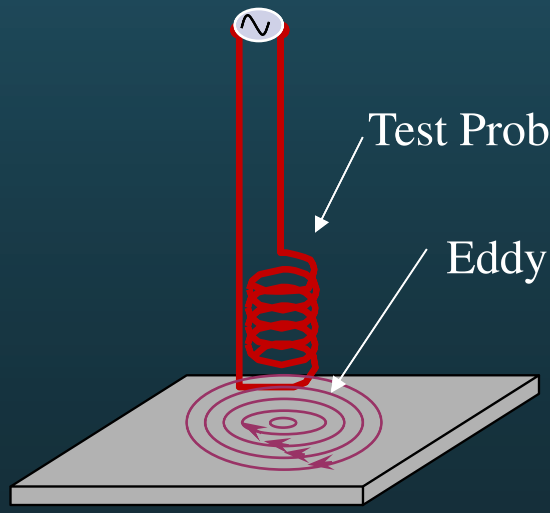
Electromagnetic Induction (cont.)

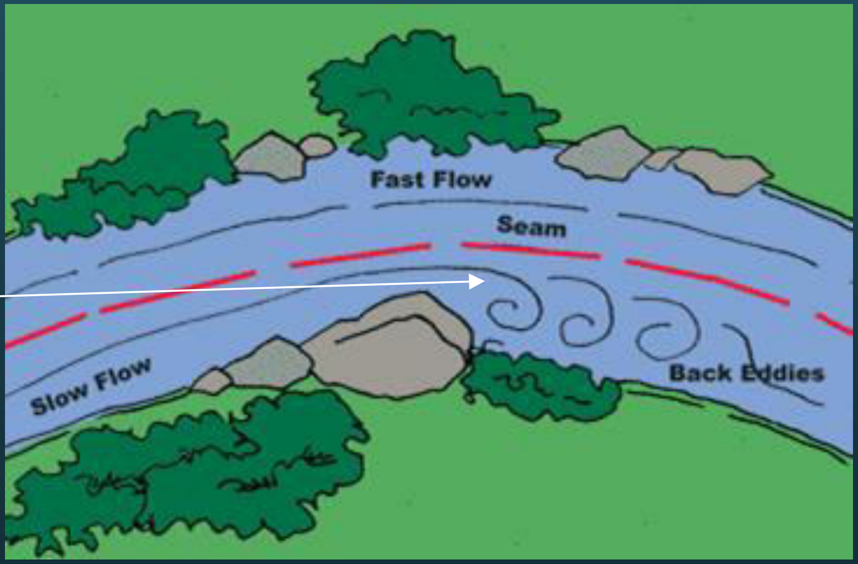
If another electrical conductor is brought into the proximity of this changing magnetic field, the reverse effect will occur. Magnetic field cutting through the second conductor will cause an “induced” current to flow in this second conductor. Eddy currents are a form of induced currents!



Generation of Eddy Currents

Eddy currents are induced electrical currents that flow in a circular path. They get their name from "eddies" that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right.





Generation of Eddy Currents (cont.)

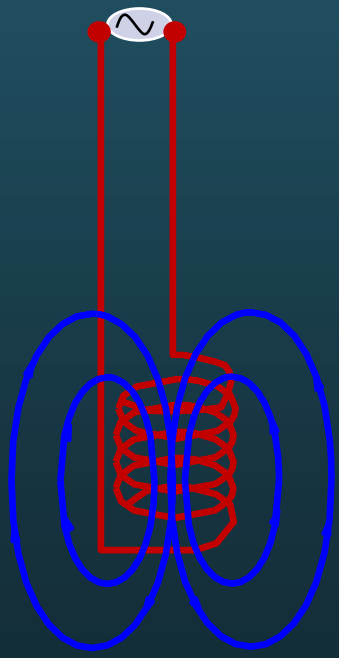
In order to generate eddy currents for an inspection a "probe" is used. Inside the probe is a length of electrical conductor which is formed into a coil.

Generation of Eddy Currents (cont.)

Alternating current is allowed to flow in the coil at a frequency chosen by the technician for the type of test involved.

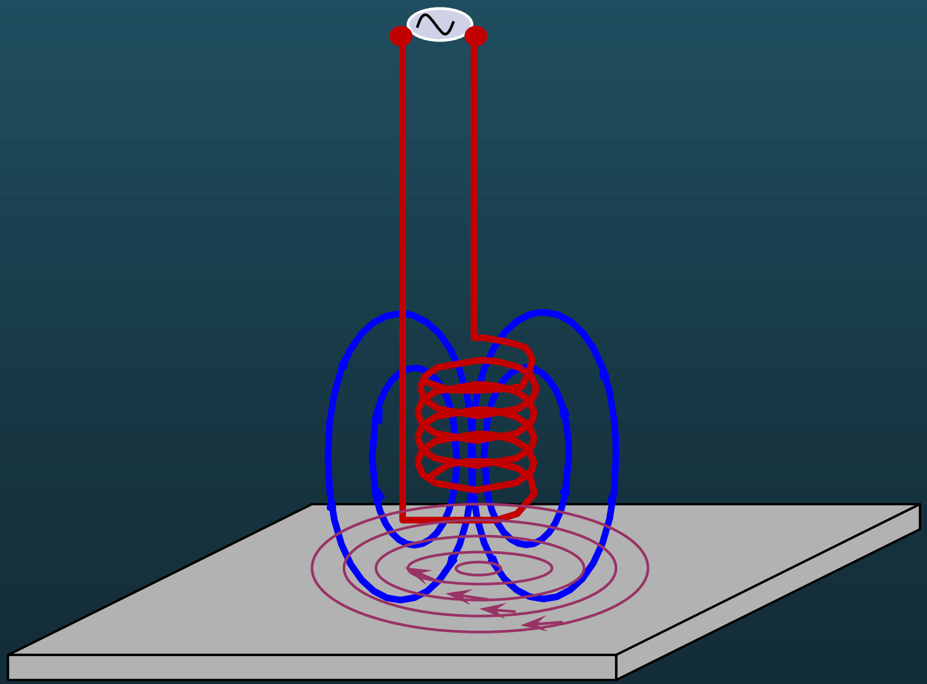
Generation of Eddy Currents (cont.)

A dynamic expanding and collapsing magnetic field forms in and around the coil as the alternating current flows through the coil.



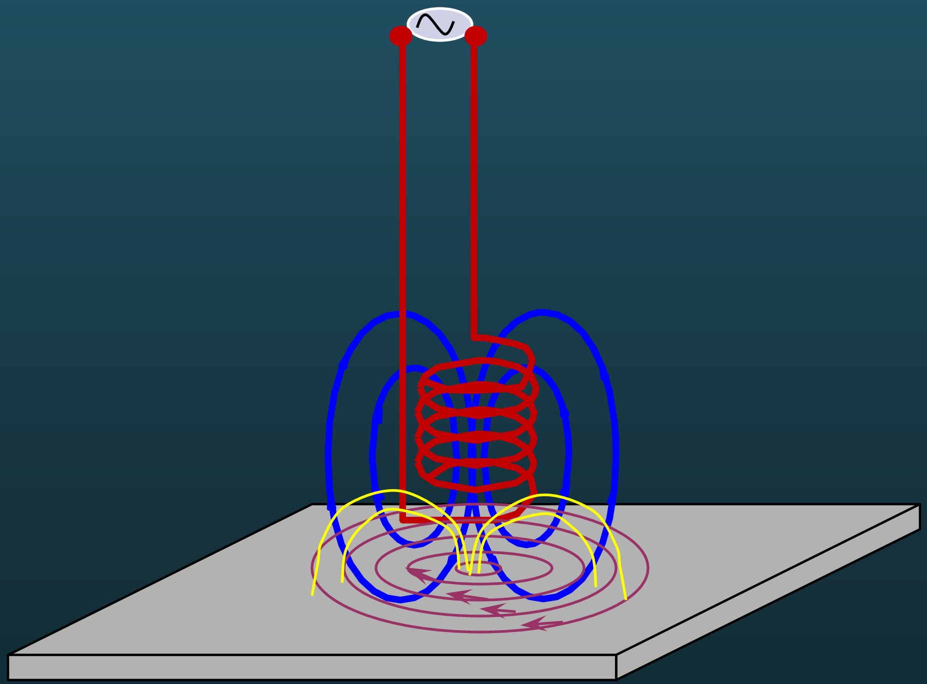
Generation of Eddy Currents (cont.)

When an electrically conductive material is placed in the coil's dynamic magnetic field electromagnetic, induction will occur and eddy currents will be induced in the material.



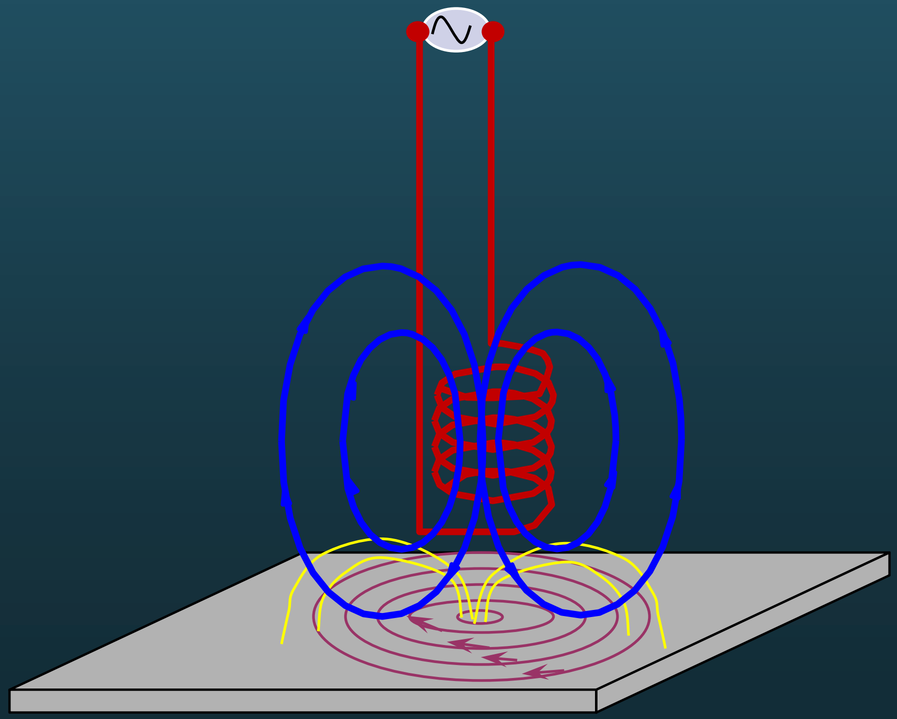
Generation of Eddy Currents (cont.)

Eddy currents flowing in the material will generate their own "secondary" magnetic field which will oppose the coil's "primary" magnetic field.



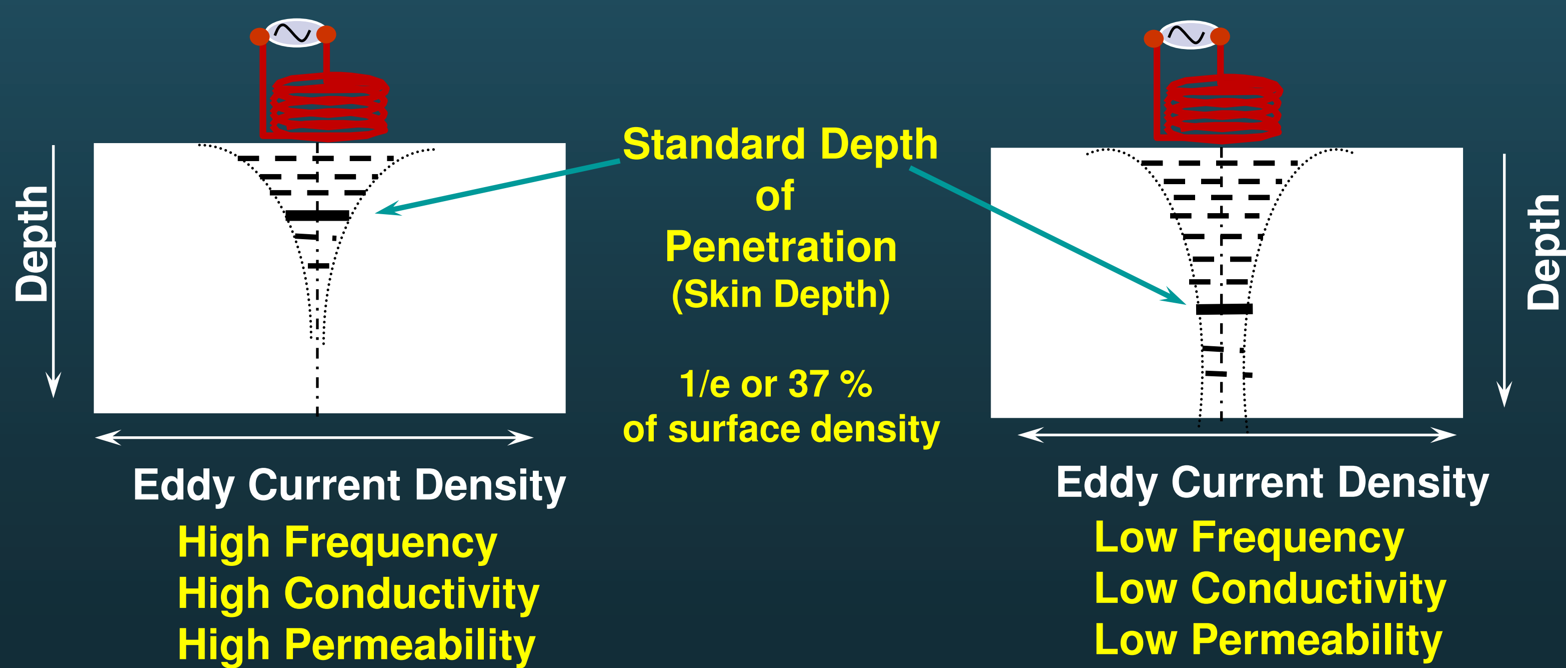
Generation of Eddy Currents (cont.)

This entire electromagnetic induction process to produce eddy currents may occur from several hundred to several million times each second depending upon inspection frequency.



Generation of Eddy Currents (cont.)

Eddy currents are strongest at the surface of the material and decrease in strength below the surface. The depth that the eddy currents are only 37% as strong as they are on the surface is known as the standard depth of penetration or skin depth. This depth changes with probe frequency, material conductivity and permeability.

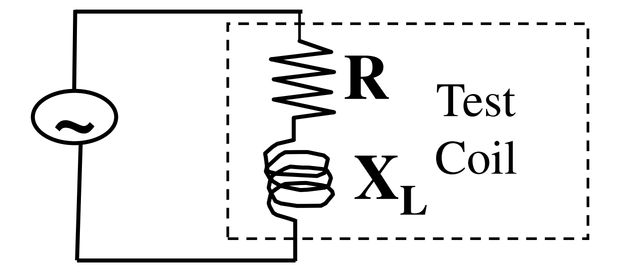


Inspection Data

- There are three characteristics of the specimen that affect the strength of the induced eddy currents.
  - The electrical conductivity of the material
  - The magnetic permeability of the material
  - The amount of solid material in the vicinity of the test coil.
- Information about the strength of the eddy currents within the specimen is determined by monitoring changes in voltage and/or current that occur in the coil.
- The strength of the eddy currents changes the electrical impedance (Z) of the coil.

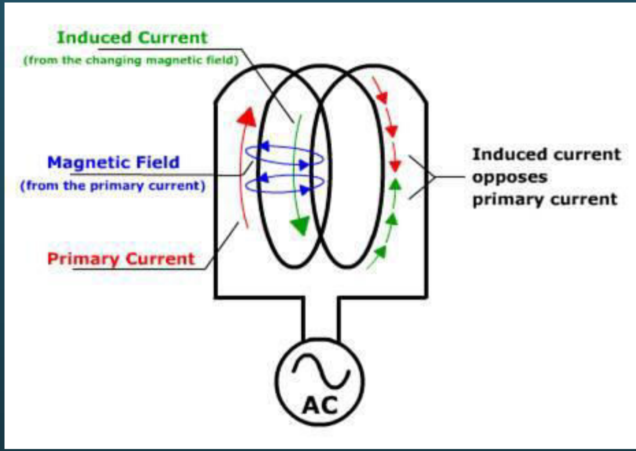
Inspection Data (cont.)

Impedance (Z) in an eddy current coil is the total opposition to current flow. In a coil, Z is made up of resistance (R) and inductive reactance (XL).



Definitions:

- Resistance - The opposition of current flow, resulting in a change of electrical energy into heat or another form of energy.
- Inductive Reactance (X_L) - Resistance to AC current flow resulting from electromagnetic induction in the coil.
- Impedance (Z) - The combined opposition to current flow resulting from inductive reactance and resistance.



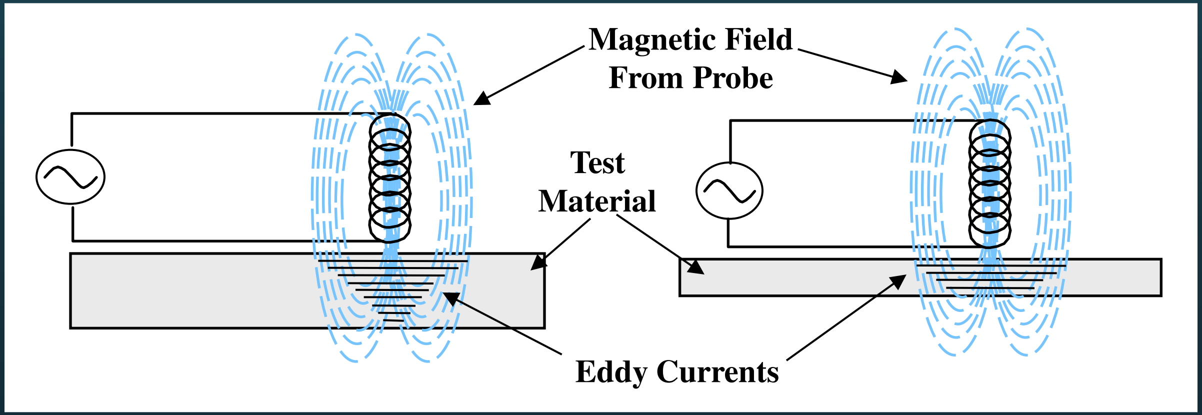
In an AC coil, induction from the magnetic field of one loop of the coil causes a secondary current in all other loops. The secondary current opposes the primary current.

Inspection Applications

One of the major advantages of eddy current as an NDT tool is the variety of inspections that can be performed. The following slides depict some of the these capabilities.

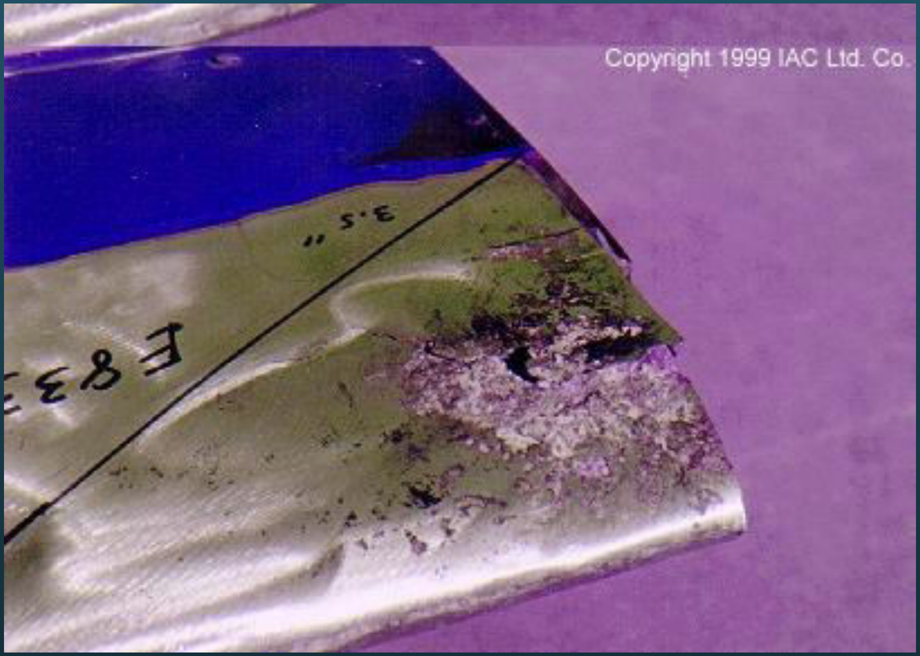
Material Thickness Measurement

- Thickness measurements are possible with eddy current inspection within certain limitations.
- Only a certain amount of eddy currents can form in a given volume of material.
- Therefore, thicker materials will support more eddy currents than thinner materials.
- The strength (amount) of eddy currents can be measured and related to the material thickness.



Material Thickness Measurement (cont.)

Eddy current inspection is often used in the aviation industries to detect material loss due to corrosion and erosion.

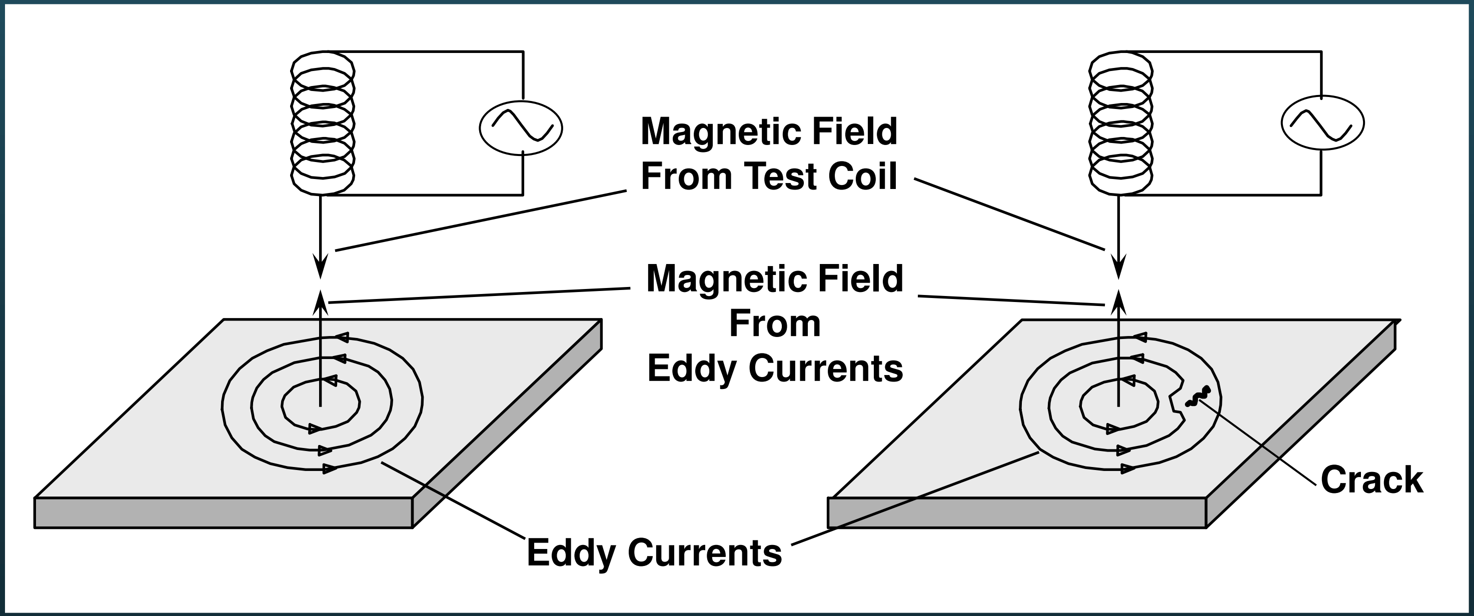


Material Thickness Measurement (cont.)

Eddy current inspection is used extensively to inspect tubing at power generation and petrochemical facilities for corrosion and erosion.

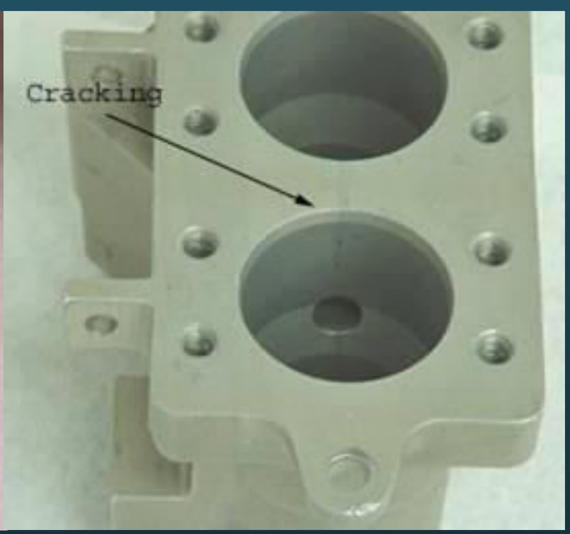
Crack Detection

Crack detection is one of the primary uses of eddy current inspection. Cracks cause a disruption in the circular flow patterns of the eddy currents and weaken their strength. This change in strength at the crack location can be detected.



Crack Detection (cont.)

Eddy current inspection is exceptionally well suited for the detection of cracks, with an especially high sensitivity to detection of surface breaking cracks.

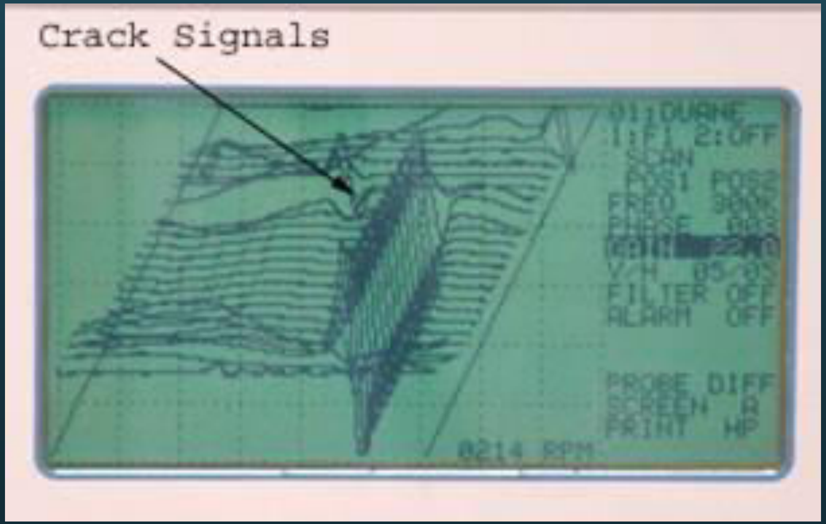


Crack Detection (cont.)

Eddy current inspection of "bead seat" area on aircraft wheel for cracks using special probe that conforms to the shape of the rim.

Crack Detection (cont.)

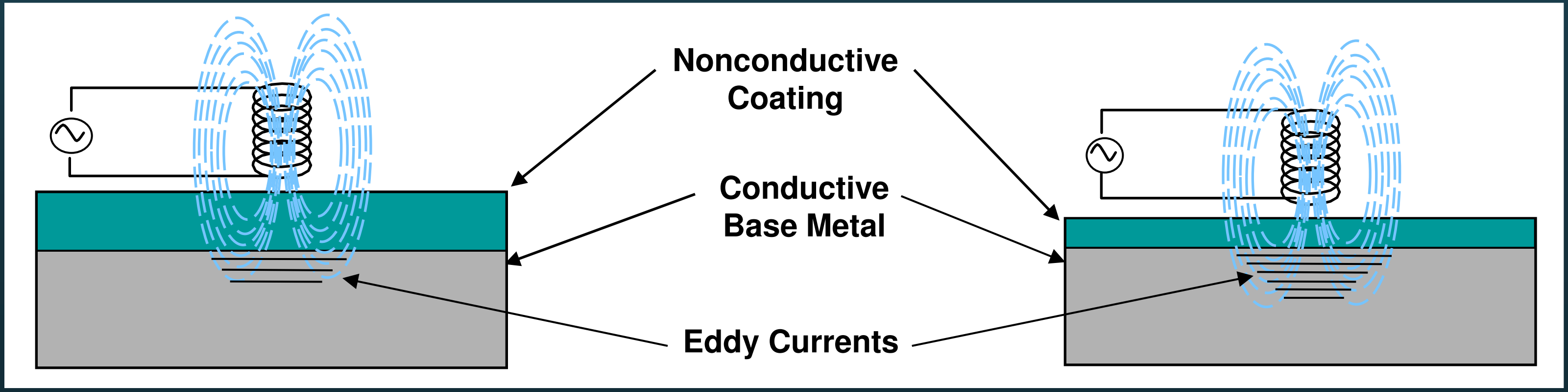
Loading points, such as fastener holes, are high stress areas and often the site of service induced fatigue cracking. Rotating probe guns can be used to inspect a large number of holes in a short period of time. The photo on the right is a waterfall plot of the cross section of a fastener hole. Each horizontal line represents one rotation of the probe gun. A vertical signal indicates a crack.



Nonconductive Coating Measurement

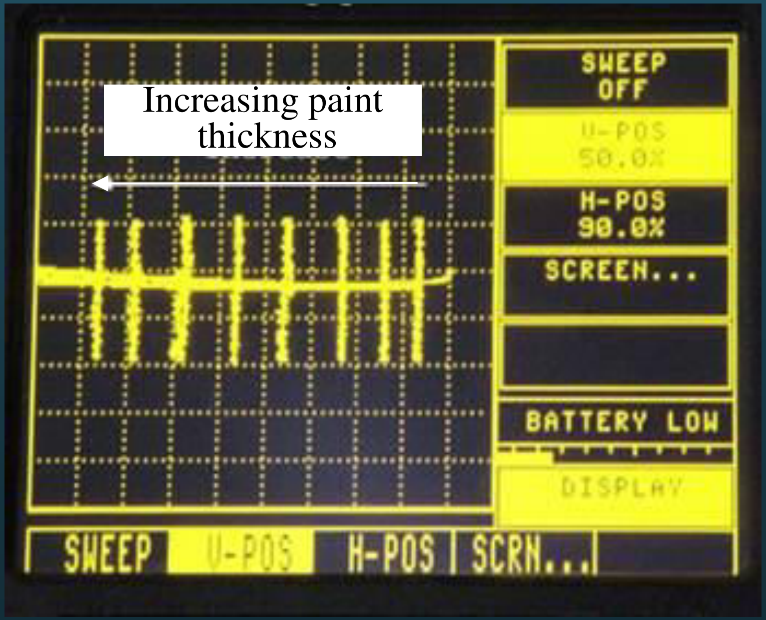
Nonconductive coatings on electrically conductive substrates can be measured very accurately with eddy current inspection. (Accuracy of less that one mil is not uncommon.)

- The coating displaces the eddy current probe from the conductive base material and this weaken the strength of the eddy currents.
- This reduction in strength can be measured and related to coating thickness.



Nonconductive Coating Measurement (cont.)

The photo to the left shows an aircraft panel paint thickness inspection. On the right, the display of a digital eddy current inspection instrument shows the different signals obtained by measuring eight different thicknesses of paint on aluminum.



Monitoring Conductivity and Permeability Variations

Eddy current inspection is sensitive to changes in a material's electrical conductivity and magnetic permeability. This "sensitivity" allows the inspection method to be used for such inspection procedures as:

- Material Identification
- Material Sorting
- Determination of heat damage
- Cladding and plating thickness measurement
- Heat treatment monitoring

Conductivity Measurements

Boeing employees in Philadelphia were given the privilege of evaluating the Liberty Bell for damage using NDT techniques. Eddy current methods were used to measure the electrical conductivity of the Bell's bronze casing at a various points to evaluate its uniformity.

Equipment

- Equipment for eddy current inspection is very diversified. Proper equipment selection is important if accurate inspection data is desired for a particular application.
- As a minimum, at least three basic pieces of equipment are needed for any eddy current examination:
  - Instrumentation
  - Probes
  - Reference Standards

Instrumentation - Meters

Meters are typically the simplest form of eddy current instrumentation.

The two general categories of meters are digital and analog.

Digital Meters

Digital meters are typically designed to examine one specific attribute of a test component such as conductivity or nonconductive coating thickness. These meters tend to have slightly higher accuracy than analog devices.

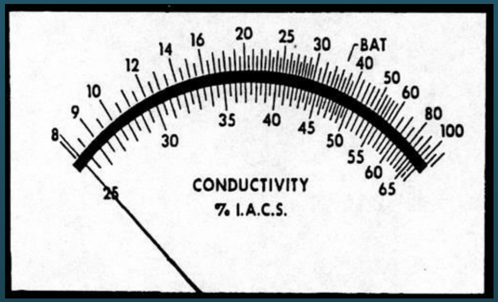
Analog Meters

Analog meters can be used for many different inspection applications such as crack detection, material thickness measurements, nonconductive coating measurements or conductive coating measurements.

Analog Meters (cont.)

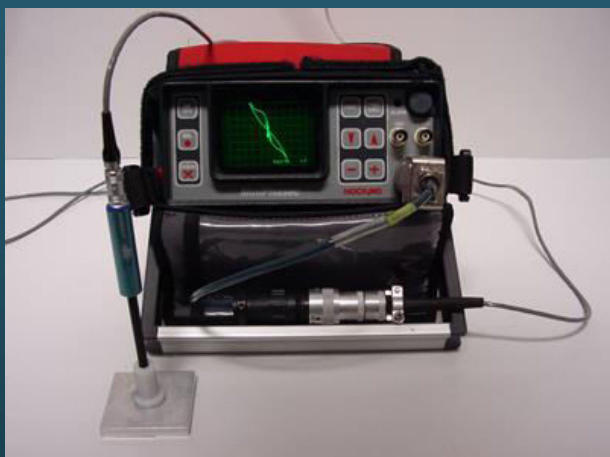
The display read-out found on most analog instruments is typically either a calibrated or uncalibrated display.

- Calibrated displays have an inherent scaling factor which correlates to the property the instrument is designed to measure such as conductivity.



- Uncalibrated displays are typically more flexible in the variety of different tests they can perform. These types of instruments, however, require the use of data extrapolation techniques if quantitative data is desired.

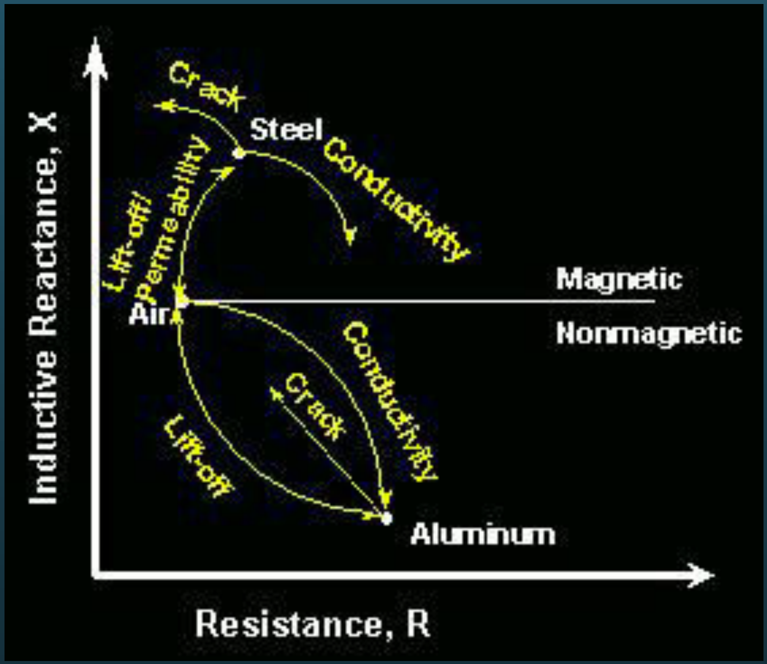
Portable Eddy Scopes



Portable Eddy Scopes (cont.)

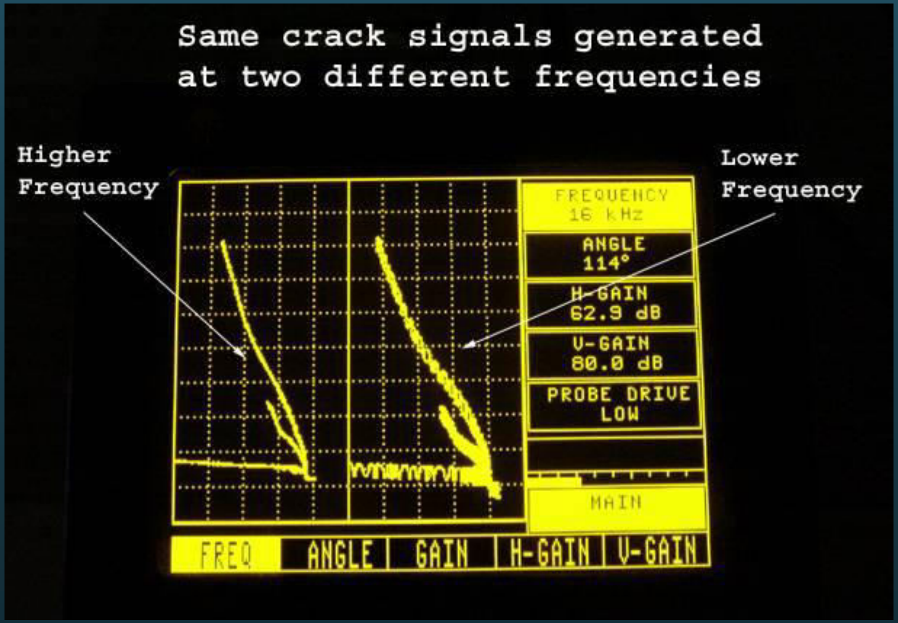
Portable eddy scopes are another category of instrumentation and they present the inspection data in the form of an impedance plane diagram.

- On the impedance diagram, the total impedance is displayed by plotting its resistance component and inductive reactance component at 90 degrees to each other.
- This is beneficial for both separation and identification of test variables that can effect inspection results.



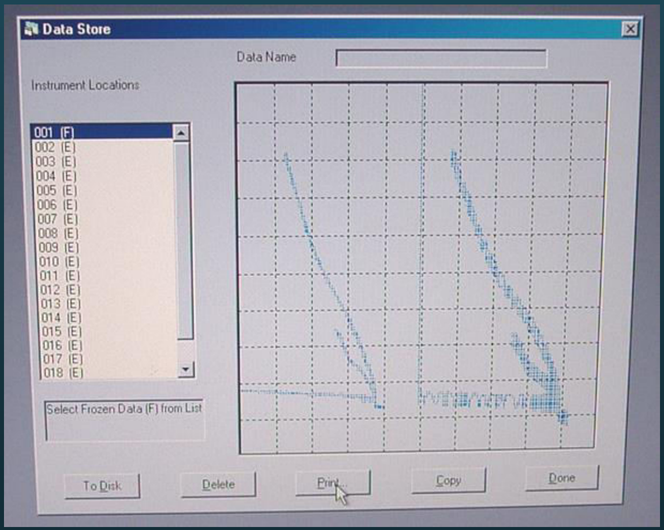
Portable Eddy Scopes (cont.)

Modern eddy scopes are usually digital based instruments which can often be purchased as either a single or dual frequency tester. Dual frequency instruments are capable of sequentially driving a probe at two different inspection frequencies.

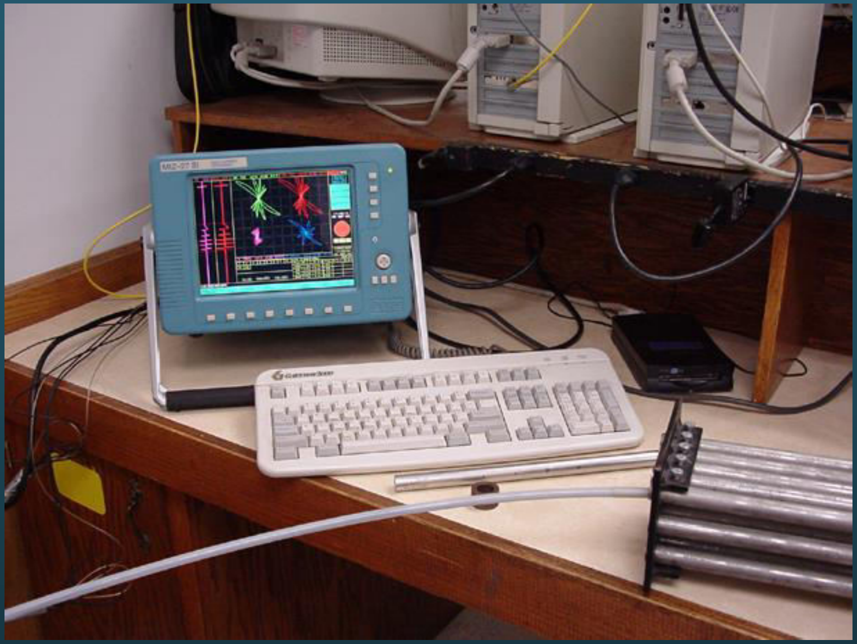


Portable Eddy Scopes (cont.)

Digital scopes often have an RS232 (serial) connection for interfacing with a serial printer or computer as well as provisions for output of signals to recording devices such as a strip-chart recorder. In addition, these instruments contain a small amount of RAM so that equipment settings as well as screen presentations can be stored for later reference.



Multi-Frequency Eddy Current Instruments



Multi-Frequency Eddy Current Instruments (cont.)

- Multi-Frequency instruments usually refer to equipment that can drive inspection coils at more than two frequencies either sequentially (multiplexing) or simultaneously.
- This type of instrumentation is used extensively for tubing inspection in the power generation, chemical and petrochemical industries.
- These instruments are often capable of being computer networked and may have as many as four probes attached to them at one time.

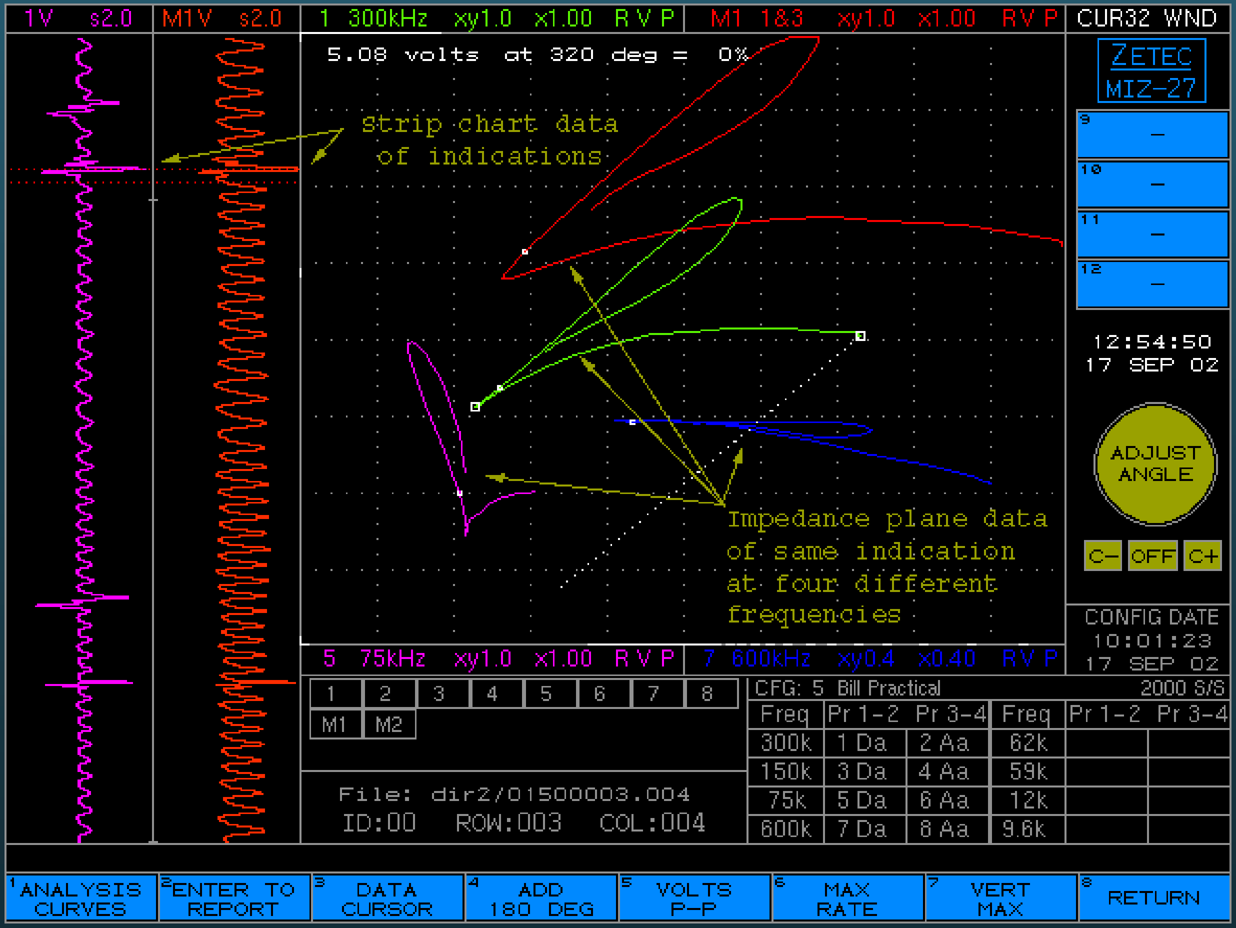
Multi-Frequency Eddy Current Instruments (cont.)

Advantages of Multi-frequency inspections:

- Allows increased inspection information to be collected from one probe pulling.
- Provides for comparison of same discontinuity signal at different frequencies.
- Allows mixing of frequencies which helps to reduce or eliminate sources of noise.
- Often improves detection, interpretation and sizing capabilities of discontinuities.

Multi-Frequency Eddy Current Instruments (cont.)

Screen of multi-frequency instrument during inspection.



Eddy Current Probes

Eddy Current Probes (cont.)

- Probes selection is critical to acquiring adequate inspection data.
- Several factors to consider include:
  - Material penetration requirements (surface vs. subsurface)
  - Sensitivity requirements
  - Type of probe connections on eddy current instrument (many variations)
  - Probe and instrument impedance matching (will probe work with instrument)
  - Probe size (smaller probes penetrate less)
  - Probe type (absolute, differential, reflection or hybrid)

Eddy Current Probes (cont.)

- Due the the large variety of probes in eddy current testing there are many different systems of classification.
- Three of the most common classifications are:
  - Surface probes
  - Inside Diameter (I.D.) or Bobbin Probes
  - Outside Diameter (O.D.) or Encircling probes

Eddy Current Probes (cont.)

Surface probes are coils that are typically mounted close to one end of a plastic housing. As the name implies, the technician moves the coil end of the probe over the surface of the test component.

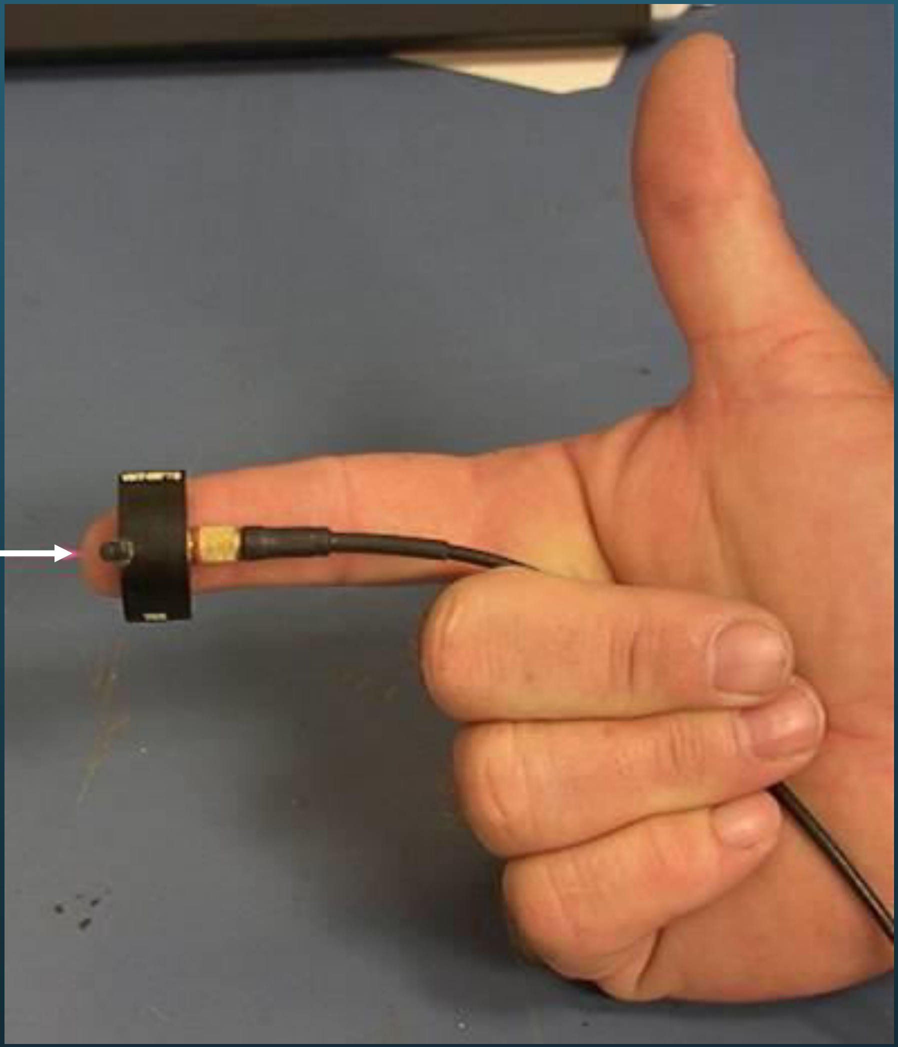
Eddy Current Probes (cont.)

Some surface probes are specifically designed for crack detection of fastener holes. These include sliding probes, ring probes and hole probes.

Eddy Current Probes (cont.)

- Surface probes can be very small in size to allow accessibility to confined areas.

Finger Probe →



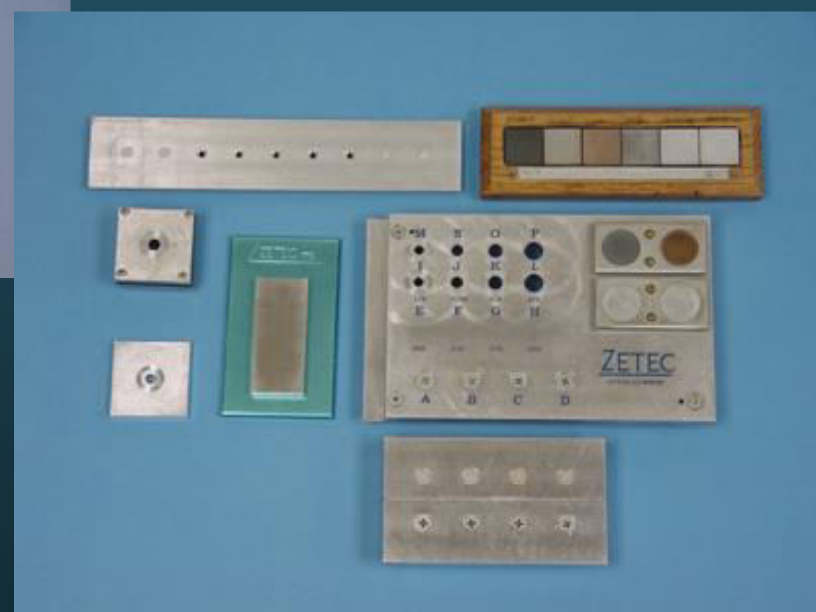
Eddy Current Probes (cont.)

Inside Diameter (I.D.) probes, also known as bobbin probes, are coils that are usually wound circumferentially around a plastic housing. These probes are primarily designed for inspection inside of tubular materials.

Eddy Current Probes (cont.)

Outside Diameter (O.D.) probes are coils that are wound the circumference of a hollow fixture. The coil is designed such that the test part is ran through the middle of the coil. These probes can be used to inspect bars, rods as well as tubes.

Reference Standards

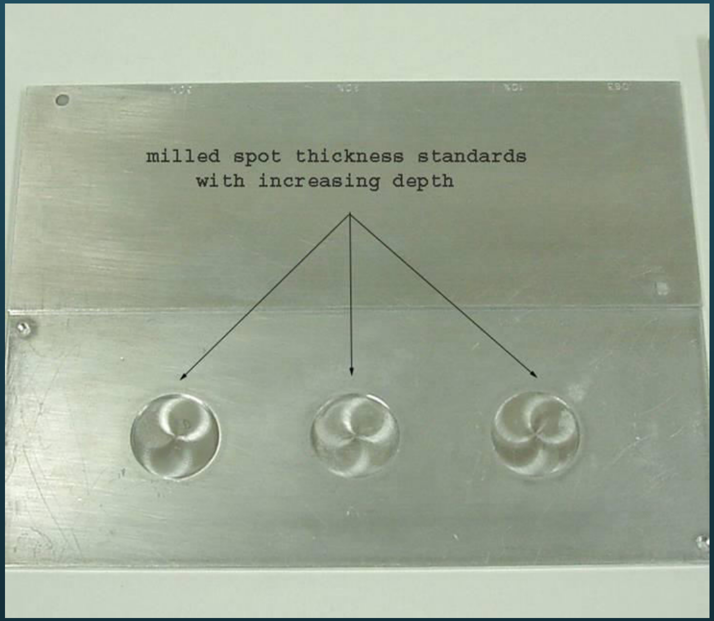


Reference Standards (cont.)

- In order to give the eddy current inspector useful data while conducting an inspection, signals generated from the test specimen must be compared with known values.
- Reference standards are typically manufactured from the same or very similar material as the test specimen.
- Many different types of standards exist for due to the variety of eddy current inspections performed.
- The following slides provide examples of specific types of standards.

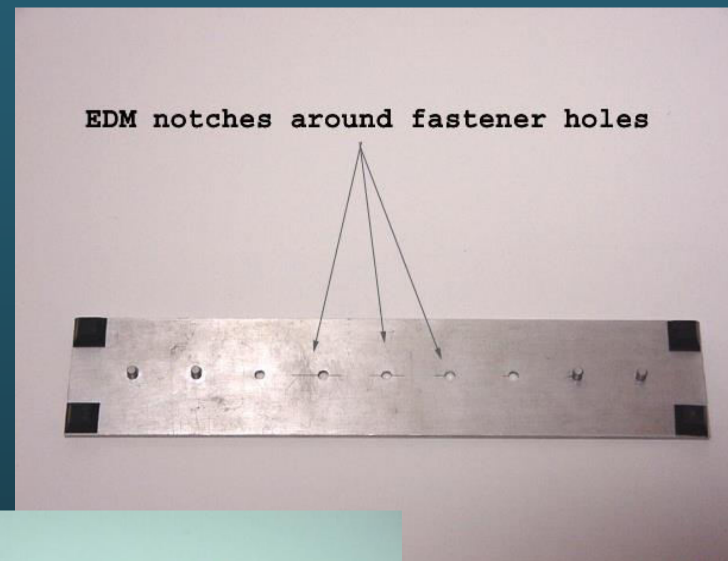
Reference Standards (cont.)

Material thickness standards used to help determine such things as material thinning caused by corrosion or erosion.



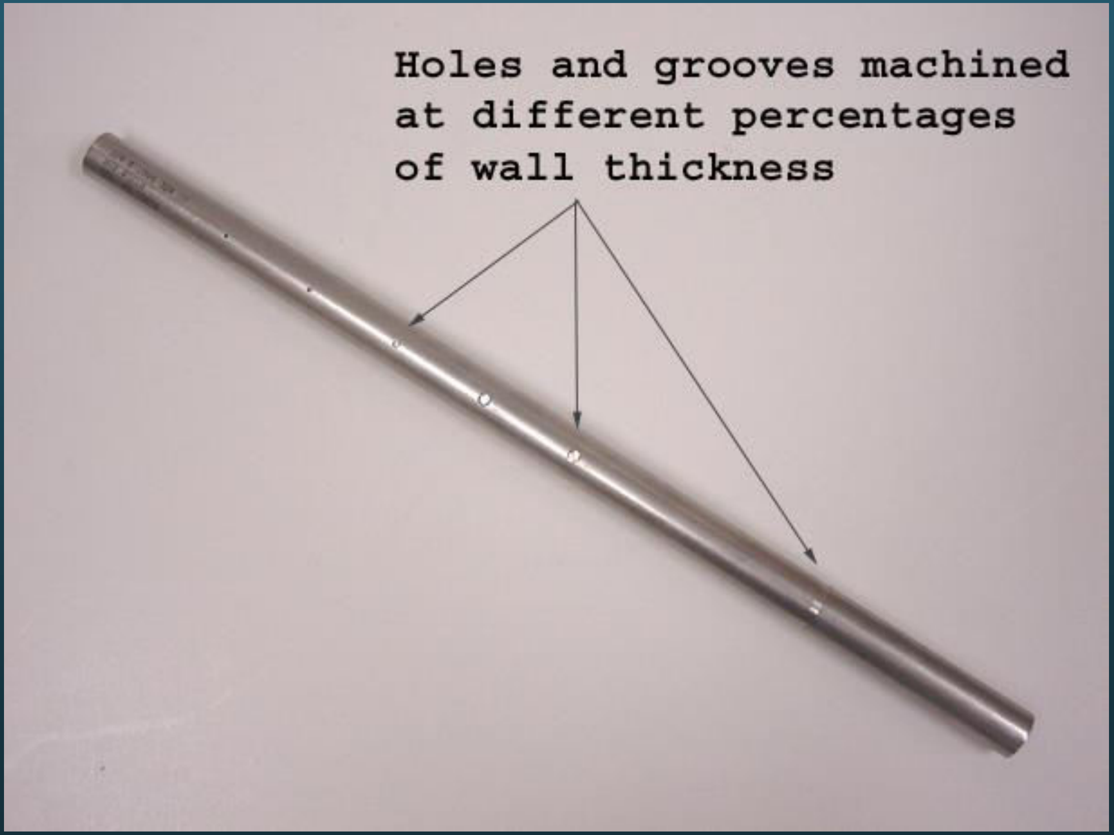
Reference Standards (cont.)

Crack Standards:



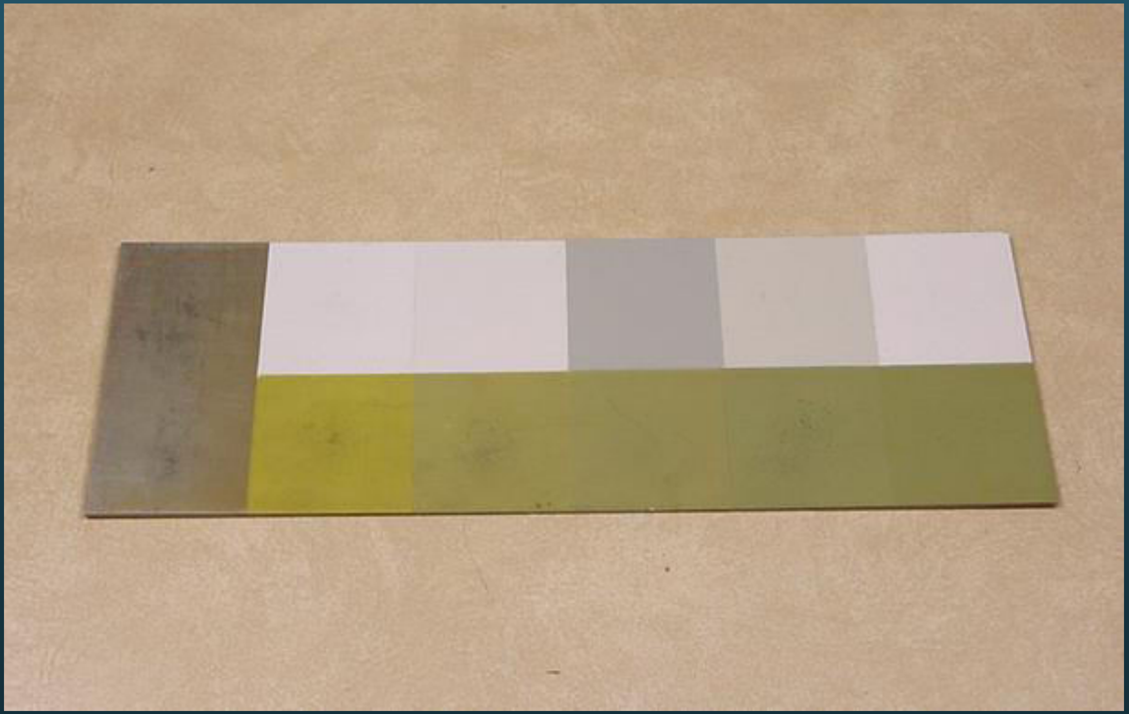
Reference Standards (cont.)

ASME Tubing Pit Standard:



Reference Standards (cont.)

Nonconductive coating (paint) standard with various thickness of paint on aluminum substrate.



Advantages of Eddy Current Inspection

- Sensitive to small cracks and other defects
- Detects surface and near surface defects
- Inspection gives immediate results
- Equipment is very portable
- Method can be used for much more than flaw detection
- Minimum part preparation is required
- Test probe does not need to contact the part
- Inspects complex shapes and sizes of conductive materials

Limitations of Eddy Current Inspection

- Only conductive materials can be inspected
- Surface must be accessible to the probe
- Skill and training required is more extensive than other techniques
- Surface finish and and roughness may interfere
- Reference standards needed for setup
- Depth of penetration is limited
- Flaws such as delaminations that lie parallel to the probe coil winding and probe scan direction are undetectable

Glossary of Terms

- **Alternating Current**: electrical current that regularly reverses direction.
- **Analog**: being or relating to a mechanism in which data is represented by continuously variable physical quantities such as a watch with hour and minute hands.
- **ASME**: acronym for American Society of Mechanical Engineers. This society is highly involved in establishing and maintaining industrial standards.

Glossary of Terms

- **CRT**: acronym for Cathode Ray Tube. Vacuum tube that uses one or more electron guns for generating an image.
- **Calibration**: adjustment of a test systems response using known values so that unknown quantities may be derived.
- **Conductor**: material capable of allowing electrical current to flow through it.
- **Discontinuity**: an interruption in the physical structure of a part. Cracks are examples of discontinuities.
- **EDM**: acronym for Electrical Discharge Machine.

Glossary of Terms

- **EDM**: acronym for Electrical Discharge Machine. Machining technique which uses an electrode and electrical current to remove metal. Sometimes used to prepare calibration standards for eddy current testing.
- **Electromagnetic Induction**: process which creates electrical current flow when a dynamic magnetic field is brought into close proximity with an electrical conductor.
- **Extrapolation**: to project or predict unknown values from know quantities.

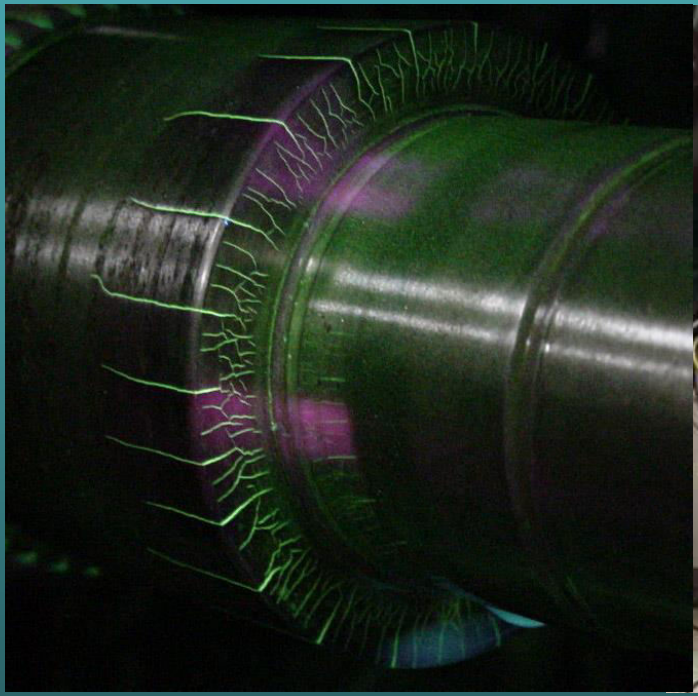
Glossary of Terms

- **I.A.C.S.**: acronym for International Annealed Copper Standard. Standard unit of measurement of electrical conductivity in eddy current testing with pure annealed copper as the standard, measuring 100% at 20 degrees Celsius.
- **Impedance Plane Diagram**: A diagram that depicts the changes in electrical impedance that occur in an eddy current coil as test variables change.
- **Multiplexing**: use of a time sharing system in which a coil is stimulated at several different frequencies one after another for a certain amount of time. Results from each stimulation can then be processed and displayed.

Glossary of Terms

- **Permeability**: the ease with which a material can be magnetized.
- **Probe**: common term used in eddy current inspection that refers to the test coil.
- **RAM**: acronym for Random Access Memory. Most modern eddy current instruments have some form of memory used as a data buffer to store information.

MAGNETIC PARTICLE TESTING



Introduction

- This module is intended to present information on the widely used method of magnetic particle inspection.
- Magnetic particle inspection can detect both production discontinuities (seams, laps, grinding cracks and quenching cracks) and in-service damage (fatigue and overload cracks).

Outline

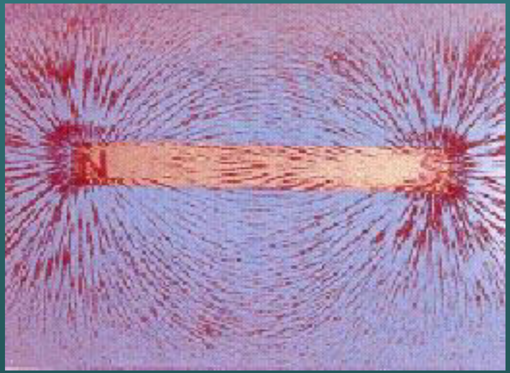
- Magnetism and Ferromagnetic Materials
- Introduction of Magnetic Particle Inspection
- Basic Procedure and Important Considerations
    1. Component pre-cleaning
    2. Introduction of magnetic field
    3. Application of magnetic media
    4. Interpretation of magnetic particle indications
- Examples of MPI Indications

Introduction to Magnetism

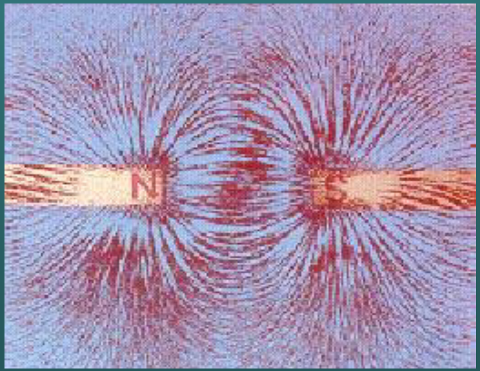
Magnetism is the ability of matter to attract other matter to itself. Objects that possess the property of magnetism are said to be magnetic or magnetized and magnetic lines of force can be found in and around the objects. A magnetic pole is a point where the a magnetic line of force exits or enters a material.

Magnetic field lines:

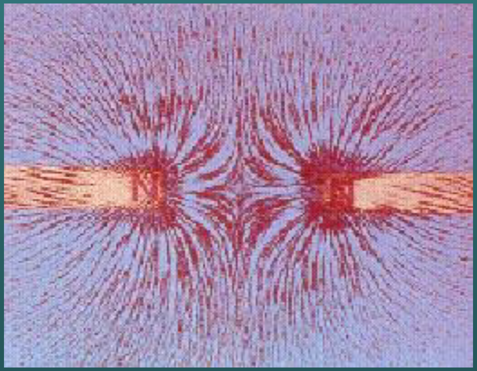
- Form complete loops.
- Do not cross.
- Follow the path of least resistance.
- All have the same strength.
- Have a direction such that they cause poles to attract or repel.



Magnetic lines of force around a bar magnet



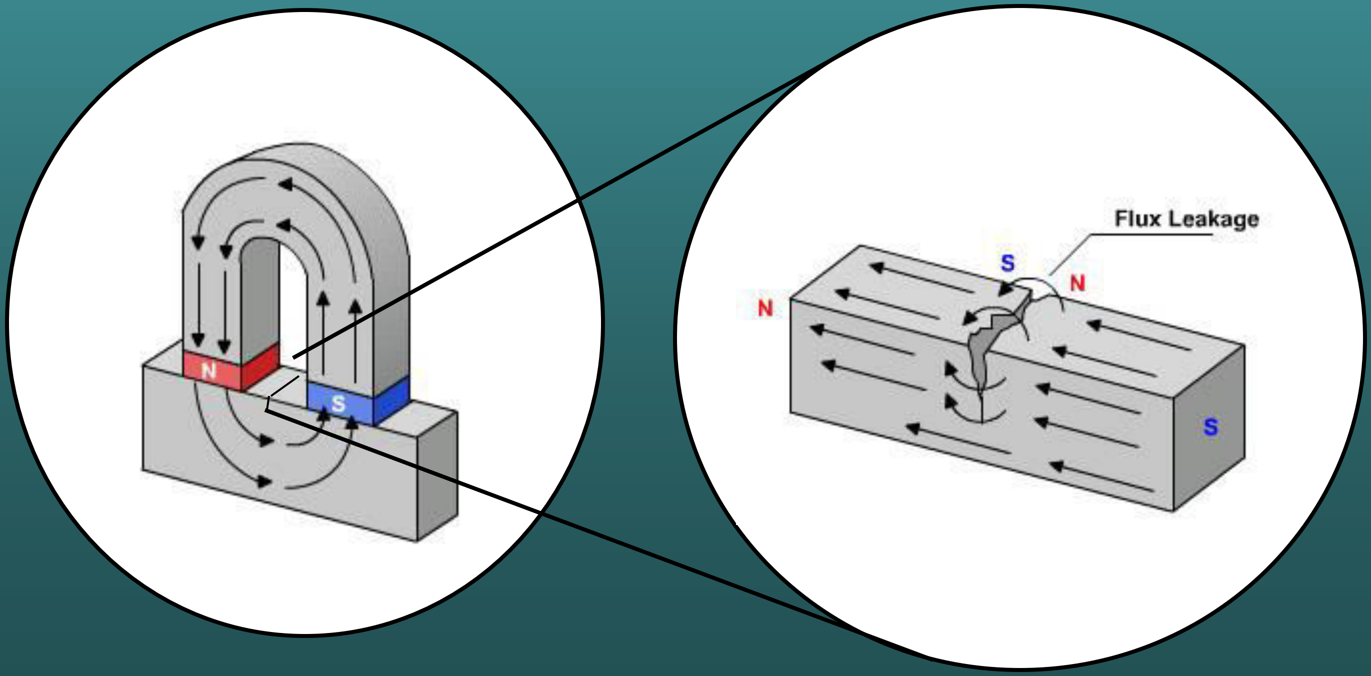
Opposite poles attracting



Similar poles repelling

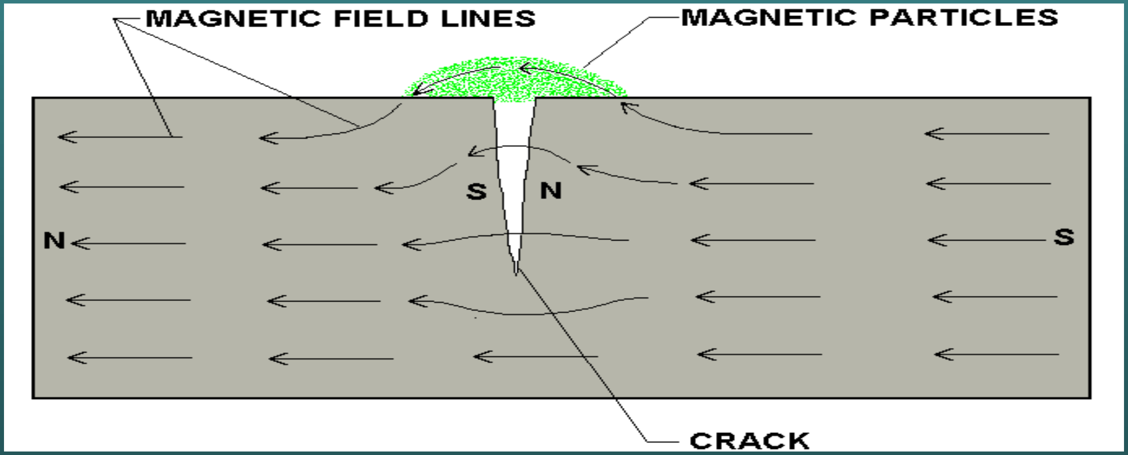
How Does Magnetic Particle Inspection Work?

A ferromagnetic test specimen is magnetized with a strong magnetic field created by a magnet or special equipment. If the specimen has a discontinuity, the discontinuity will interrupt the magnetic field flowing through the specimen and a leakage field will occur.



How Does Magnetic Particle Inspection Work? (Cont.)

Finely milled iron particles coated with a dye pigment are applied to the test specimen. These particles are attracted to leakage fields and will cluster to form an indication directly over the discontinuity. This indication can be visually detected under proper lighting conditions.



Basic Procedure

Basic steps involved:

1. Component pre-cleaning

2. Introduction of magnetic field

3. Application of magnetic media

4. Interpretation of magnetic particle indications

Pre-cleaning

When inspecting a test part with the magnetic particle method it is essential for the particles to have an unimpeded path for migration to both strong and weak leakage fields alike. The part's surface should be clean and dry before inspection.

Contaminants such as oil, grease, or scale may not only prevent particles from being attracted to leakage fields, they may also interfere with interpretation of indications.

Introduction of the Magnetic Field

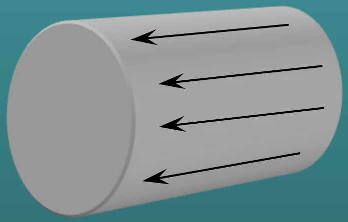
The required magnetic field can be introduced into a component in a number of different ways.

1. Using a permanent magnet or an electromagnet that contacts the test piece
2. Flowing an electrical current through the specimen
3. Flowing an electrical current through a coil of wire around the part or through a central conductor running near the part.

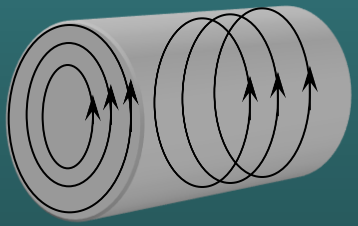
Direction of the Magnetic Field

Two general types of magnetic fields (longitudinal and circular) may be established within the specimen. The type of magnetic field established is determined by the method used to magnetize the specimen.

- A longitudinal magnetic field has magnetic lines of force that run parallel to the long axis of the part.

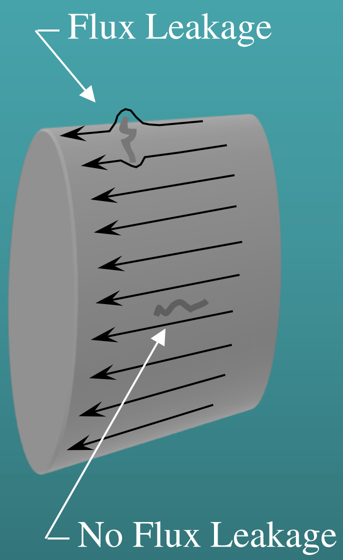


- A circular magnetic field has magnetic lines of force that run circumferentially around the perimeter of a part.

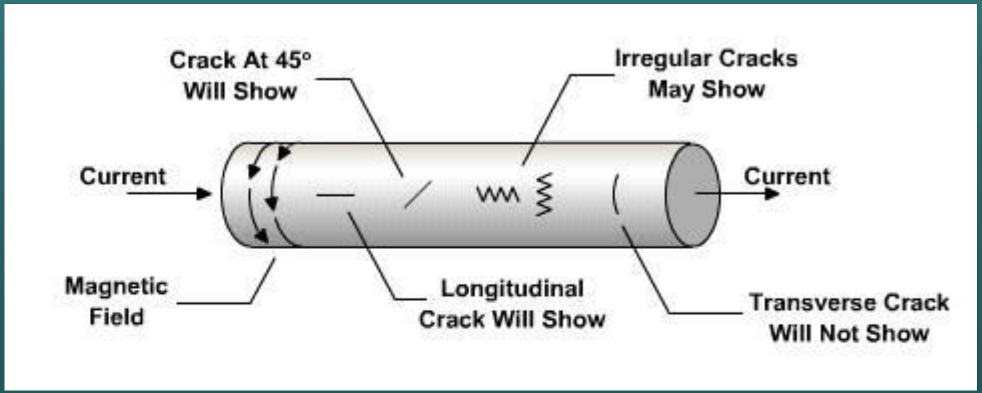


Importance of Magnetic Field Direction

Being able to magnetize the part in two directions is important because the best detection of defects occurs when the lines of magnetic force are established at right angles to the longest dimension of the defect. This orientation creates the largest disruption of the magnetic field within the part and the greatest flux leakage at the surface of the part. An orientation of 45 to 90 degrees between the magnetic field and the defect is necessary to form an indication.

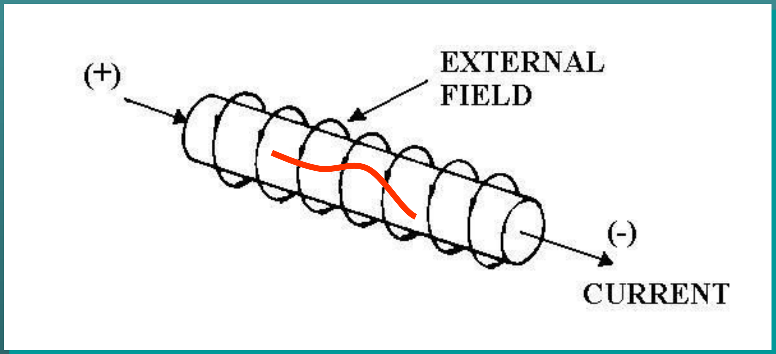


Since defects may occur in various and unknown directions, each part is normally magnetized in two directions at right angles to each other.

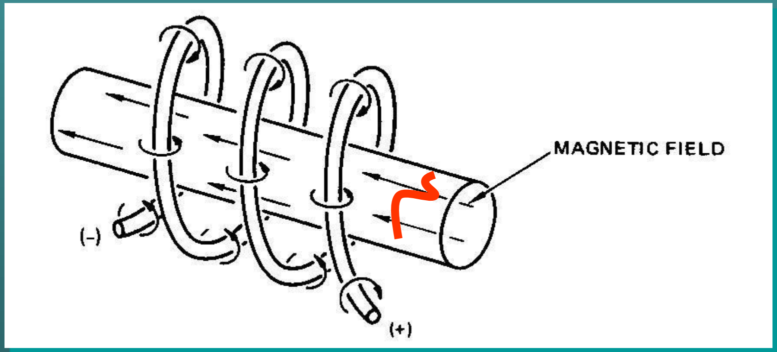


Question

- From the previous slide regarding the optimum test sensitivity, which kinds of defect are easily found in the images below?

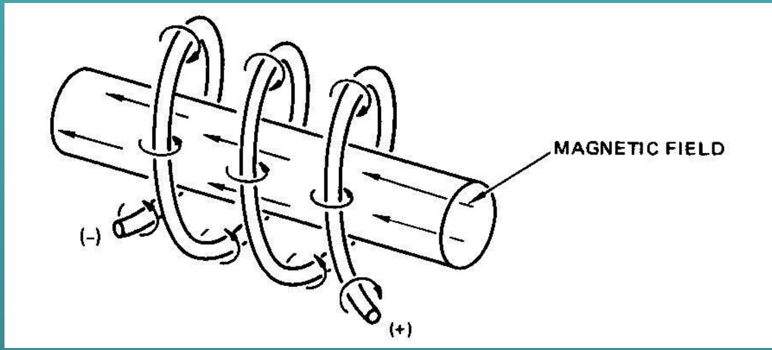


Longitudinal (along the axis)



Transverse (perpendicular the axis)

Producing a Longitudinal Magnetic Field Using a Coil



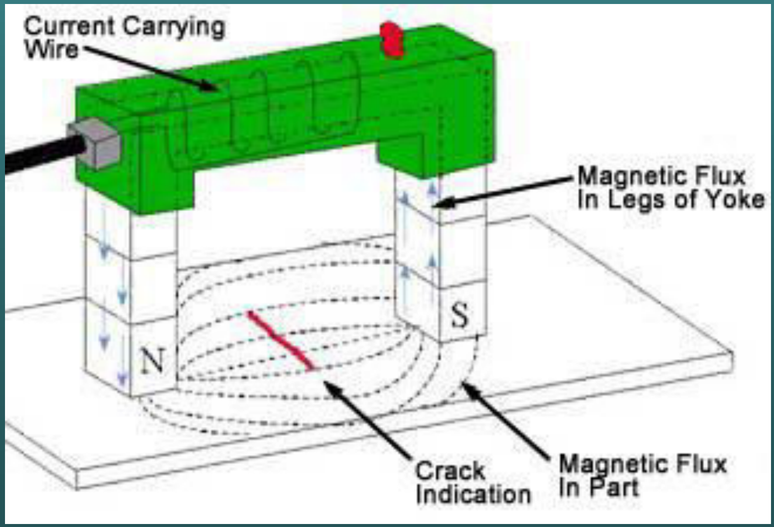

Coil on Wet Horizontal Inspection Unit

A longitudinal magnetic field is usually established by placing the part near the inside or a coil's annulus. This produces magnetic lines of force that are parallel to the long axis of the test part.

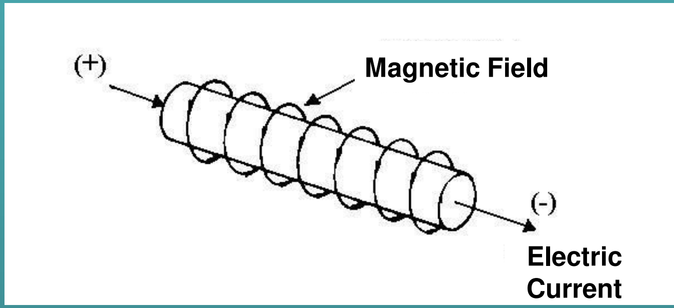

Portable Coil

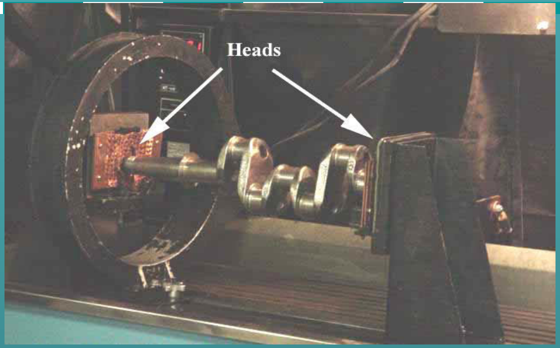
Producing a Longitudinal Field Using Permanent or Electromagnetic Magnets

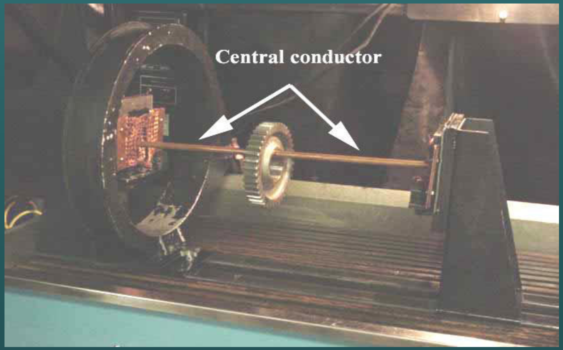
Permanent magnets and electromagnetic yokes are also often used to produce a longitudinal magnetic field. The magnetic lines of force run from one pole to the other, and the poles are positioned such that any flaws present run normal to these lines of force.



Circular Magnetic Fields



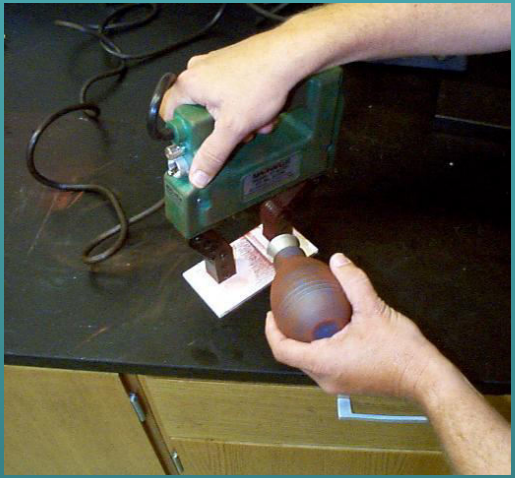




Circular magnetic fields are produced by passing current through the part or by placing the part in a strong circular magnet field.

A headshot on a wet horizontal test unit and the use of prods are several common methods of injecting current in a part to produce a circular magnetic field. Placing parts on a central conductors carrying high current is another way to produce the field.

Application of Magnetic Media (Wet Versus Dry)



MPI can be performed using either dry particles, or particles suspended in a liquid. With the dry method, the particles are lightly dusted on to the surface. With the wet method, the part is flooded with a solution carrying the particles.

The dry method is more portable. The wet method is generally more sensitive since the liquid carrier gives the magnetic particles additional mobility.

Dry Magnetic Particles

Magnetic particles come in a variety of colors. A color that produces a high level of contrast against the background should be used.

Wet Magnetic Particles

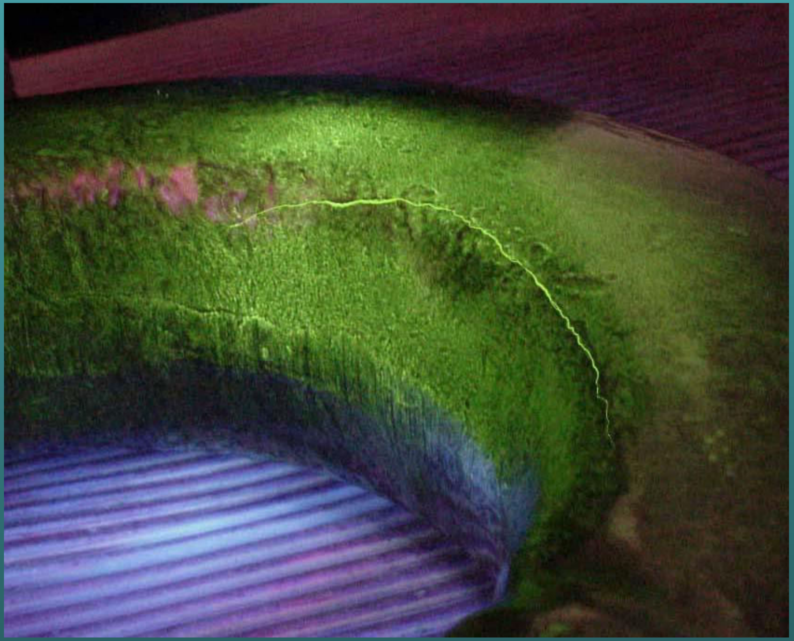
Wet particles are typically supplied as visible or fluorescent. Visible particles are viewed under normal white light and fluorescent particles are viewed under black light.

Interpretation of Indications

After applying the magnetic field, indications that form must interpreted. This process requires that the inspector distinguish between relevant and non-relevant indications.

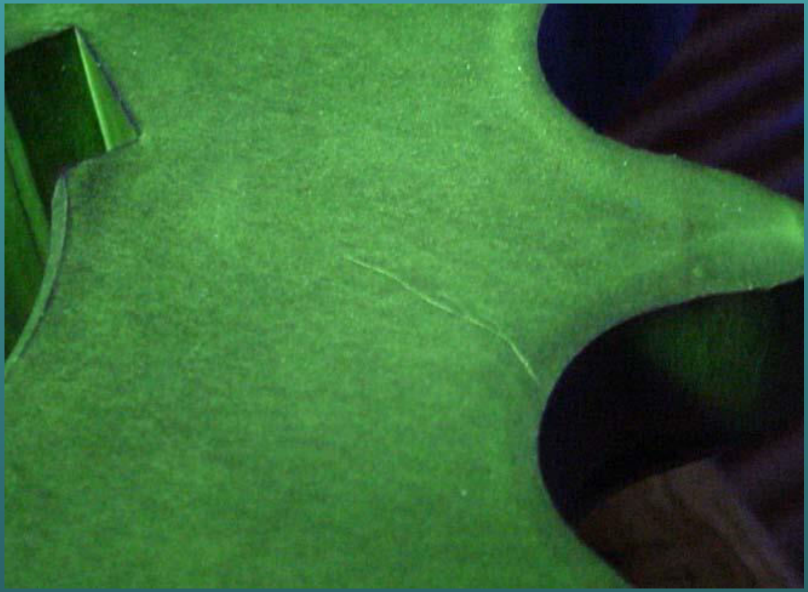
The following series of images depict relevant indications produced from a variety of components inspected with the magnetic particle method.

Crane Hook with Service Induced Crack



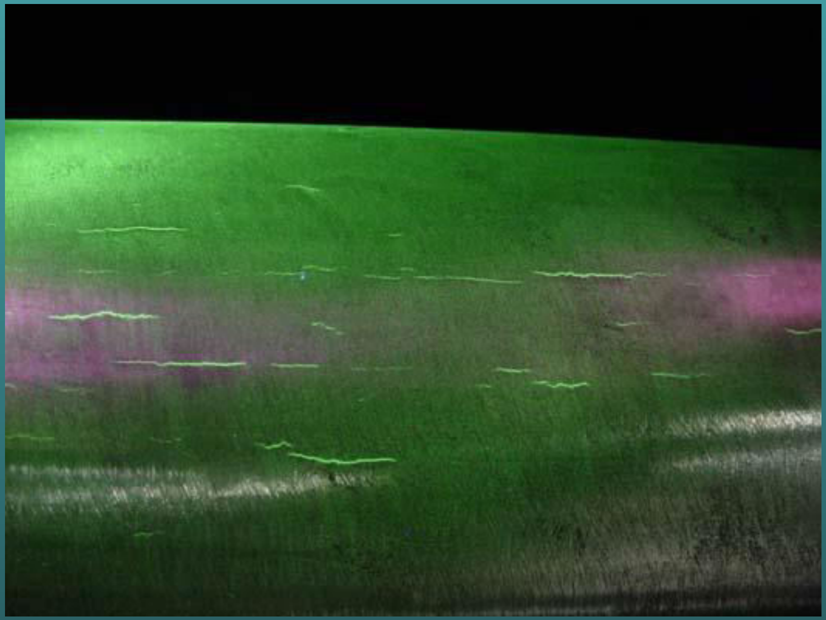
Fluorescent, Wet Particle Method

Gear with
Service Induced Crack



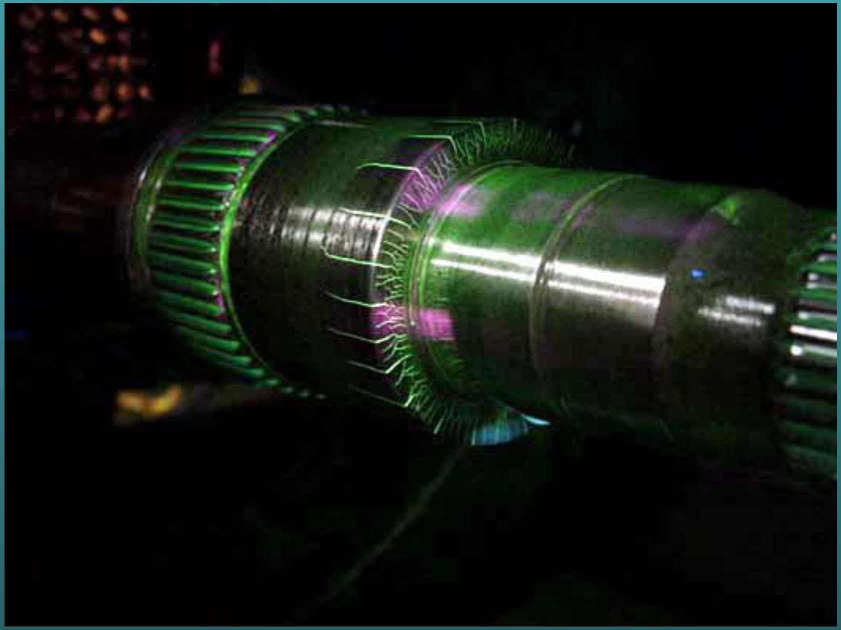
Fluorescent, Wet Particle Method

Drive Shaft with Heat Treatment Induced Cracks



Fluorescent, Wet Particle Method

Splined Shaft with Service Induced Cracks



Fluorescent, Wet Particle Method

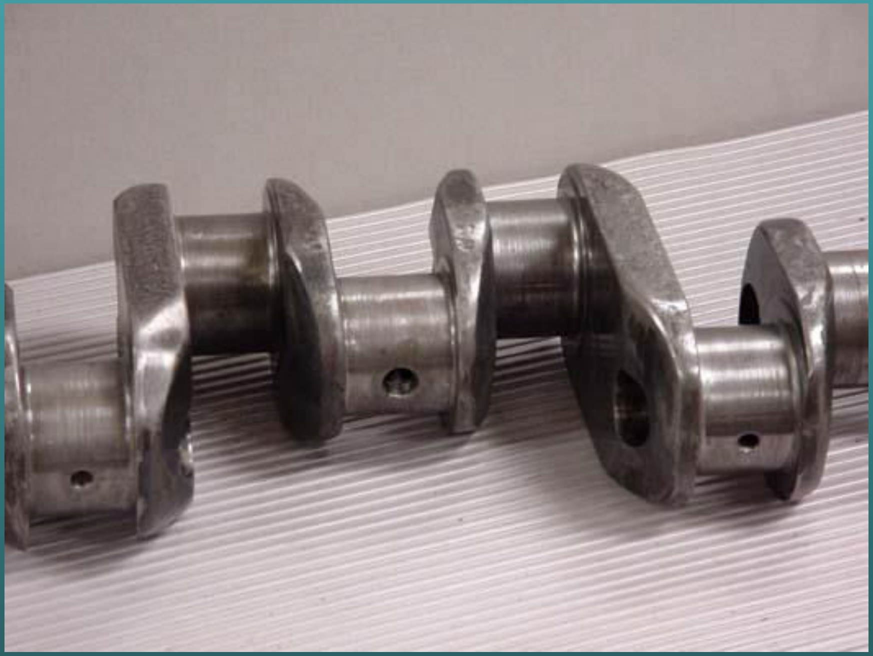
Threaded Shaft with Service Induced Crack

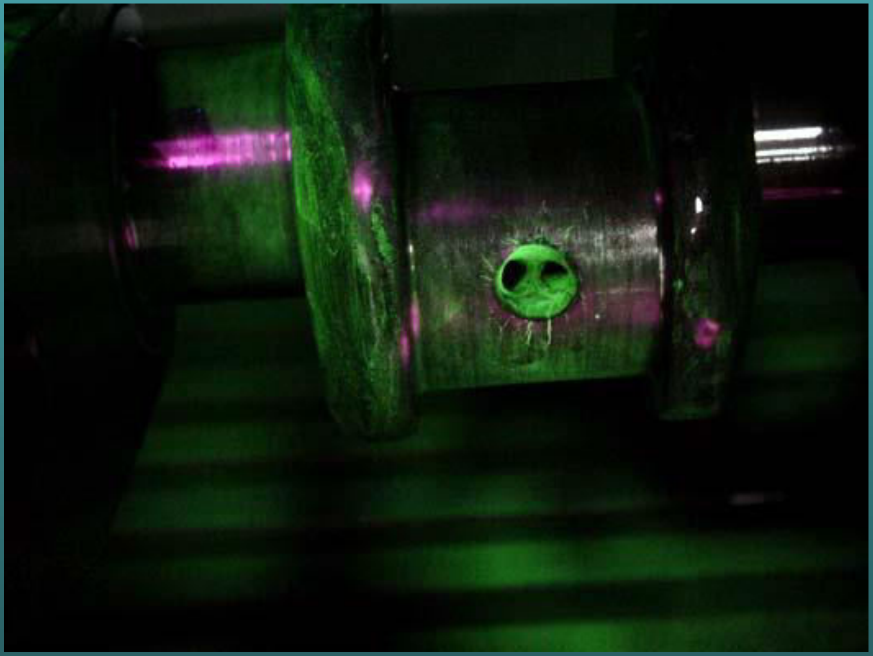
Fluorescent, Wet Particle Method

Large Bolt with Service Induced Crack

Fluorescent, Wet Particle Method

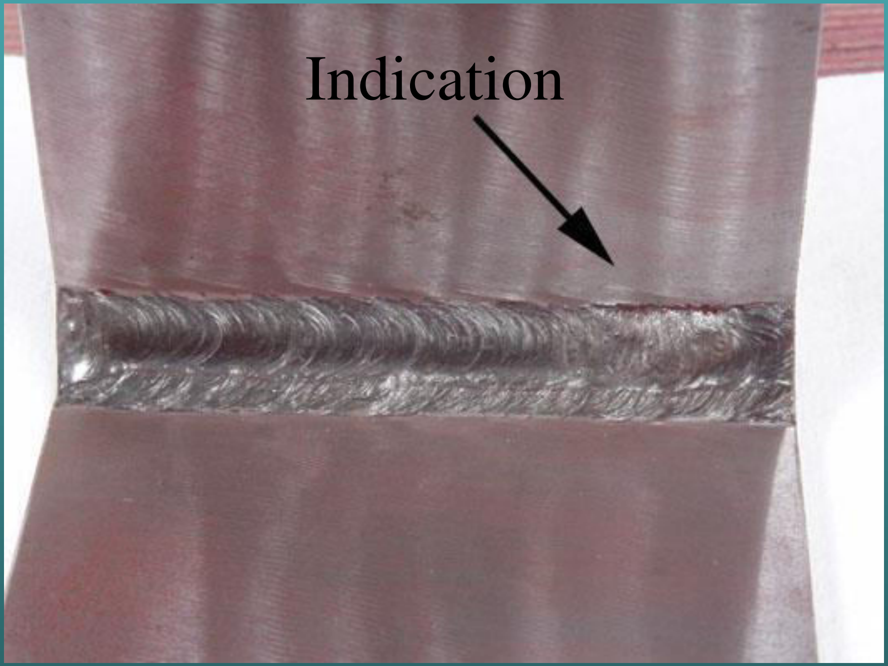
Crank Shaft with Service Induced Crack Near Lube Hole





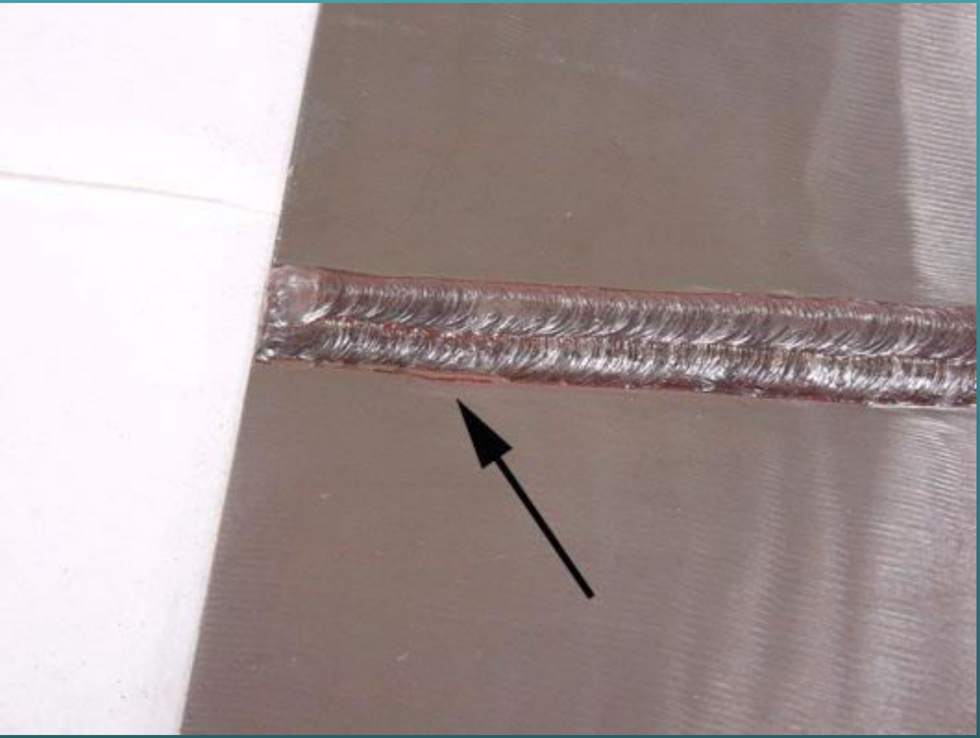
Fluorescent, Wet Particle Method

Lack of Fusion in SMAW Weld



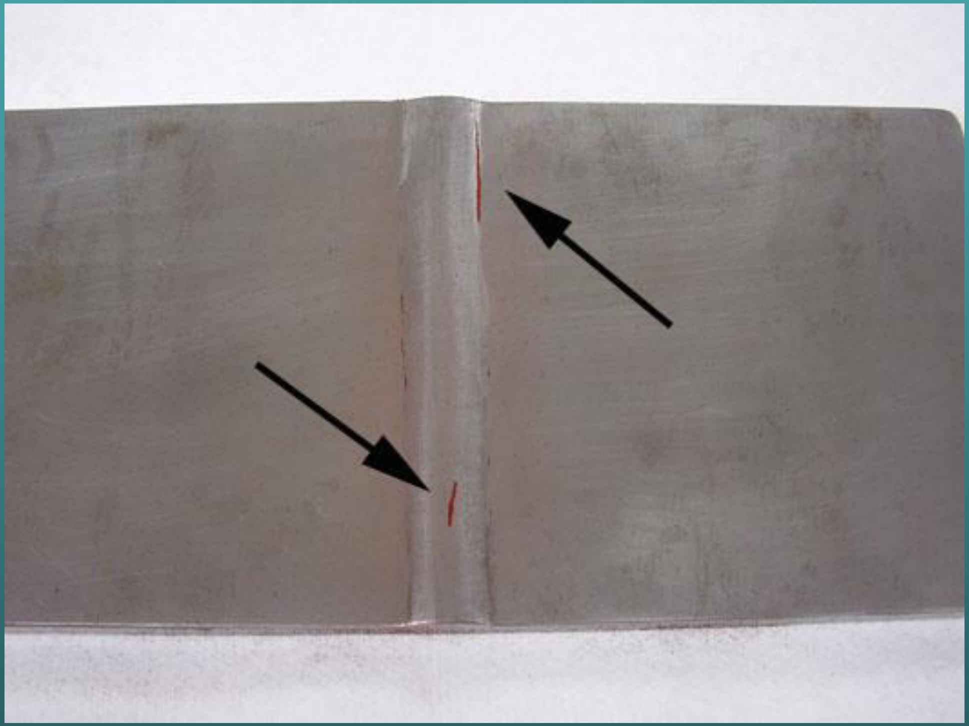
Visible, Dry Powder Method

Toe Crack in SMAW Weld



Visible, Dry Powder Method

Throat and Toe Cracks in Partially Ground Weld



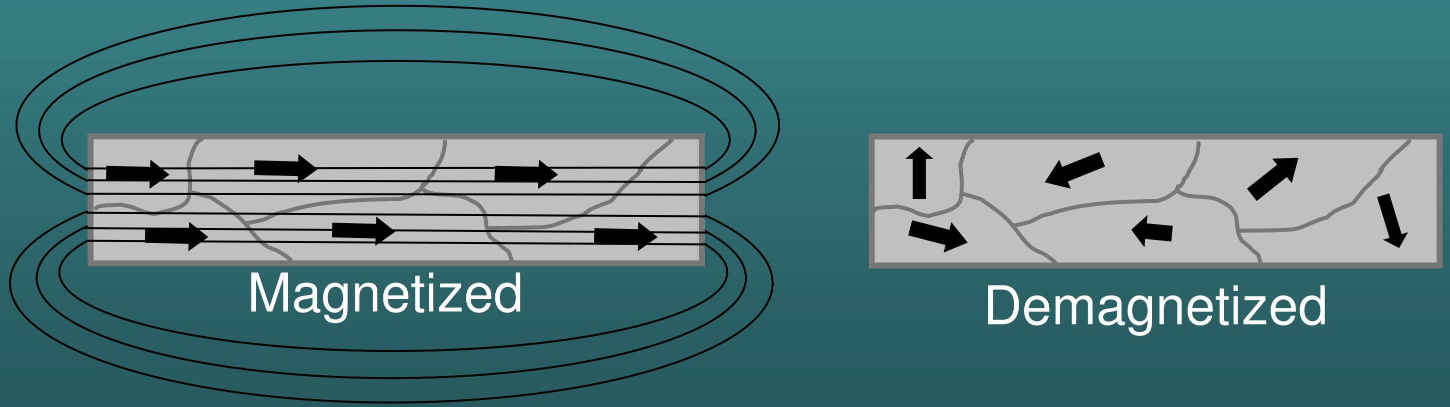
Visible, Dry Powder Method

Demagnetization

- Parts inspected by the magnetic particle method may sometimes have an objectionable residual magnetic field that may interfere with subsequent manufacturing operations or service of the component.
- Possible reasons for demagnetization include:
  - May interfere with welding and/or machining operations
  - Can effect gauges that are sensitive to magnetic fields if placed in close proximity.
  - Abrasive particles may adhere to components surface and cause and increase in wear to engines components, gears, bearings etc.

Demagnetization (Cont.)

- Demagnetization requires that the residual magnetic field is reversed and reduced by the inspector.
- This process will scramble the magnetic domains and reduce the strength of the residual field to an acceptable level.



Advantages of Magnetic Particle Inspection

- Can detect both surface and near sub-surface defects.
- Can inspect parts with irregular shapes easily.
- Precleaning of components is not as critical as it is for some other inspection methods. Most contaminants within a flaw will not hinder flaw detectability.
- Fast method of inspection and indications are visible directly on the specimen surface.
- Considered low cost compared to many other NDT methods.
- Is a very portable inspection method especially when used with battery powered equipment.

Limitations of Magnetic Particle Inspection

- Cannot inspect non-ferrous materials such as aluminum, magnesium or most stainless steels.
- Inspection of large parts may require use of equipment with special power requirements.
- Some parts may require removal of coating or plating to achieve desired inspection sensitivity.
- Limited subsurface discontinuity detection capabilities. Maximum depth sensitivity is approximately 0.6” (under ideal conditions).
- Post cleaning, and post demagnetization is often necessary.
- Alignment between magnetic flux and defect is important

Glossary of Terms

- **Black Light:** ultraviolet light which is filtered to produce a wavelength of approximately 365 nanometers. Black light will cause certain materials to fluoresce.
- **Central conductor:** an electrically conductive bar usually made of copper used to introduce a circular magnetic field in to a test specimen.
- **Coil:** an electrical conductor such a copper wire or cable that is wrapped in several or many loops that are brought close to one another to form a strong longitudinal magnetic field.

Glossary of Terms

- **Discontinuity:** an interruption in the structure of the material such as a crack.
- **Ferromagnetic:** a material such as iron, nickel and cobalt or one of it's alloys that is strongly attracted to a magnetic field.
- **Heads:** electrical contact pads on a wet horizontal magnetic particle inspection machine. The part to be inspected is clamped and held in place between the heads and shot of current is sent through the part from the heads to create a circular magnetic field in the part.
- **Leakage field:** a disruption in the magnetic field. This disruption must extend to the surface of the part for particles to be attracted.

Glossary of Terms

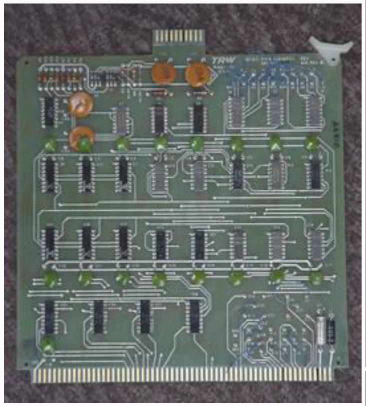
- **Non-relevant indications:** indications produced due to some intended design feature of a specimen such a keyways, splines or press fits.
- **Prods:** two electrodes usually made of copper or aluminum that are used to introduce current in to a test part. This current in turn creates a circular magnetic field where each prod touches the part. (Similar in principal to a welding electrode and ground clamp).
- **Relevant indications:** indications produced from something other than a design feature of a test specimen. Cracks, stringers, or laps are examples of relevant indications.

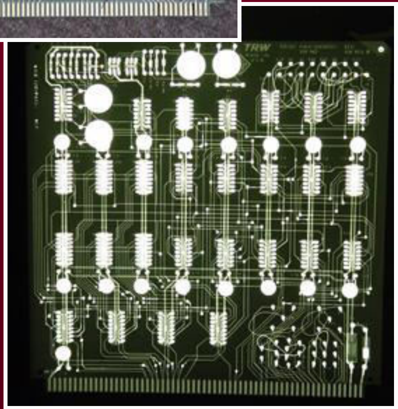
Glossary of Terms

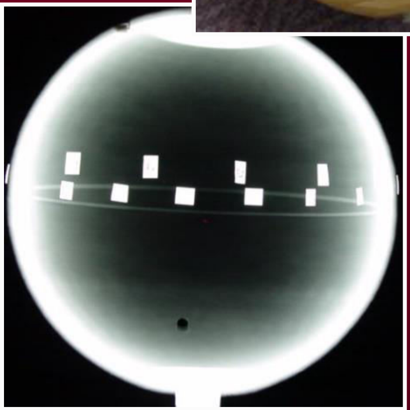
- **Suspension:** a bath created by mixing particles with either oil or water.
- **Yoke:** a horseshoe magnet used to create a longitudinal magnetic field. Yokes may be made from permanent magnets or electromagnets.

RADIATION
CAUTION
RADIOACTIVE
MATERIALS

RADIOGRAPHIC TESTING







Introduction

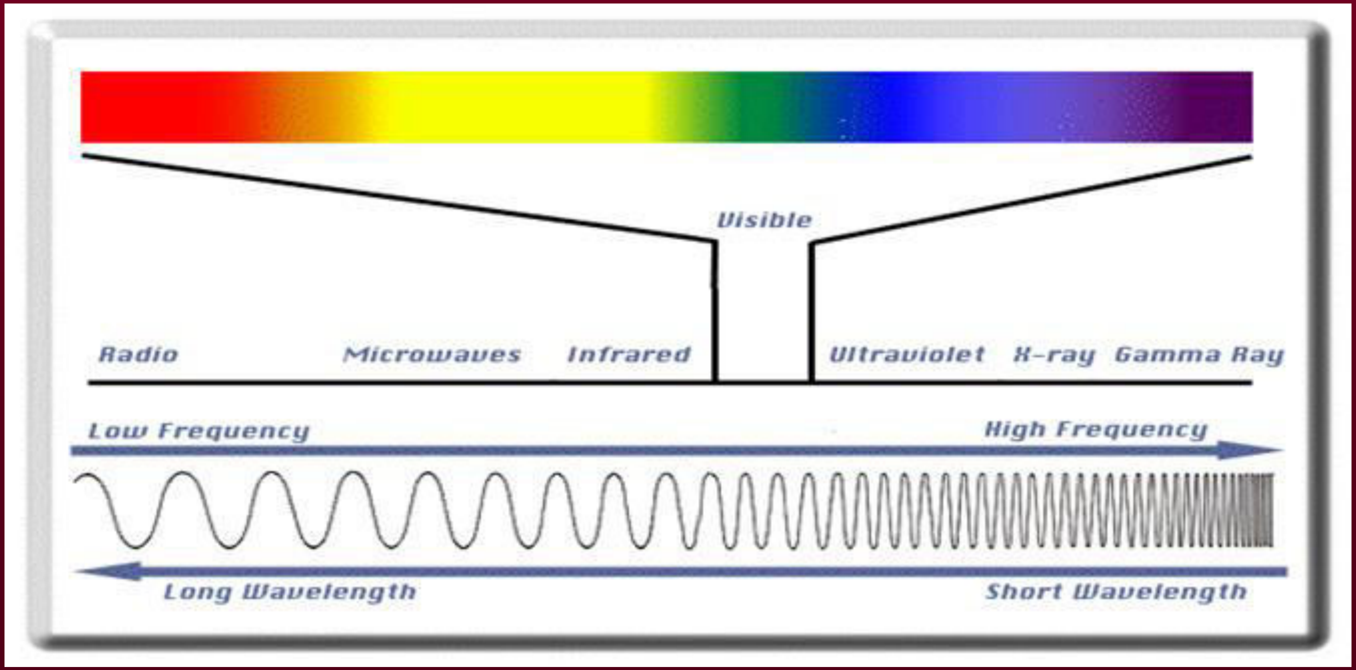
- This module presents information on the NDT method of radiographic inspection or radiography.
- Radiography uses penetrating radiation that is directed towards a component.
- The component stops some of the radiation. The amount that is stopped or absorbed is affected by material density and thickness differences.
- These differences in "absorption" can be recorded on film, or electronically.

Outline

- Electromagnetic Radiation
- General Principles of Radiography
- Sources of Radiation
  - Gamma Radiography
  - X-ray Radiography
- Imaging Modalities
  - Film Radiography
  - Computed Radiography
  - Real-Time Radiography
  - Direct Digital Radiography
  - Computed Radiography
- Radiation Safety
- Advantages and Limitations
- Glossary of Terms

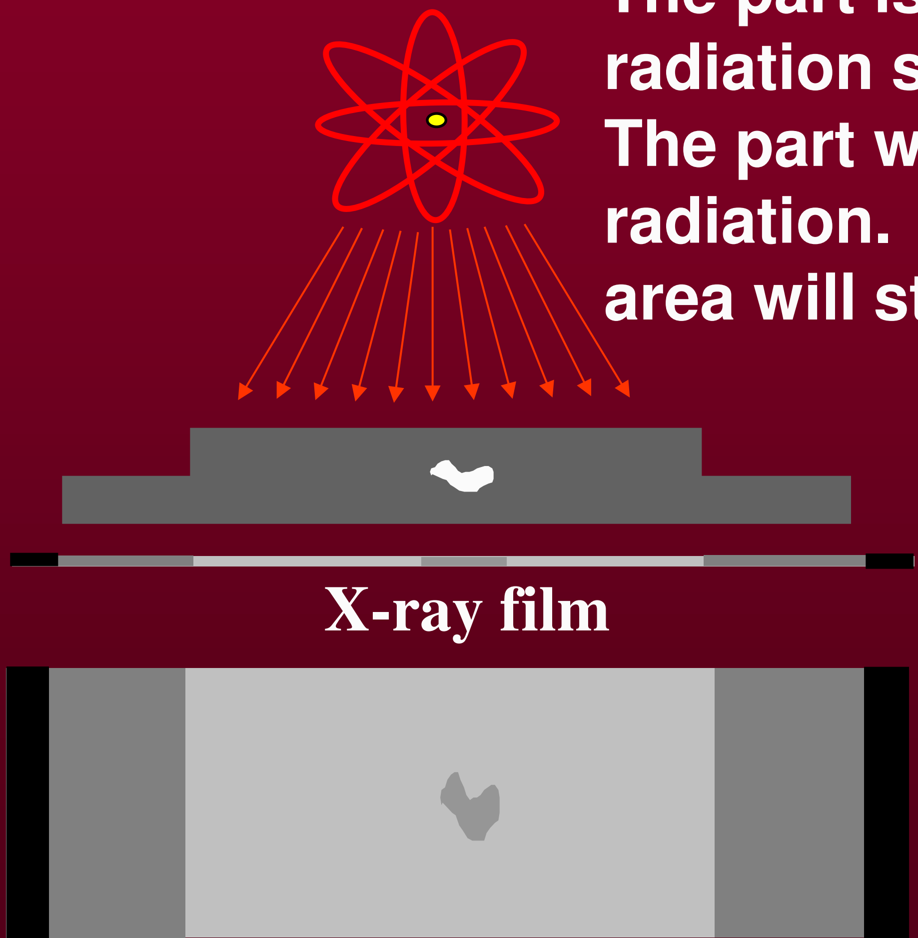
Electromagnetic Radiation

The radiation used in Radiography testing is a higher energy (shorter wavelength) version of the electromagnetic waves that we see every day. Visible light is in the same family as x-rays and gamma rays.



General Principles of Radiography

The part is placed between the radiation source and a piece of film. The part will stop some of the radiation. Thicker and more dense area will stop more of the radiation.



Top view of developed film

The film darkness (density) will vary with the amount of radiation reaching the film through the test object.

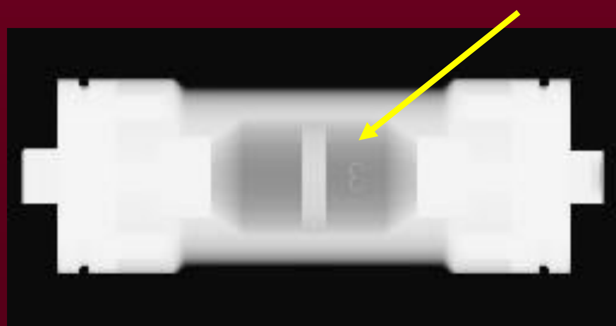
= less exposure

= more exposure

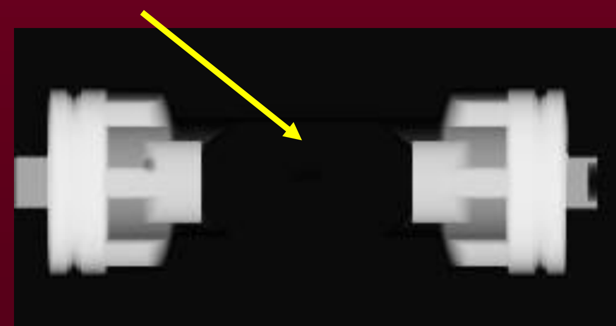
General Principles of Radiography

- The energy of the radiation affects its penetrating power. Higher energy radiation can penetrate thicker and more dense materials.
- The radiation energy and/or exposure time must be controlled to properly image the region of interest.

Thin Walled Area



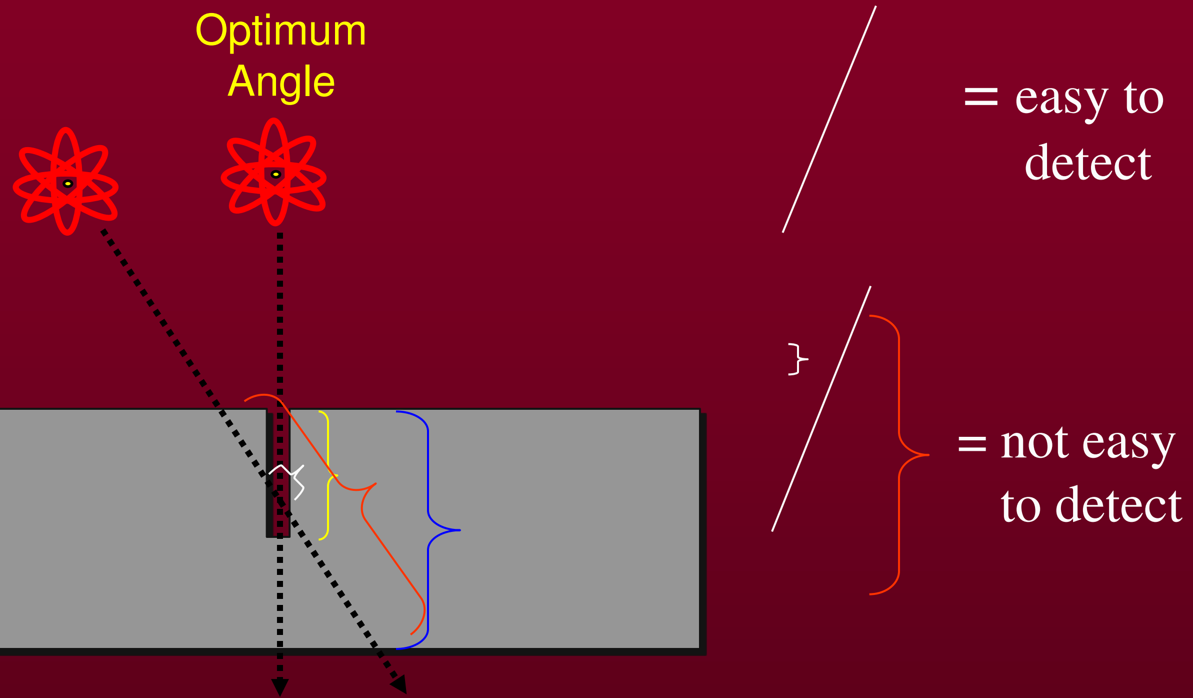
Low Energy Radiation



High energy Radiation

Flaw Orientation

Radiography has sensitivity limitations when detecting cracks.

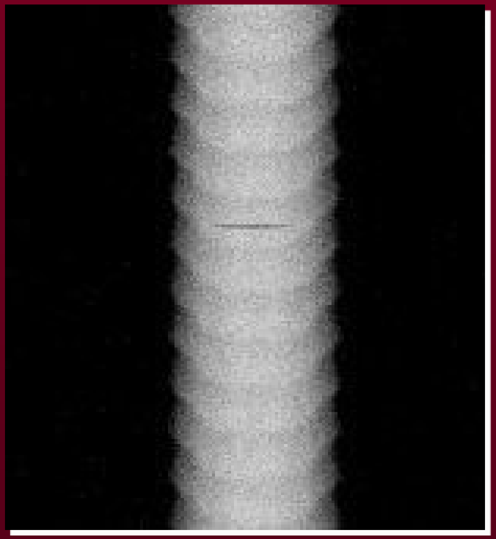


X-rays “see” a crack as a thickness variation and the larger the variation, the easier the crack is to detect.

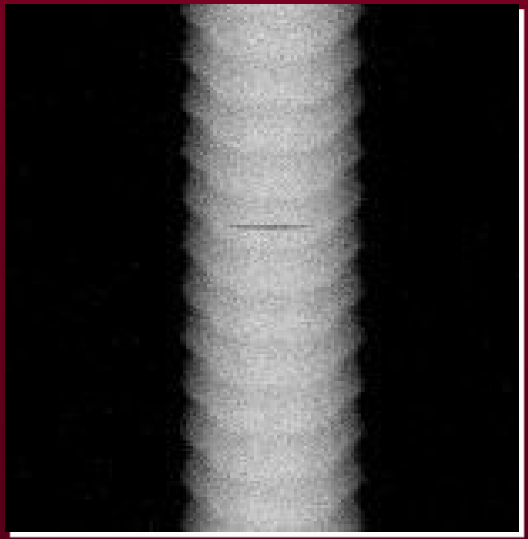
When the path of the x-rays is not parallel to a crack, the thickness variation is less and the crack may not be visible.

Flaw Orientation (cont.)

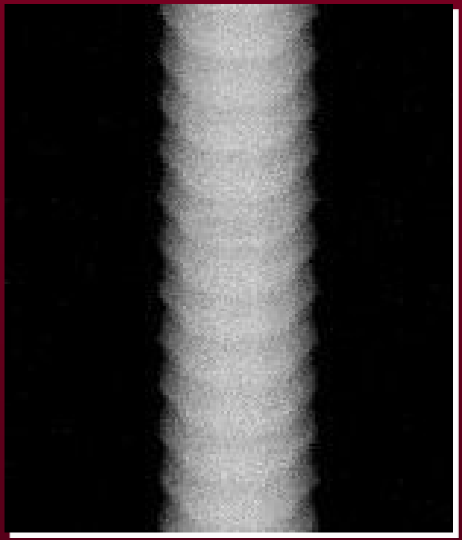
Since the angle between the radiation beam and a crack or other linear defect is so critical, the orientation of defect must be well known if radiography is going to be used to perform the inspection.



0°



10°



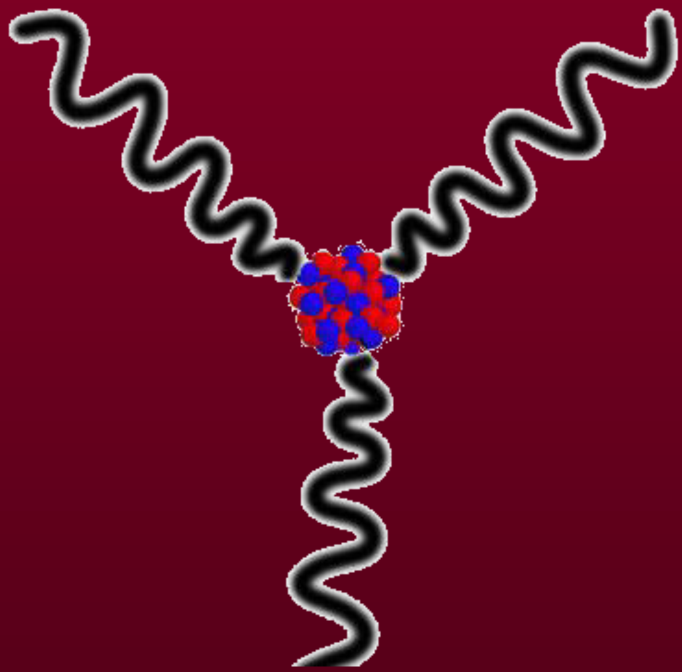
20°

Radiation Sources

Two of the most commonly used sources of radiation in industrial radiography are x-ray generators and gamma ray sources. Industrial radiography is often subdivided into “X-ray Radiography” or “Gamma Radiography”, depending on the source of radiation used.

Gamma Radiography

- Gamma rays are produced by a radioisotope.
- A radioisotope has an unstable nuclei that does not have enough binding energy to hold the nucleus together.
- The spontaneous breakdown of an atomic nucleus resulting in the release of energy and matter is known as radioactive decay.



Gamma Radiography (cont.)

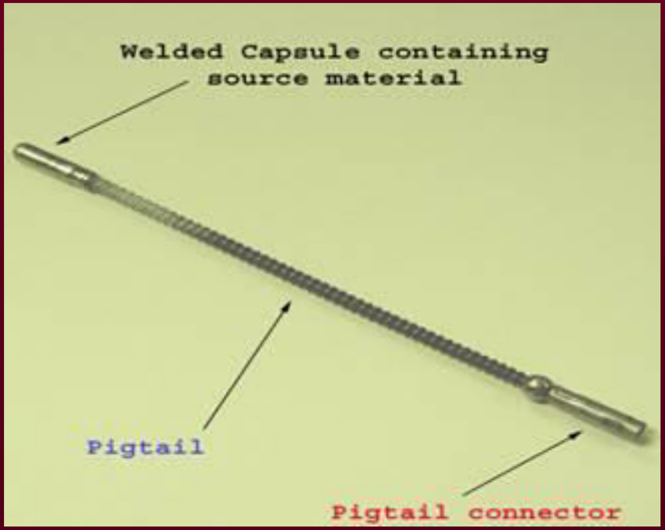
- Most of the radioactive material used in industrial radiography is artificially produced.
- This is done by subjecting stable material to a source of neutrons in a special nuclear reactor.
- This process is called activation.

Gamma Radiography (cont.)

Unlike X-rays, which are produced by a machine, gamma rays cannot be turned off. Radioisotopes used for gamma radiography are encapsulated to prevent leakage of the material.

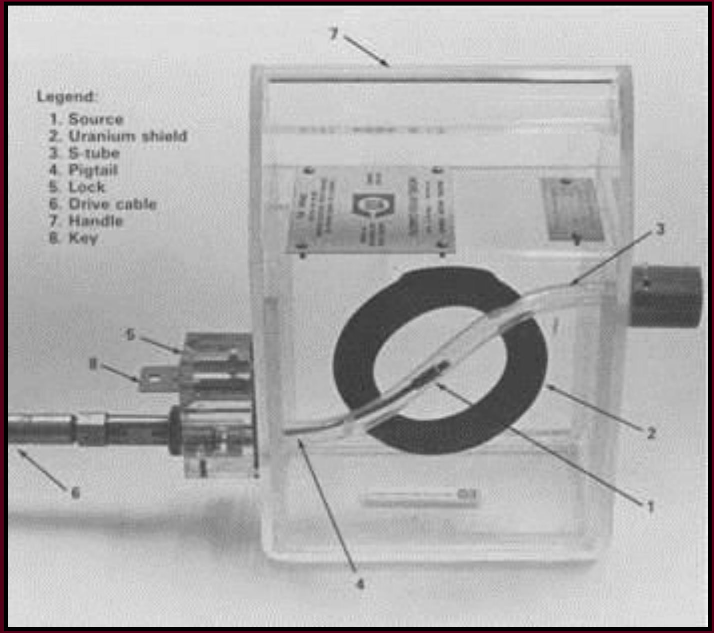
The radioactive “capsule” is attached to a cable to form what is often called a “pigtail.”

The pigtail has a special connector at the other end that attaches to a drive cable.



Gamma Radiography (cont.)

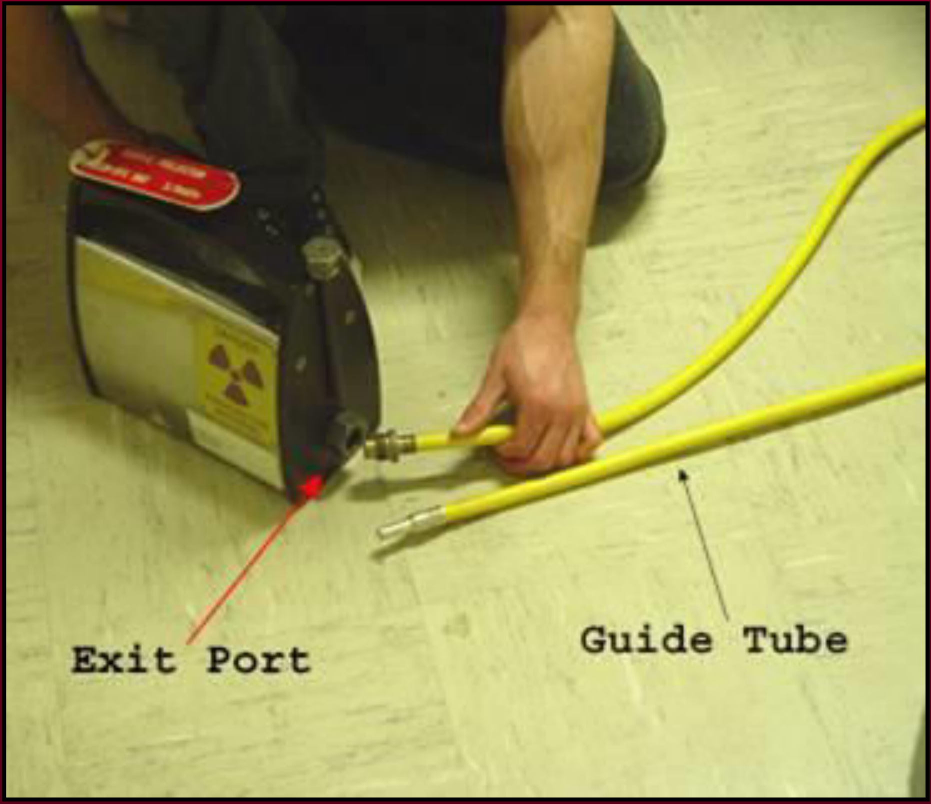
A device called a "camera" is used to store, transport and expose the pigtail containing the radioactive material. The camera contains shielding material which reduces the radiographer's exposure to radiation during use.



Gamma Radiography (cont.)

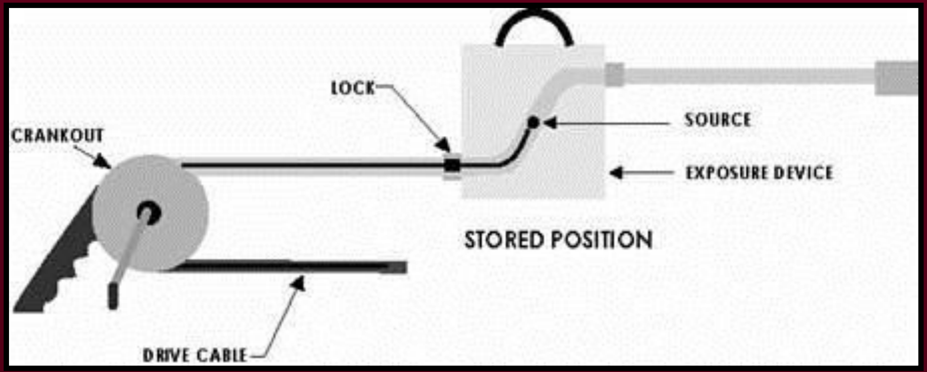
A hose-like device called a guide tube is connected to a threaded hole called an “exit port” in the camera.

The radioactive material will leave and return to the camera through this opening when performing an exposure!



Gamma Radiography (cont.)

A “drive cable” is connected to the other end of the camera. This cable, controlled by the radiographer, is used to force the radioactive material out into the guide tube where the gamma rays will pass through the specimen and expose the recording device.

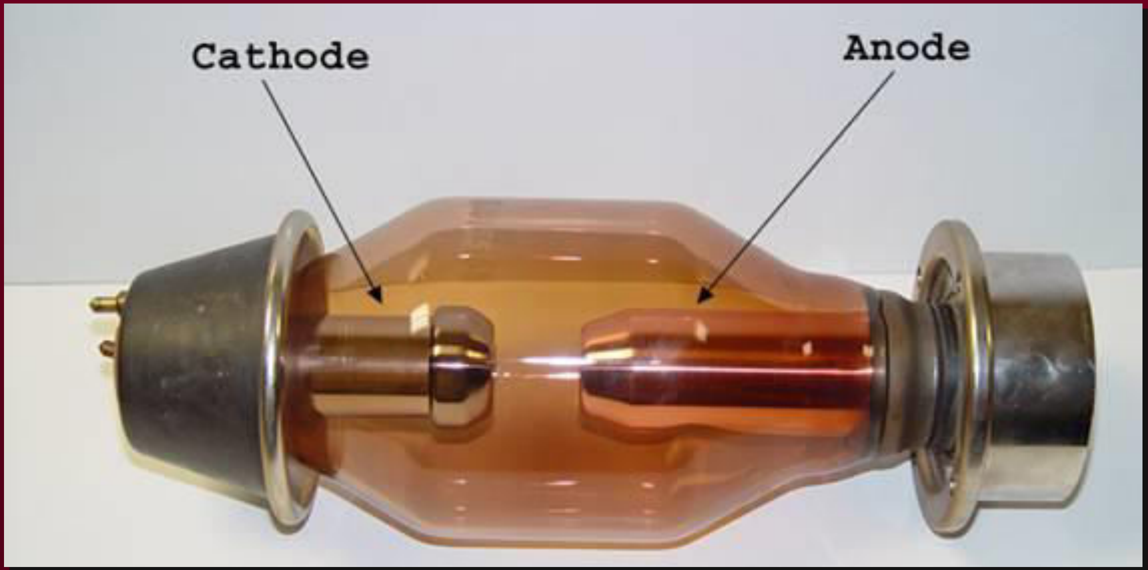


X-ray Radiography

Unlike gamma rays, x-rays are produced by an X-ray generator system. These systems typically include an X-ray tube head, a high voltage generator, and a control console.

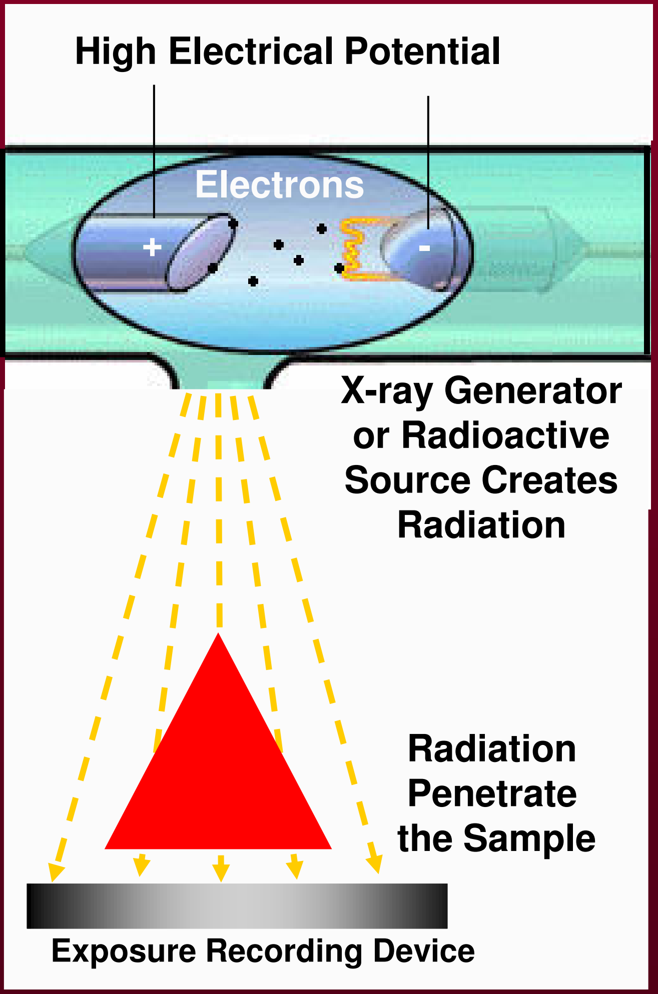
X-ray Radiography (cont.)

- X-rays are produced by establishing a very high voltage between two electrodes, called the anode and cathode.
- To prevent arcing, the anode and cathode are located inside a vacuum tube, which is protected by a metal housing.



X-ray Radiography (cont.)

- The cathode contains a small filament much the same as in a light bulb.
- Current is passed through the filament which heats it. The heat causes electrons to be stripped off.
- The high voltage causes these "free" electrons to be pulled toward a target material (usually made of tungsten) located in the anode.
- The electrons impact against the target. This impact causes an energy exchange which causes x-rays to be created.

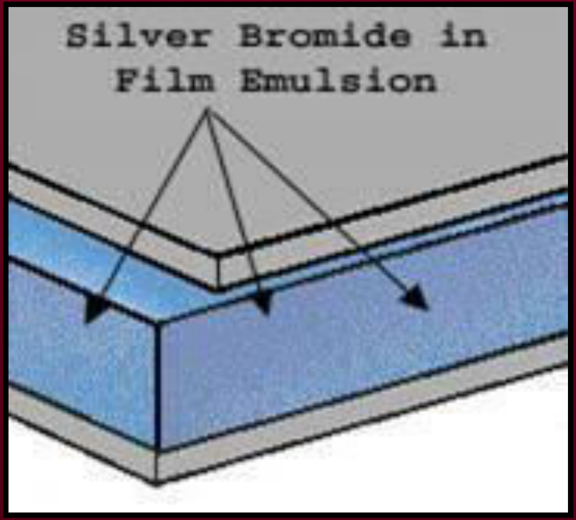


Imaging Modalities

Several different imaging methods are available to display the final image in industrial radiography:

- Film Radiography
- Real Time Radiography
- Computed Tomography (CT)
- Digital Radiography (DR)
- Computed Radiography (CR)

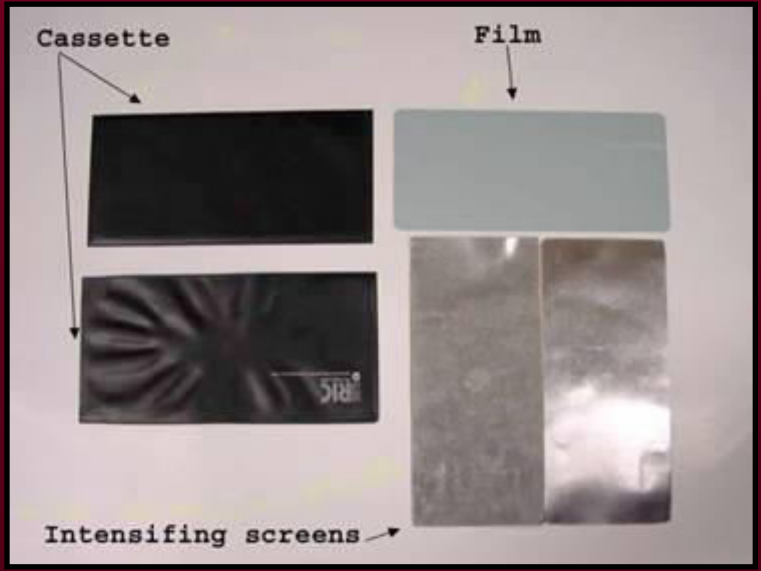
Film Radiography



- One of the most widely used and oldest imaging mediums in industrial radiography is radiographic film.
- Film contains microscopic material called silver bromide.
- Once exposed to radiation and developed in a darkroom, silver bromide turns to black metallic silver which forms the image.

Film Radiography (cont.)

- Film must be protected from visible light. Light, just like x-rays and gamma rays, can expose film. Film is loaded in a "light proof" cassette in a darkroom.
- This cassette is then placed on the specimen opposite the source of radiation. Film is often placed between screens to intensify radiation.

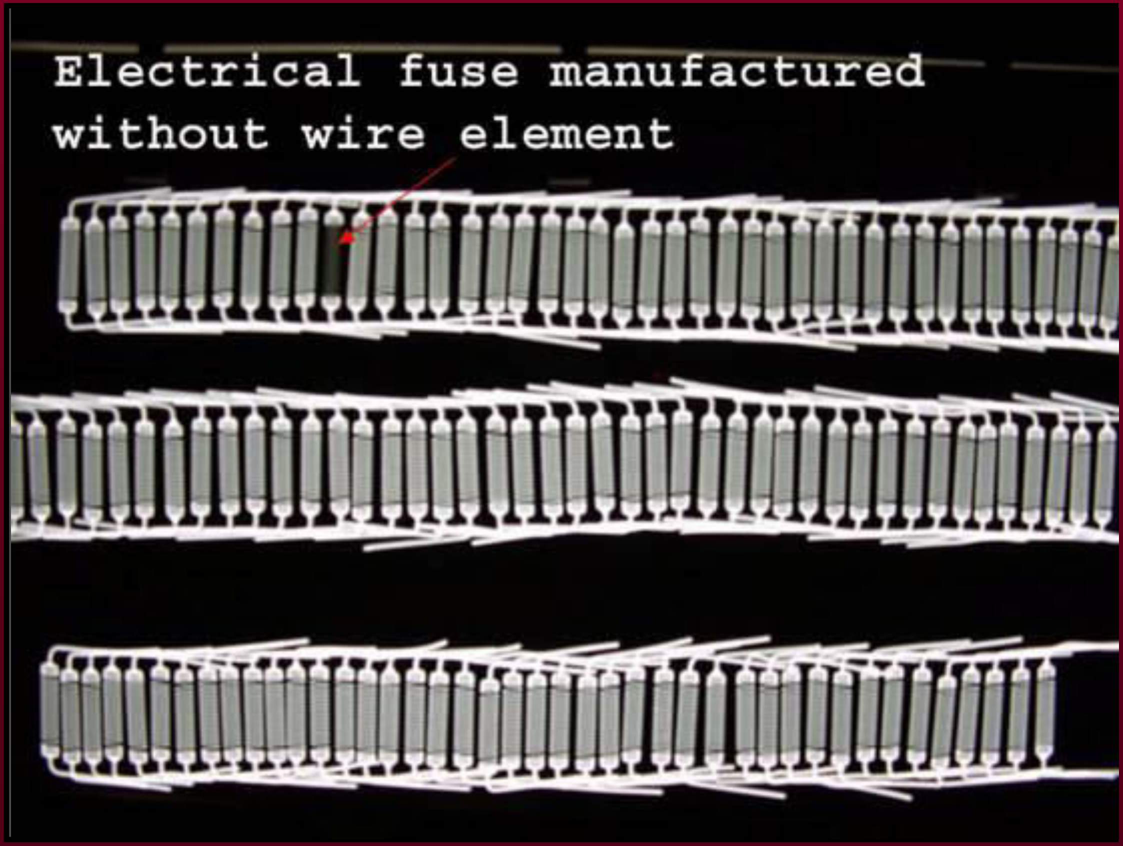


Film Radiography (cont.)

- In order for the image to be viewed, the film must be "developed" in a darkroom. The process is very similar to photographic film development.
- Film processing can either be performed manually in open tanks or in an automatic processor.

Film Radiography (cont.)

Once developed, the film is typically referred to as a “radiograph.”



Digital Radiography

- One of the newest forms of radiographic imaging is “Digital Radiography”.
- Requiring no film, digital radiographic images are captured using either special phosphor screens or flat panels containing micro-electronic sensors.
- No darkrooms are needed to process film, and captured images can be digitally enhanced for increased detail.
- Images are also easily archived (stored) when in digital form.

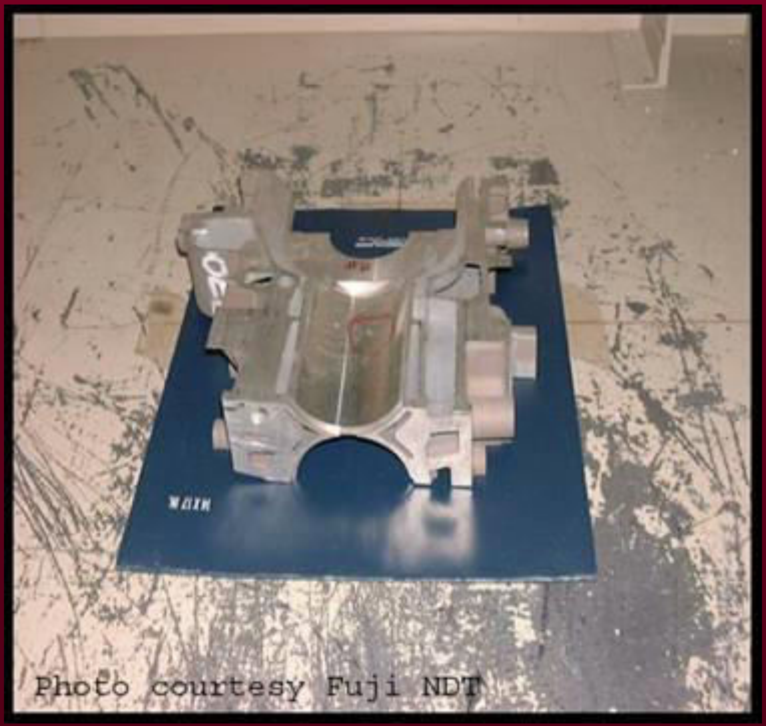
Digital Radiography (cont.)

There are a number of forms of digital radiographic imaging including:

- Computed Radiography (CR)
- Real-time Radiography (RTR)
- Direct Radiographic Imaging (DR)
- Computed Tomography

Computed Radiography

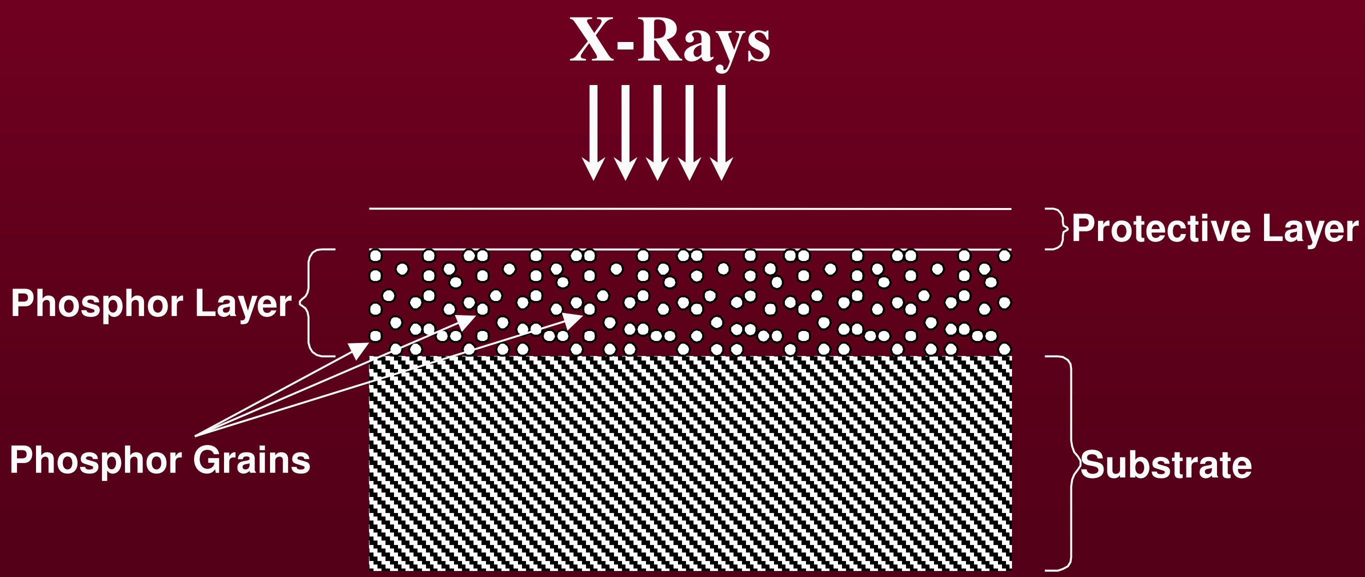
Computed Radiography (CR) is a digital imaging process that uses a special imaging plate which employs storage phosphors.



Computed Radiography (cont.)

X-rays penetrating the specimen stimulate the phosphors. The stimulated phosphors remain in an excited state.

CR Phosphor Screen Structure



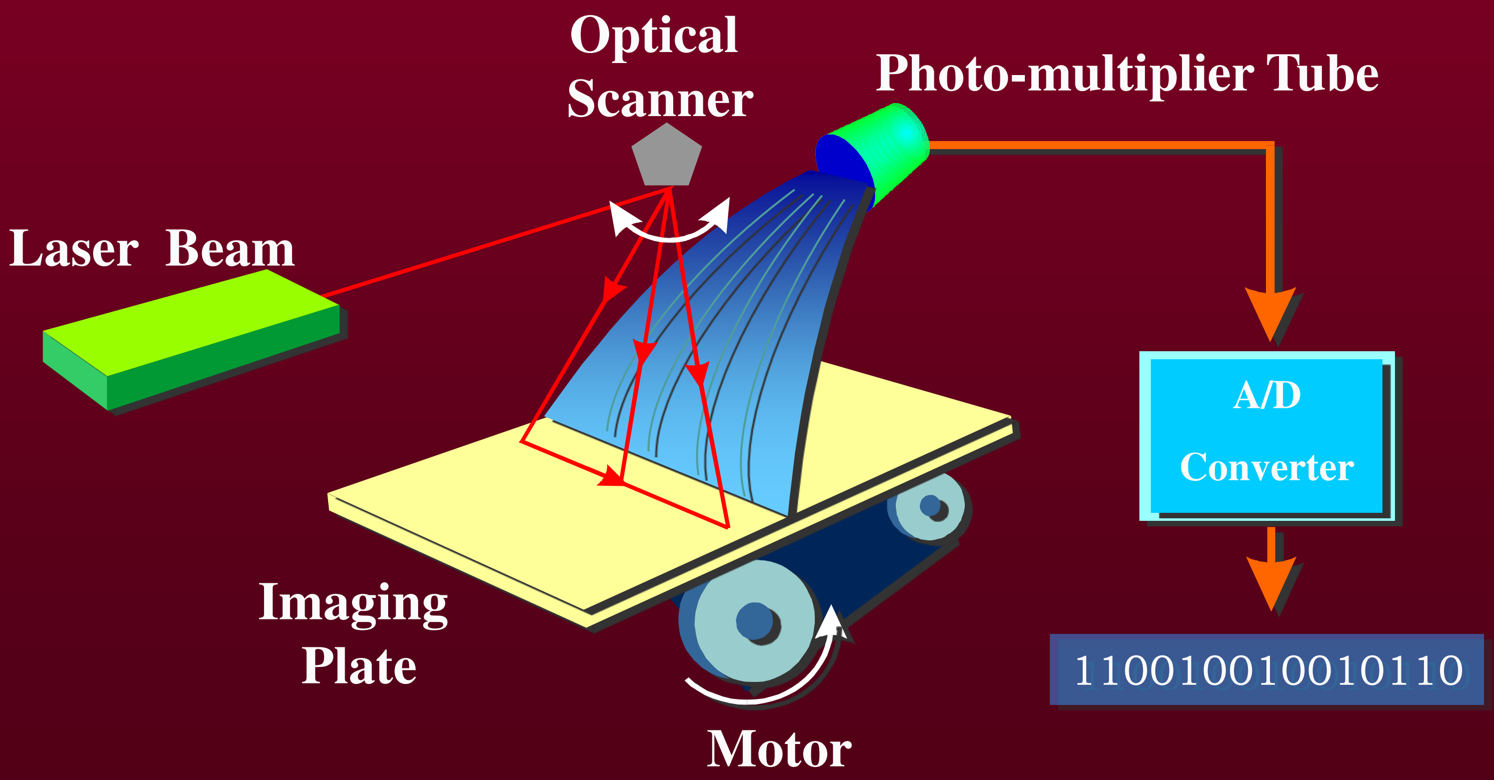
Computed Radiography (cont.)

After exposure:

The imaging plate is read electronically and erased for re-use in a special scanner system.

Computed Radiography (cont.)

As a laser scans the imaging plate, light is emitted where X-rays stimulated the phosphor during exposure. The light is then converted to a digital value.

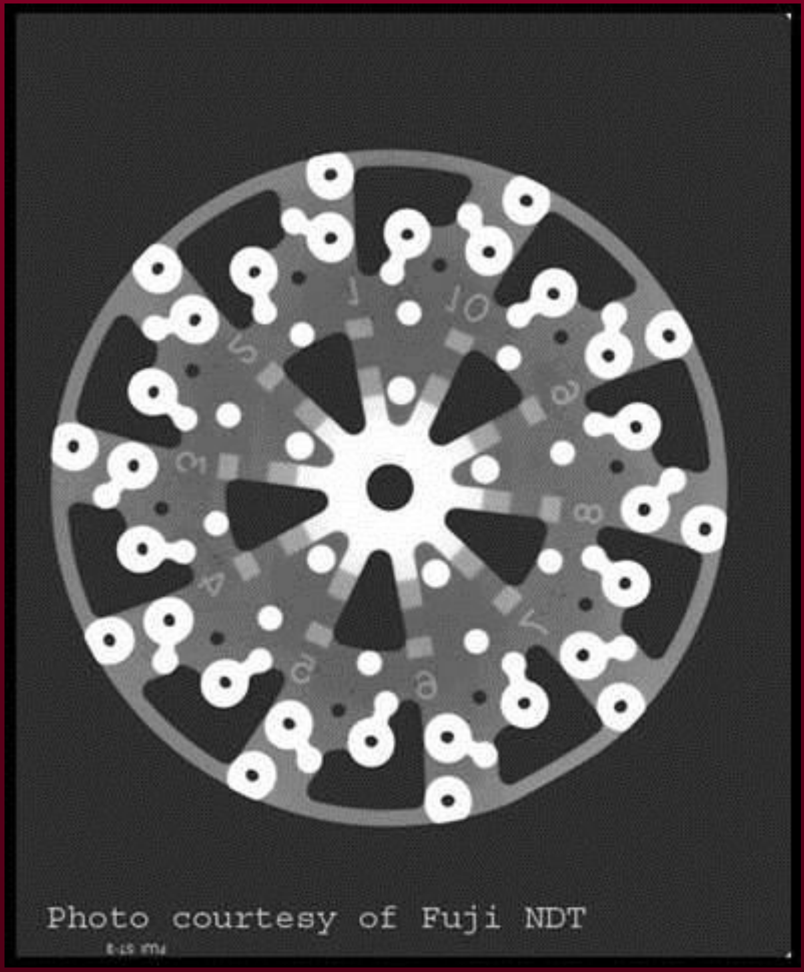


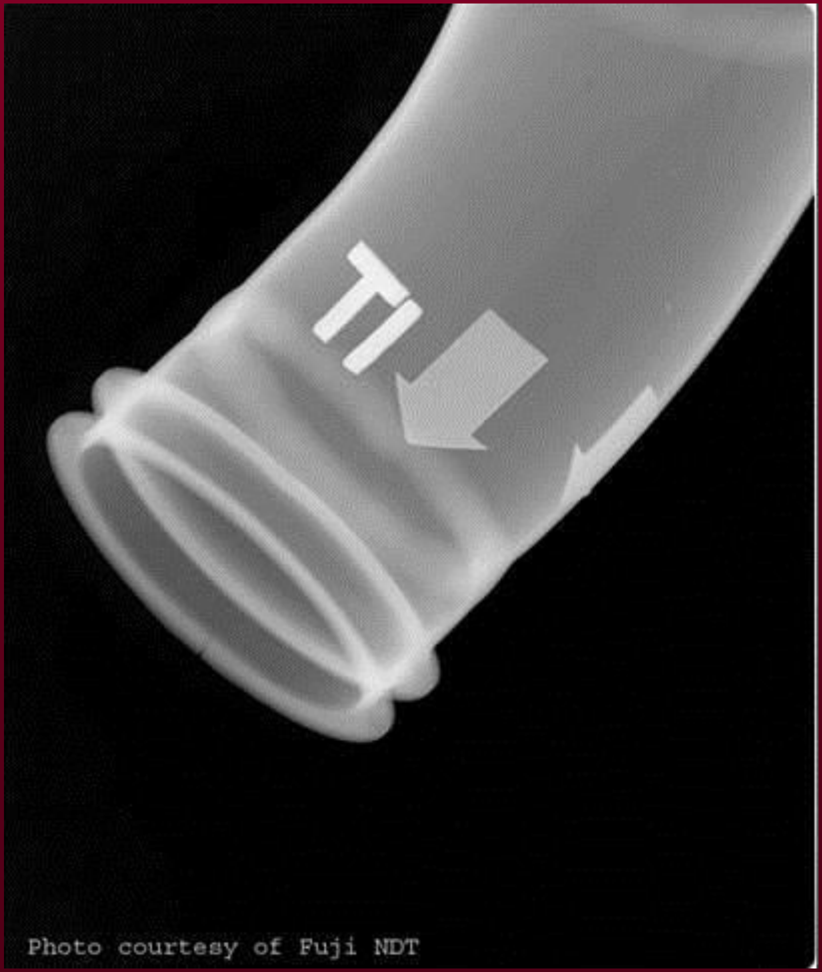
Computed Radiography (cont.)

Digital images are typically sent to a computer workstation where specialized software allows manipulation and enhancement.

Computed Radiography (cont.)

Examples of computed radiographs:





Real-Time Radiography

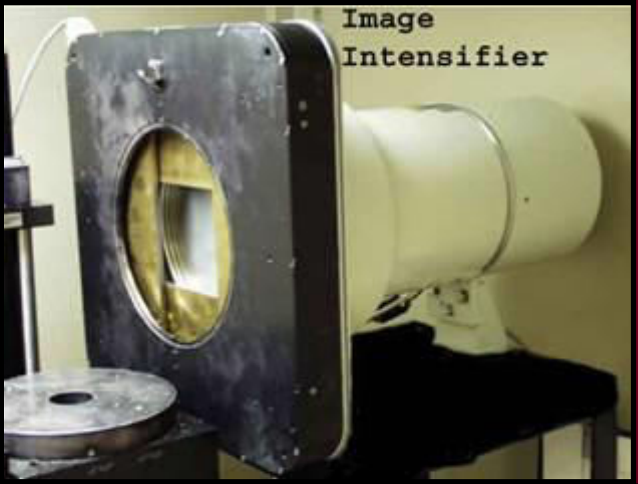
- Real-Time Radiography (RTR) is a term used to describe a form of radiography that allows electronic images to be captured and viewed in real time.
- Because image acquisition is almost instantaneous, X-ray images can be viewed as the part is moved and rotated.
- Manipulating the part can be advantageous for several reasons:
  - It may be possible to image the entire component with one exposure.
  - Viewing the internal structure of the part from different angular prospectives can provide additional data for analysis.
  - Time of inspection can often be reduced.

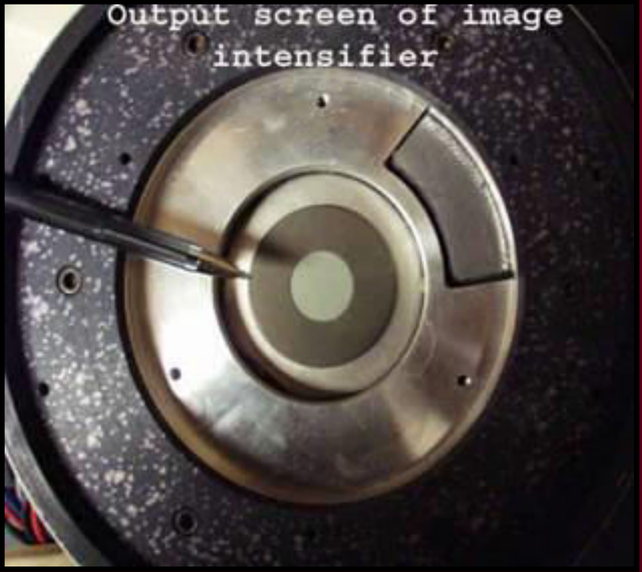
Real-Time Radiography (cont.)

- The equipment needed for an RTR includes:
  - X-ray tube
  - Image intensifier or other real-time detector
  - Camera
  - Computer with frame grabber board and software
  - Monitor
  - Sample positioning system (optional)

Real-Time Radiography (cont.)

- The image intensifier is a device that converts the radiation that passes through the specimen into light.
- It uses materials that fluoresce when struck by radiation.
- The more radiation that reaches the input screen, the more light that is given off.
- The image is very faint on the input screen so it is intensified onto a small screen inside the intensifier where the image is viewed with a camera.





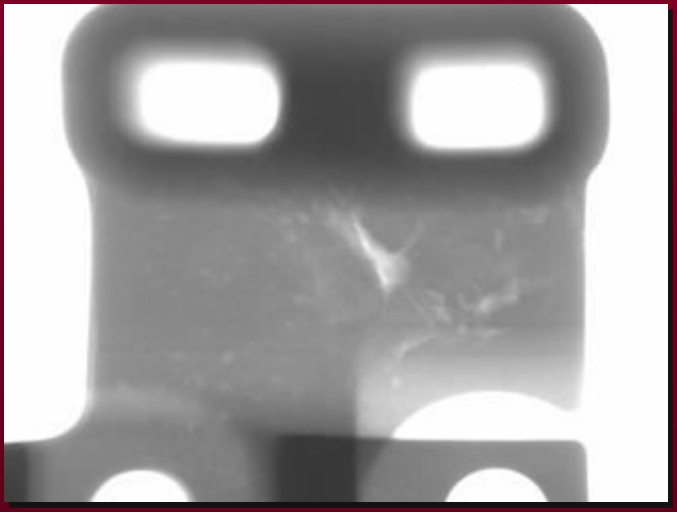
Real-Time Radiography (cont.)

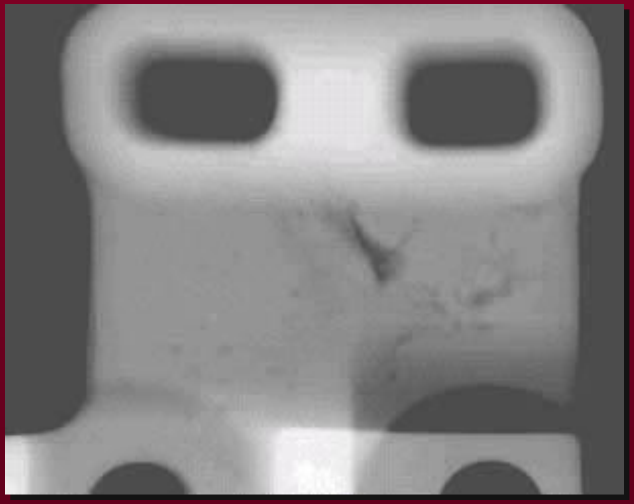
- A special camera which captures the light output of the screen is located near the image intensifying screen.
- The camera is very sensitive to a variety of different light intensities.

- A monitor is then connected to the camera to provide a viewable image.
- If a sample positioning system is employed, the part can be moved around and rotated to image different internal features of the part.

Real-Time Radiography (cont.)

Comparing Film and Real-Time Radiography





Real-time images are lighter in areas where more X-ray photons reach and excite the fluorescent screen.

Film images are darker in areas where more X-ray photons reach and ionize the silver molecules in the film.

Direct Radiography

- Direct radiography (DR) is a form of real-time radiography that uses a special flat panel detector.
- The panel works by converting penetrating radiation passing through the test specimen into minute electrical charges.
- The panel contains many micro-electronic capacitors. The capacitors form an electrical charge pattern image of the specimen.
- Each capacitor's charge is converted into a pixel which forms the digital image.

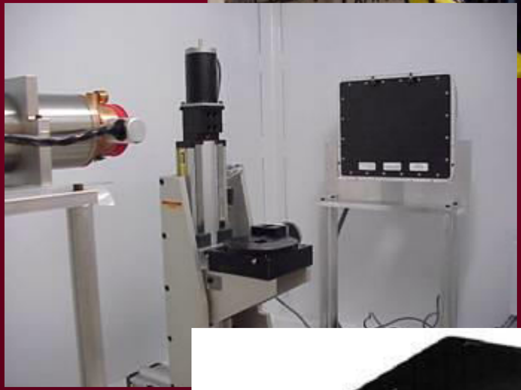
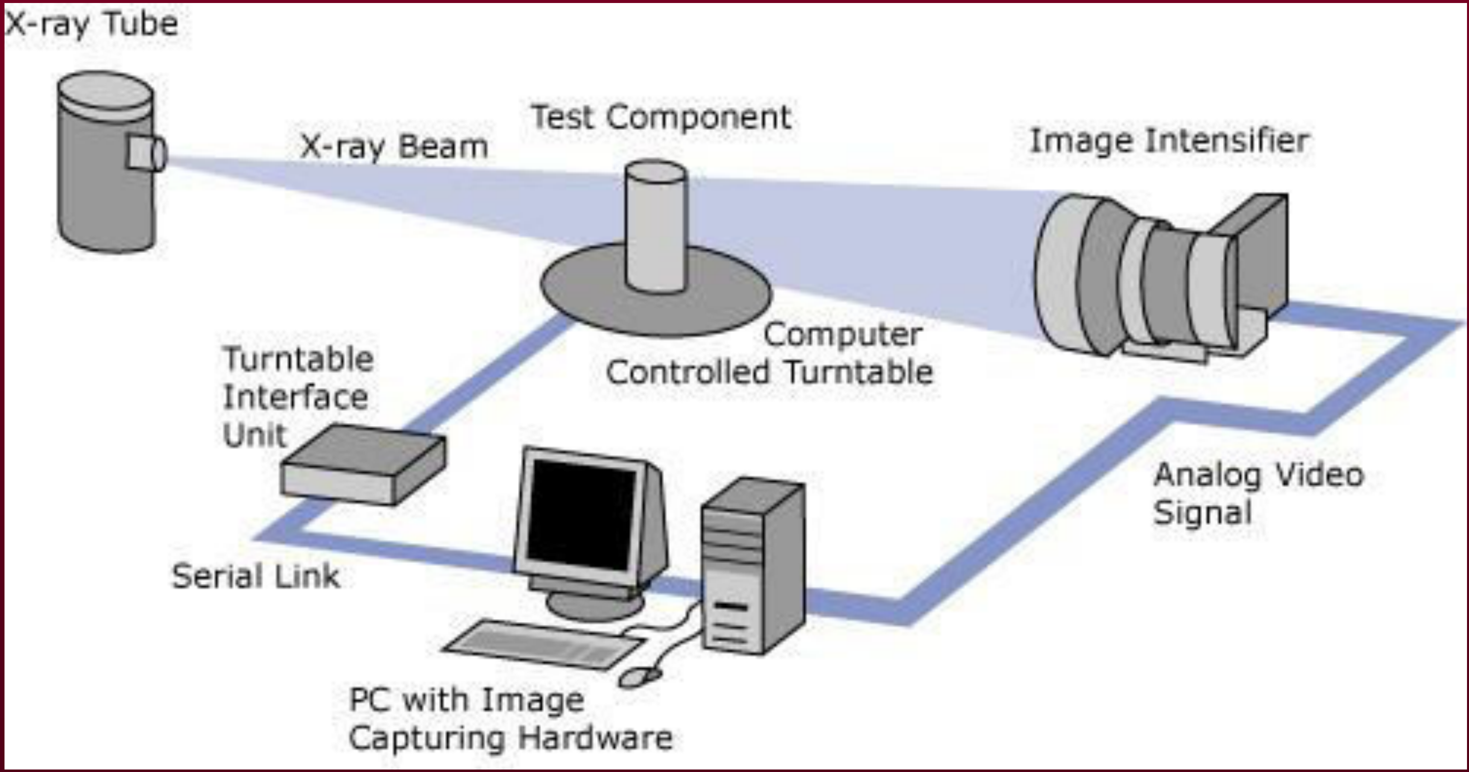


Image courtesy AFGA NDT

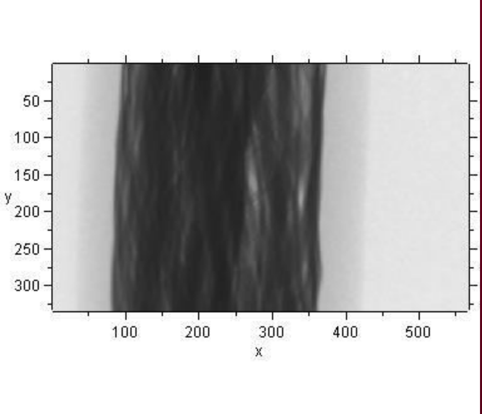
Computed Tomography

Computed Tomography (CT) uses a real-time inspection system employing a sample positioning system and special software.

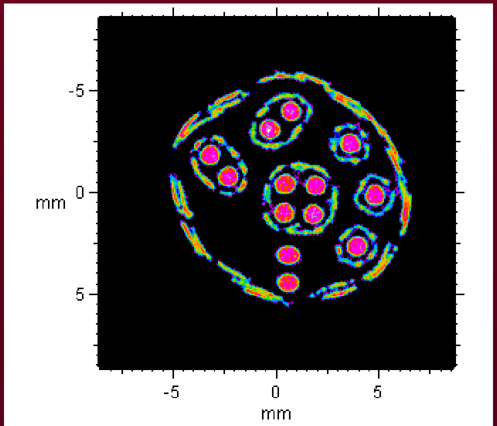


Computed Tomography (cont.)

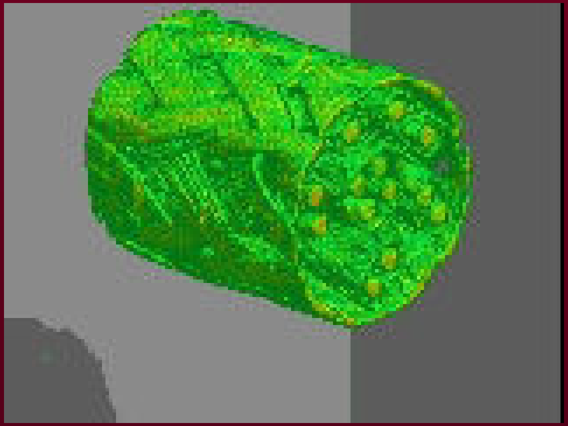
- Many separate images are saved (grabbed) and complied into 2-dimensional sections as the sample is rotated.
- 2-D images are them combined into 3-dimensional images.



Real-Time Captures



Compiled 2-D Images



Compiled 3-D Structure

Image Quality

- Image quality is critical for accurate assessment of a test specimen's integrity.
- Various tools called Image Quality Indicators (IQIs) are used for this purpose.
- There are many different designs of IQIs. Some contain artificial holes of varying size drilled in metal plaques while others are manufactured from wires of differing diameters mounted next to one another.

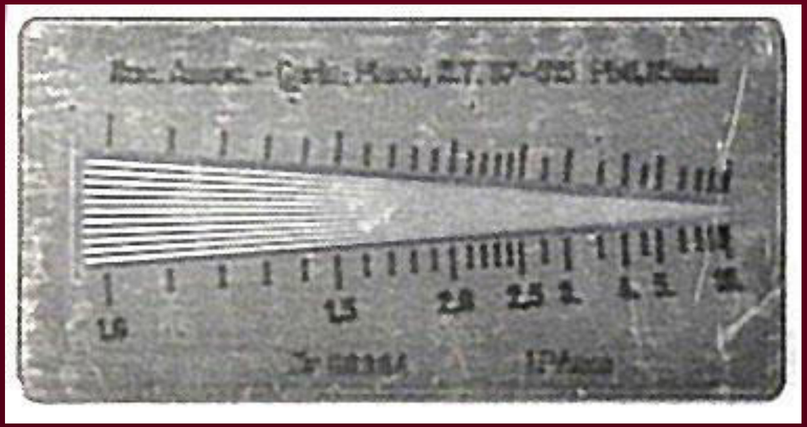
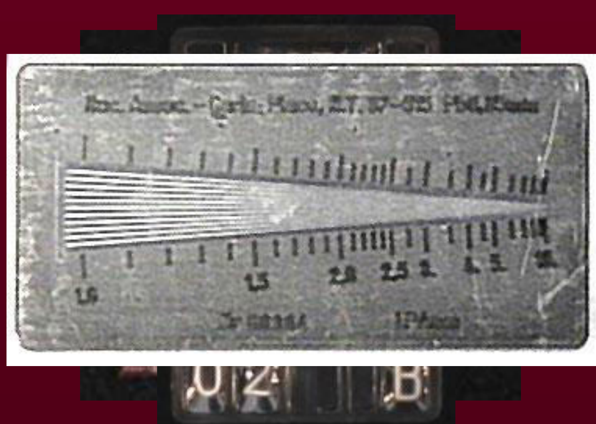
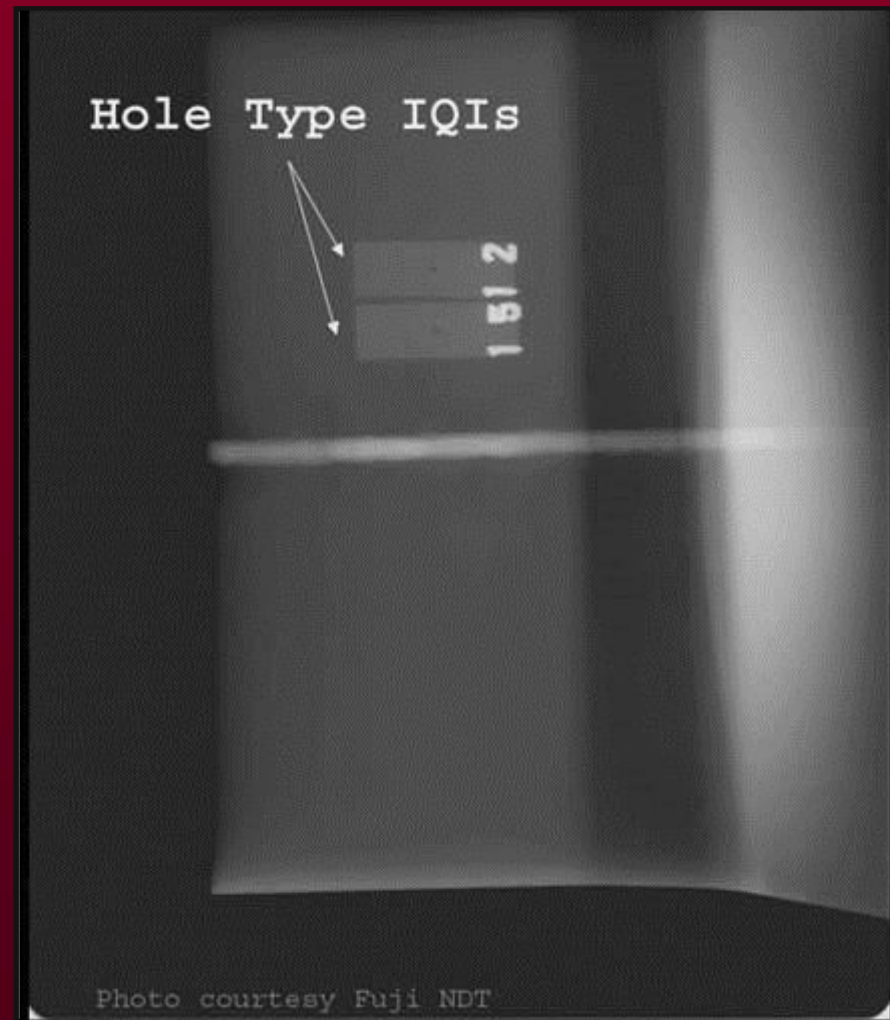


Image Quality (cont.)

- IQIs are typically placed on or next to a test specimen.
- Quality typically being determined based on the smallest hole or wire diameter that is reproduced on the image.



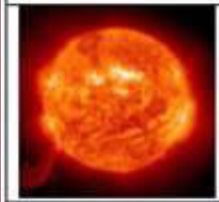
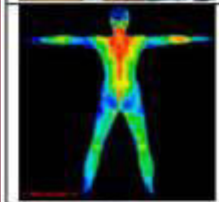


Radiation Safety

Use of radiation sources in industrial radiography is heavily regulated by state and federal organizations due to potential public and personal risks.

Radiation Safety (cont.)

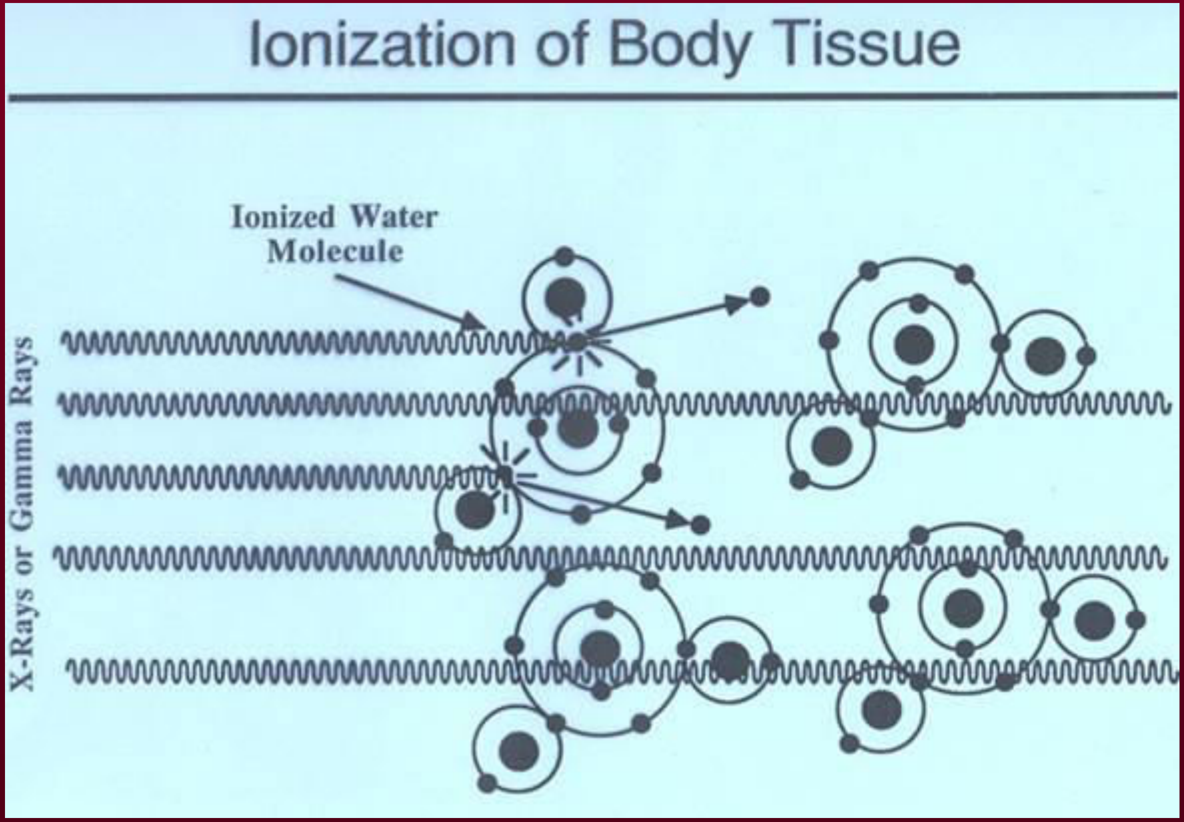
There are many sources of radiation. In general, a person receives roughly 100 mrem/year from natural sources and roughly 100 mrem/year from manmade sources.

Natural Sources		Annual Dose (mrem/year)
	Cosmic rays (radiation from the sun and outer space)	28
	Building materials	4
	The human body	25
	The earth	26

Manmade Sources		Annual Dose (mrem/year)
	Medical (primarily from diagnostic X-rays)	90
	Fallout from atomic bombs	5
	Nuclear power production	.3
	Consumer products (mostly from color TV sets)	1

Radiation Safety (cont.)

X-rays and gamma rays are forms of ionizing radiation, which means that they have the ability to form ions in the material that is penetrated. All living organisms are sensitive to the effects of ionizing radiation (radiation burns, x-ray food pasteurization, etc.)



X-rays and gamma rays have enough energy to liberate electrons from atoms and damage the molecular structure of cells.

This can cause radiation burns or cancer.

Radiation Safety (cont.)

Technicians who work with radiation must wear monitoring devices that keep track of their total absorption, and alert them when they are in a high radiation area.


Survey Meter

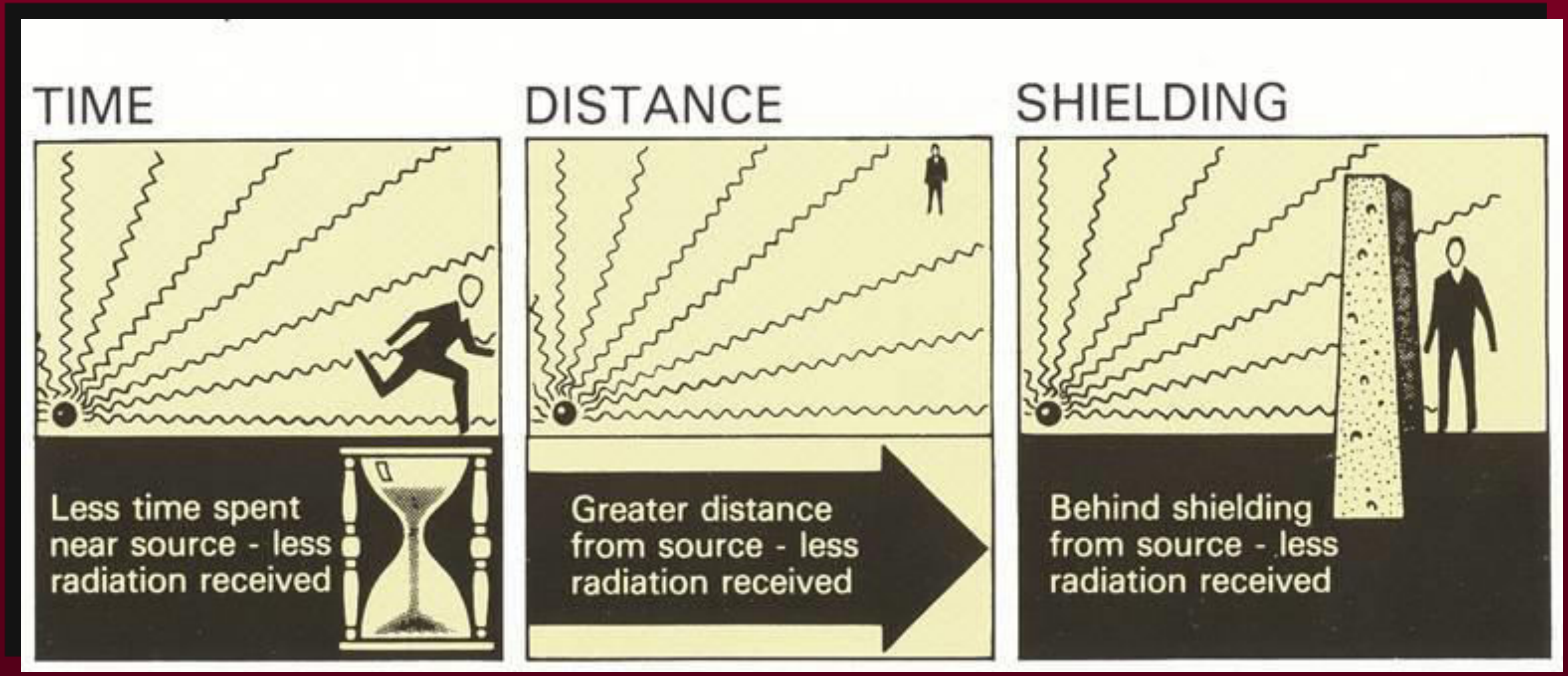

Pocket Dosimeter

Radiation Alarm

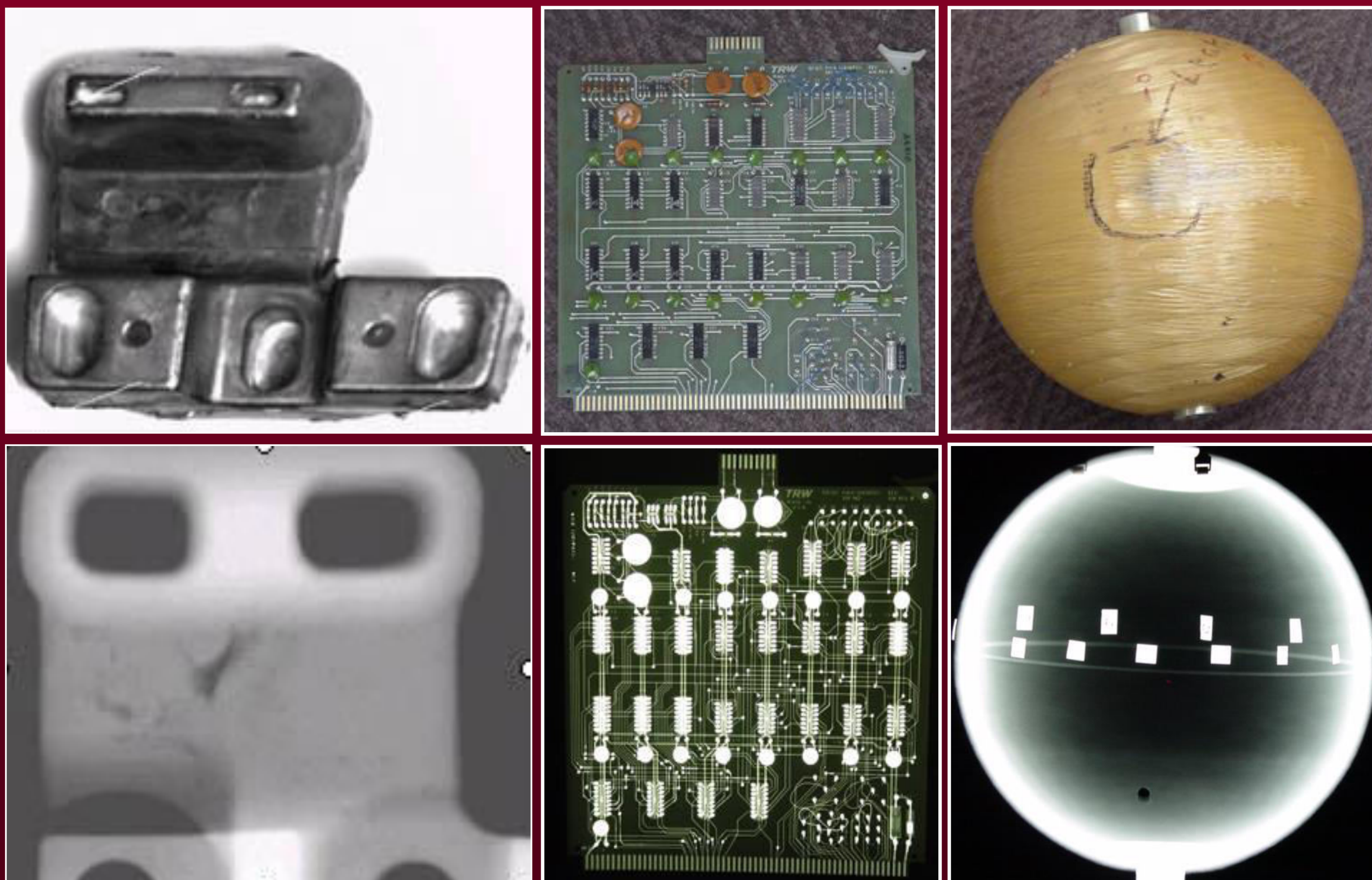
Radiation Badge

Radiation Safety (cont.)

There are three means of protection to help reduce exposure to radiation:

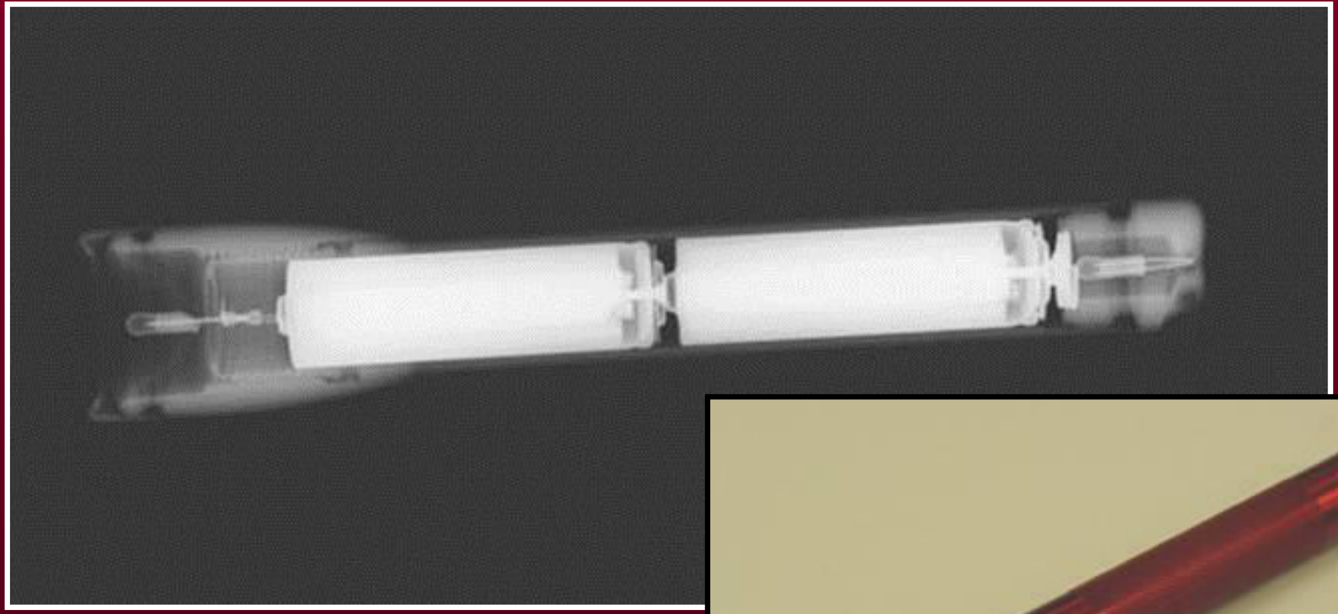


Radiographic Images

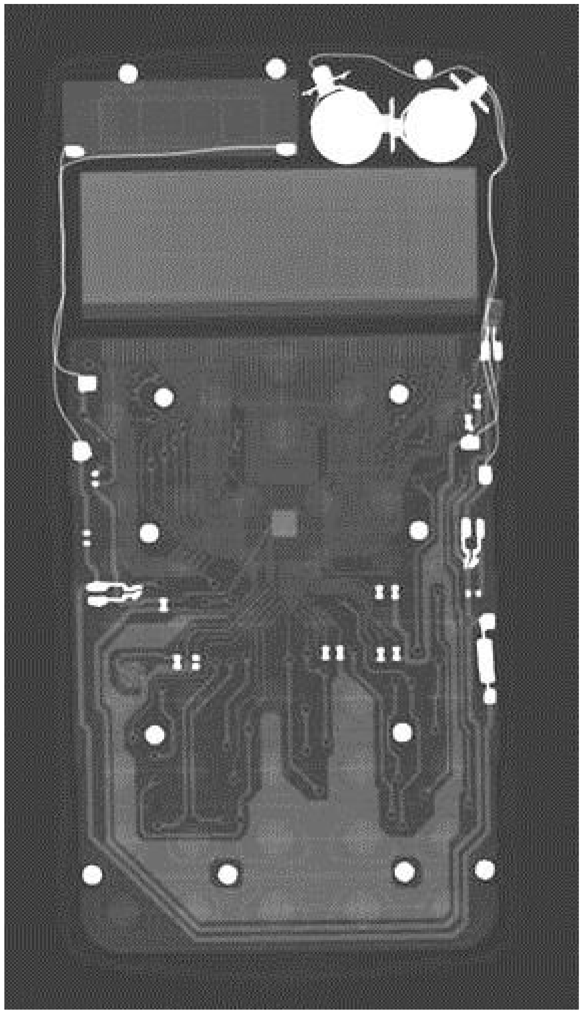


Radiographic Images

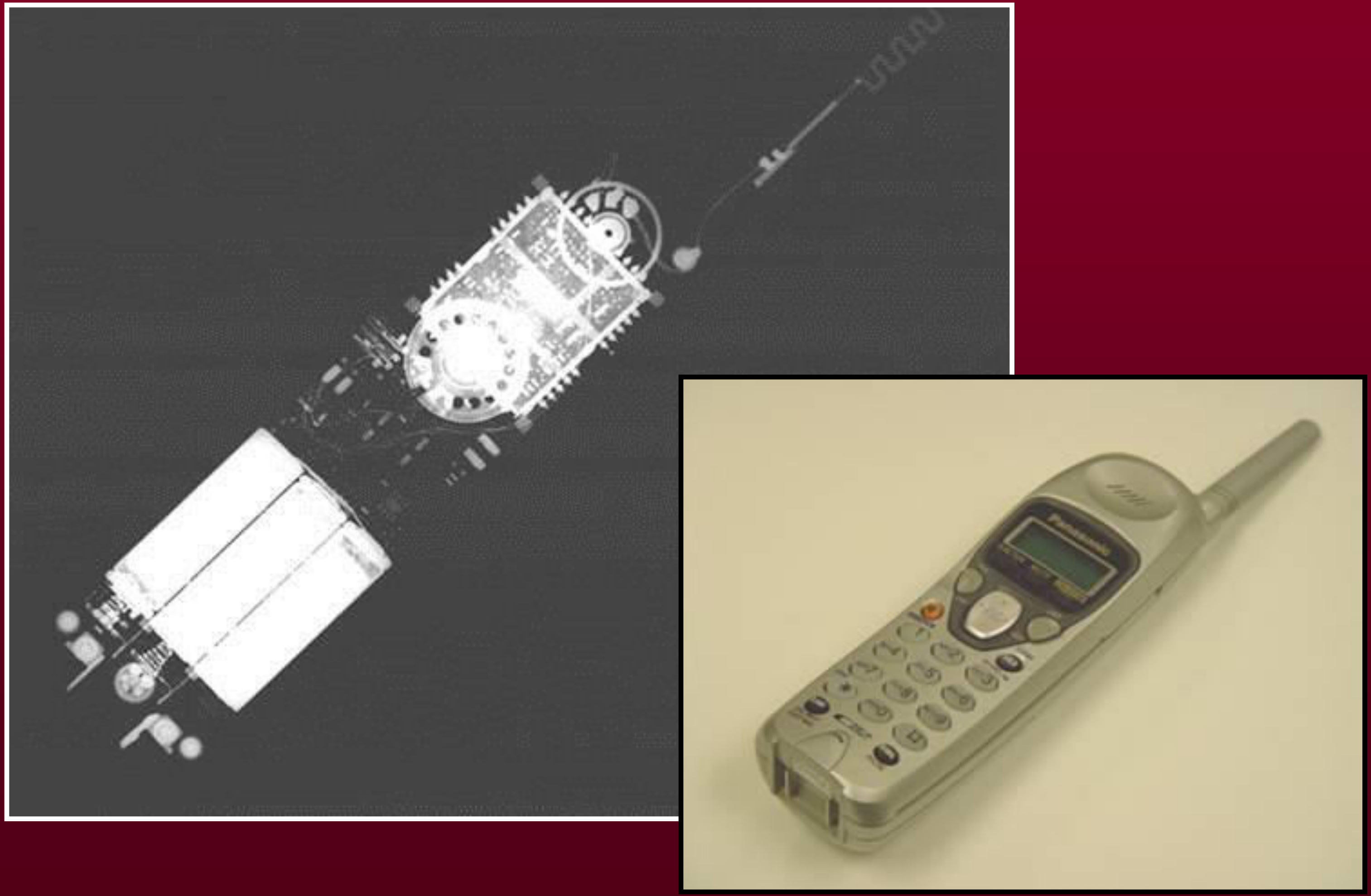
Can you determine what object was radiographed in this and the next three slides?



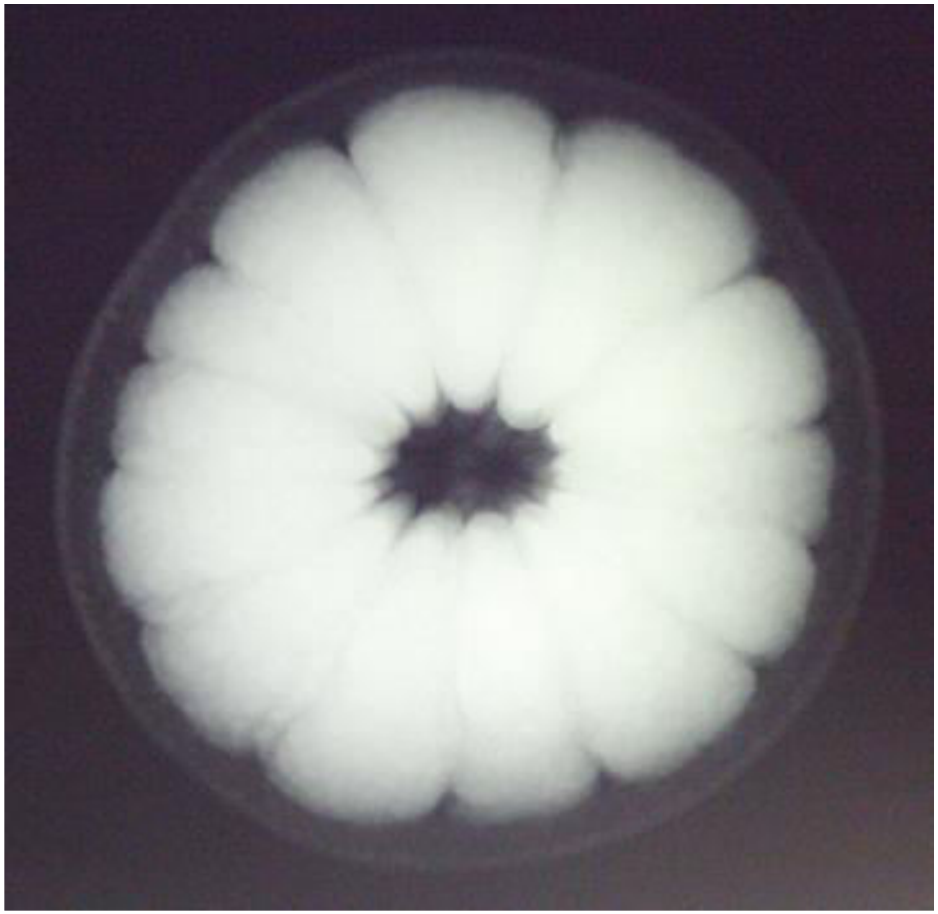
Radiographic Images



Radiographic Images



Radiographic Images



Advantages of Radiography

- Technique is not limited by material type or density.
- Can inspect assembled components.
- Minimum surface preparation required.
- Sensitive to changes in thickness, corrosion, voids, cracks, and material density changes.
- Detects both surface and subsurface defects.
- Provides a permanent record of the inspection.

Disadvantages of Radiography

- Many safety precautions for the use of high intensity radiation.
- Many hours of technician training prior to use.
- Access to both sides of sample required.
- Orientation of equipment and flaw can be critical.
- Determining flaw depth is impossible without additional angled exposures.
- Expensive initial equipment cost.

Glossary of Terms

- **Activation:** the process of creating radioactive material from stable material usually by bombarding a stable material with a large number of free neutrons. This process typically takes place in a special nuclear reactor.
- **Anode:** a positively charged electrode.
- **Automatic Film Processor:** a machine designed to develop film with very little human intervention. Automatic processors are very fast compared to manual development.

Glossary of Terms

- **Capacitor:** an electrical device that stores an electrical charge which can be released on demand.
- **Cathode:** a negatively charged electrode.
- **Darkroom:** a darkened room for the purpose of film development. Film is very sensitive to exposure by visible light and may be ruined.
- **Exposure:** the process of radiation penetrating and object.
- **Gamma Rays**: electromagnetic radiation emitted from the nucleus of a some radioactive materials.

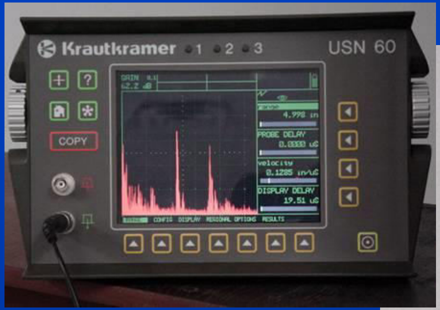
Glossary of Terms

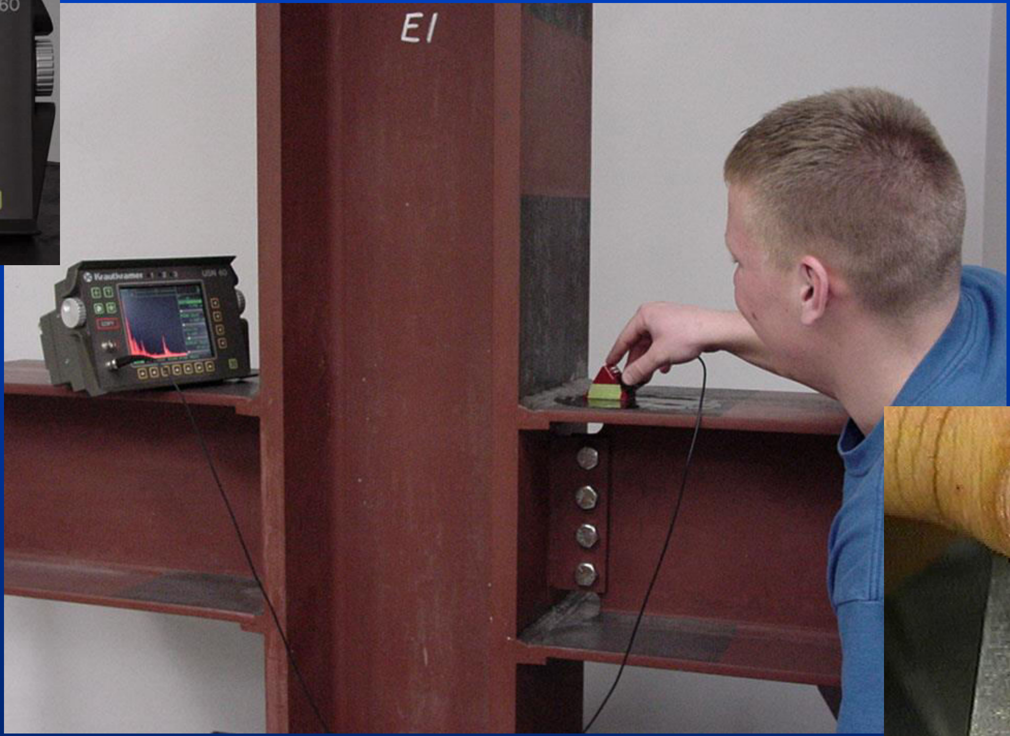
- **Phosphor:** a chemical substance that emits light when excited by radiation.
- **Pixel:** Short for ***Picture Element,*** a pixel is a single point in a graphic image. Graphics monitors display pictures by dividing the display screen into thousands (or millions) of pixels, arranged in rows and columns. The pixels are so close together that they appear connected.
- **Photo-multiplier tube:** an amplifier used to convert light into electrical signals.

Glossary of Terms

- **Radioactive:** to give off radiation spontaneously.
- **Radiograph:** an image of the internal structure of and object produced using a source of radiation and a recording device.
- **Silver Bromide:** silver and bromine compound used in film emulsion to form the image seen on a radiograph.

Ultrasonic Testing





Introduction

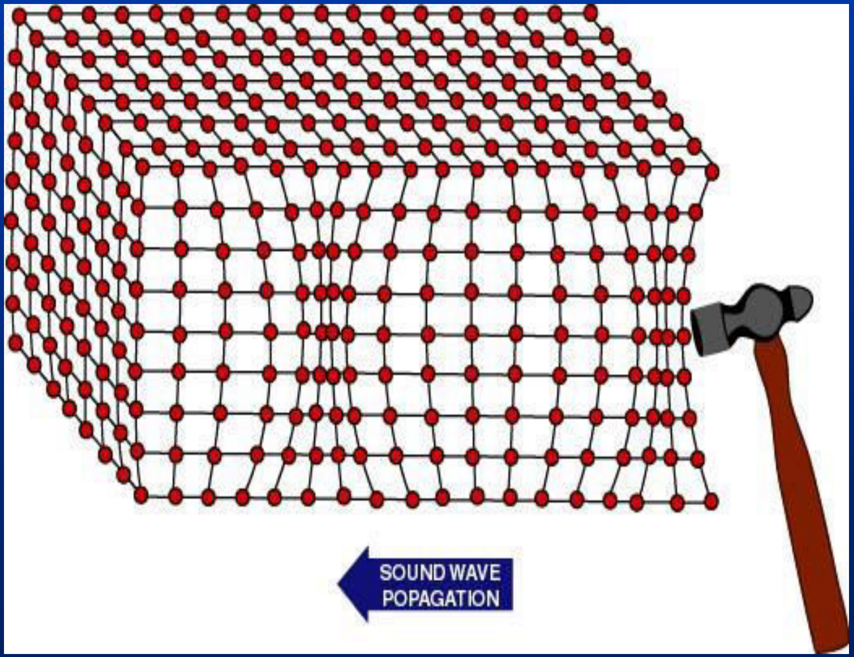
- This module presents an introduction to the NDT method of ultrasonic testing.
- Ultrasonic testing uses high frequency sound energy to conduct examinations and make measurements.
- Ultrasonic examinations can be conducted on a wide variety of material forms including castings, forgings, welds, and composites.
- A considerable amount of information about the part being examined can be collected, such as the presence of discontinuities, part or coating thickness; and acoustical properties can often be correlated to certain properties of the material.

Outline

- **Applications**
- **Basic Principles of sound generation**
- **Pulse echo and through transmission testing**
- **Inspection applications**
- **Equipment**
  - Transducers
  - Instrumentation
  - Reference Standards
- **Data presentation**
- **Advantages and Limitations**
- **Glossary of terms**

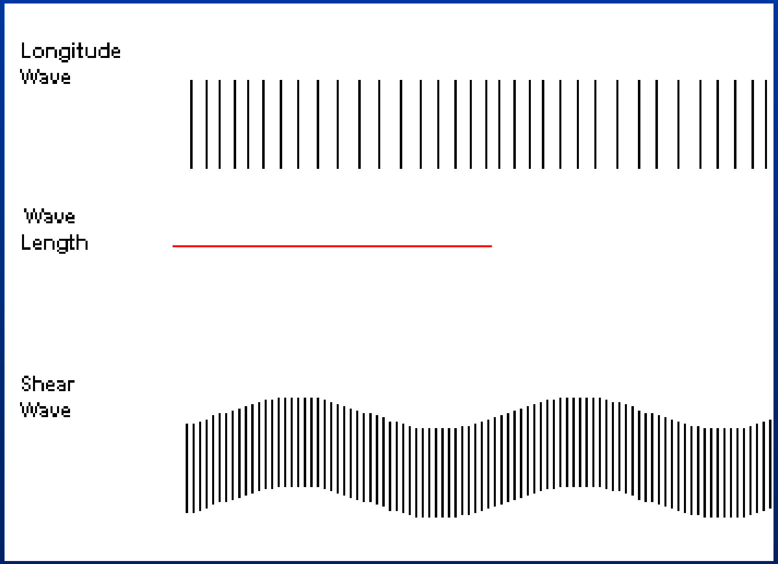
Basic Principles of Sound

- Sound is produced by a vibrating body and travels in the form of a wave.
- Sound waves travel through materials by vibrating the particles that make up the material.
- The pitch of the sound is determined by the frequency of the wave (vibrations or cycles completed in a certain period of time).
- Ultrasound is sound with a pitch too high to be detected by the human ear.



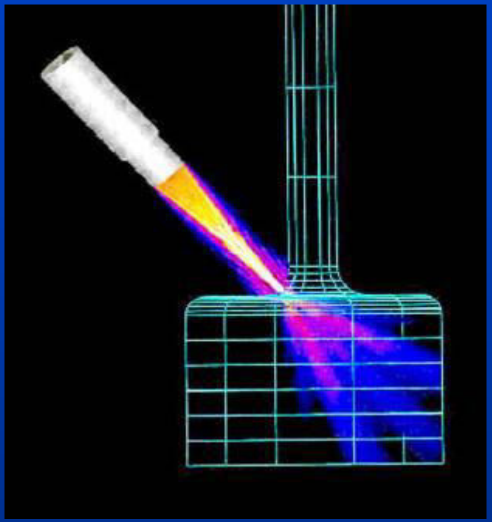
Basic Principles of Sound (cont.)

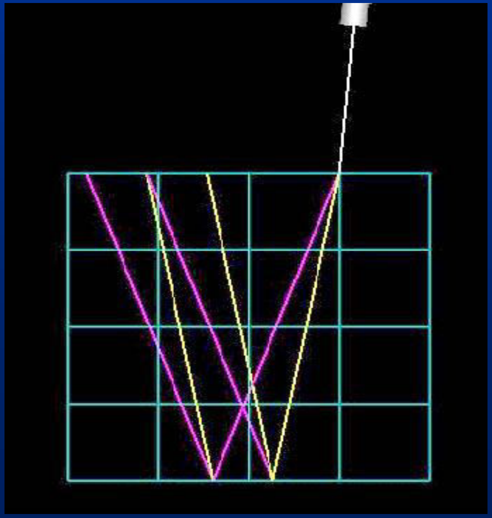
- The measurement of sound waves from crest to crest determines its wavelength (λ).
- The time is takes a sound wave to travel a distance of one complete wavelength is the same amount of time it takes the source to execute one complete vibration.
- The sound wavelength is inversely proportional to its frequency. ($\lambda = 1/f$)
- Several wave modes of vibration are used in ultrasonic inspection. The most common are longitudinal, shear, and Rayleigh (surface) waves.



Basic Principles of Sound (cont.)

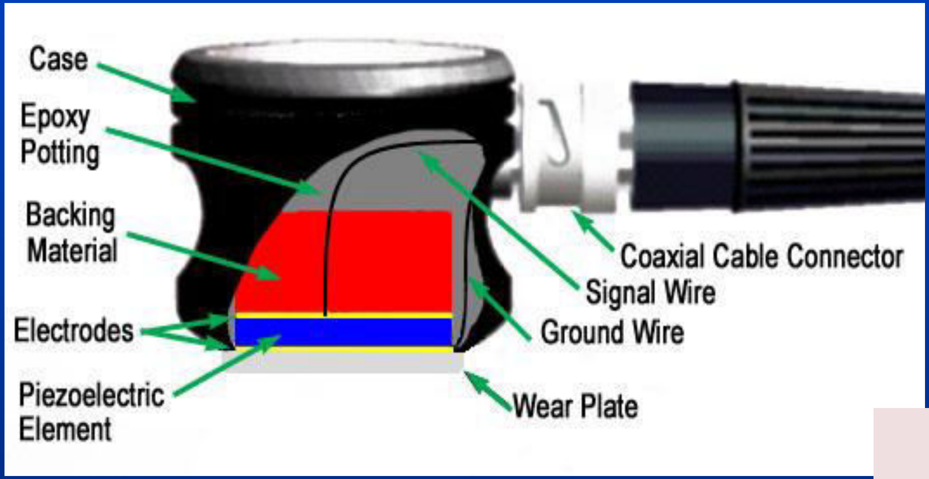
- Ultrasonic waves are very similar to light waves in that they can be reflected, refracted, and focused.
- Reflection and refraction occurs when sound waves interact with interfaces of differing acoustic properties.
- In solid materials, the vibrational energy can be split into different wave modes when the wave encounters an interface at an angle other than 90 degrees.
- Ultrasonic reflections from the presence of discontinuities or geometric features enables detection and location.
- The velocity of sound in a given material is constant and can only be altered by a change in the mode of energy.



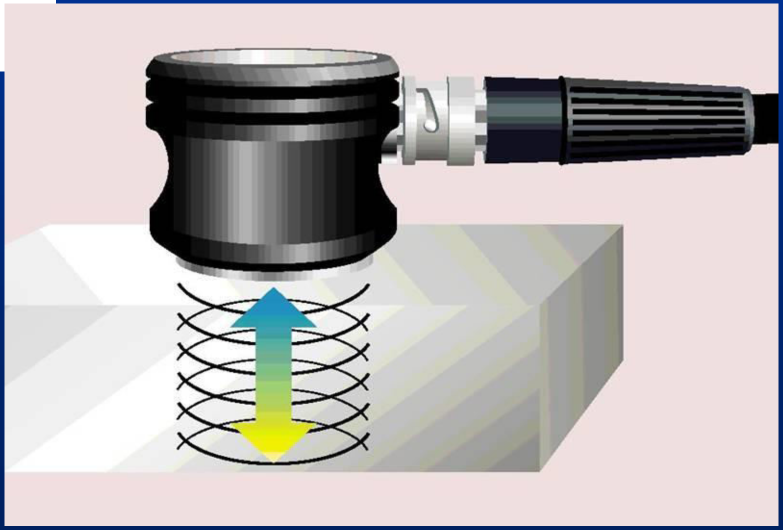


Ultrasound Generation

Ultrasound is generated with a transducer.



A piezoelectric element in the transducer converts electrical energy into mechanical vibrations (sound), and vice versa.



The transducer is capable of both transmitting and receiving sound energy.

Principles of Ultrasonic Inspection

- Ultrasonic waves are introduced into a material where they travel in a straight line and at a constant speed until they encounter a surface.
- At surface interfaces some of the wave energy is reflected and some is transmitted.
- The amount of reflected or transmitted energy can be detected and provides information about the size of the reflector.
- The travel time of the sound can be measured and this provides information on the distance that the sound has traveled.

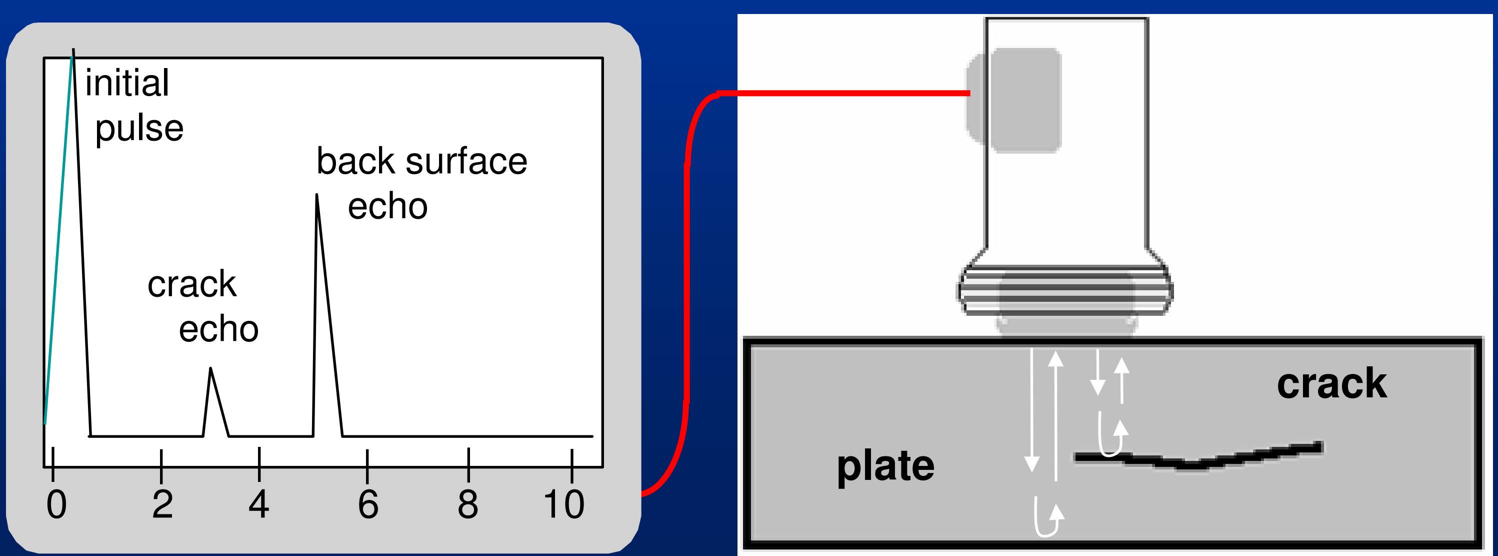
Test Techniques

- Ultrasonic testing is a very versatile inspection method, and inspections can be accomplished in a number of different ways.
- Ultrasonic inspection techniques are commonly divided into three primary classifications.
  - **Pulse-echo and Through Transmission**
    (Relates to whether reflected or transmitted energy is used)
  - **Normal Beam and Angle Beam**
    (Relates to the angle that the sound energy enters the test article)
  - **Contact and Immersion**
    (Relates to the method of coupling the transducer to the test article)

Each of these techniques will be discussed briefly in the following slides.

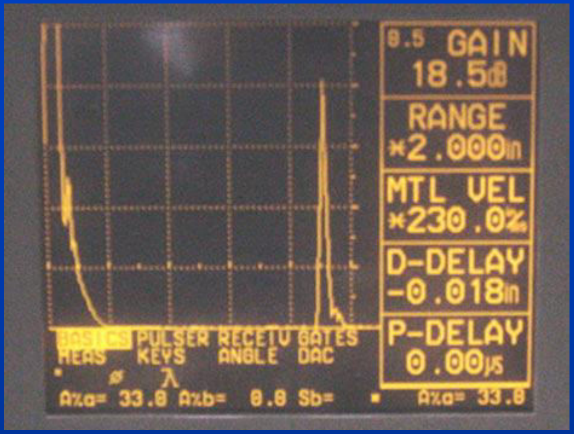
Test Techniques - Pulse-Echo

- In pulse-echo testing, a transducer sends out a pulse of energy and the same or a second transducer listens for reflected energy (an echo).
- Reflections occur due to the presence of discontinuities and the surfaces of the test article.
- The amount of reflected sound energy is displayed versus time, which provides the inspector information about the size and the location of features that reflect the sound.



UT Instrument Screen

Test Techniques – Pulse-Echo (cont.)



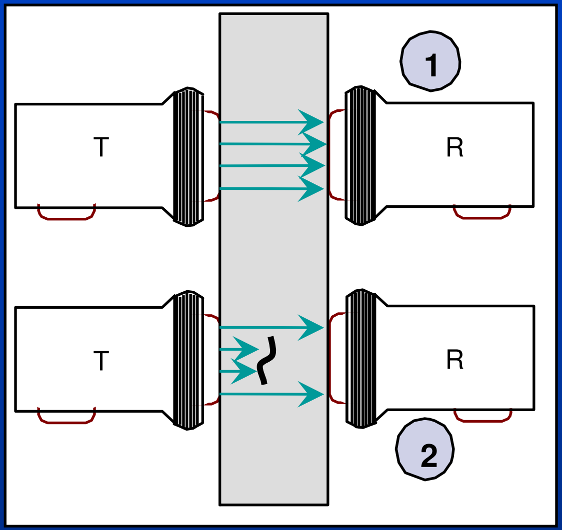
Digital display showing signal generated from sound reflecting off back surface.

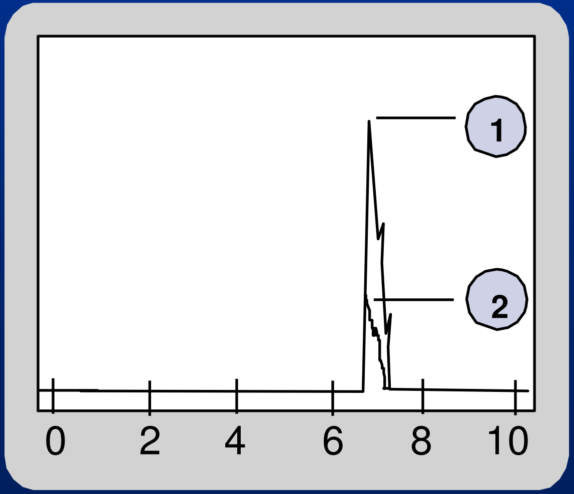
Digital display showing the presence of a reflector midway through material, with lower amplitude back surface reflector.

The pulse-echo technique allows testing when access to only one side of the material is possible, and it allows the location of reflectors to be precisely determined.

Test Techniques – Through-Transmission

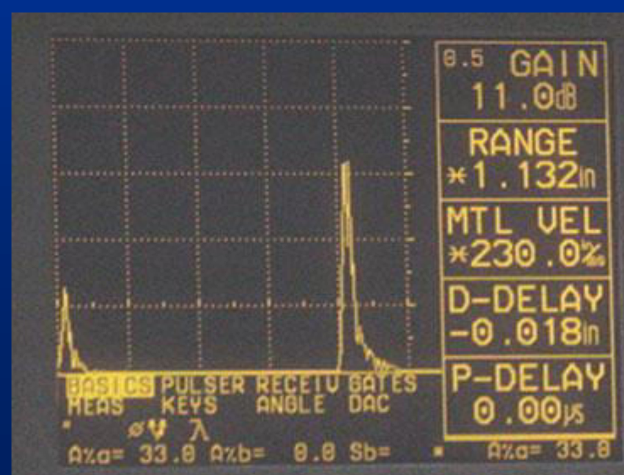
- Two transducers located on opposing sides of the test specimen are used. One transducer acts as a transmitter, the other as a receiver.
- Discontinuities in the sound path will result in a partial or total loss of sound being transmitted and be indicated by a decrease in the received signal amplitude.
- Through transmission is useful in detecting discontinuities that are not good reflectors, and when signal strength is weak. It does not provide depth information.





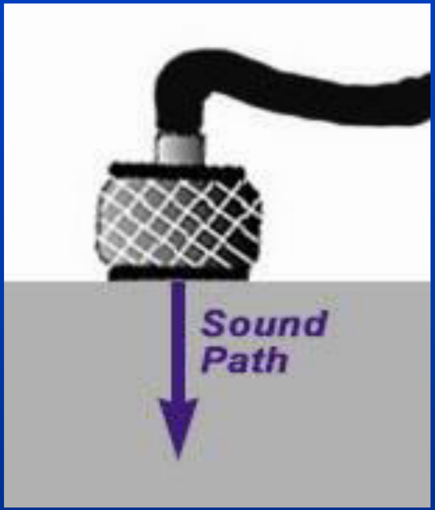
Test Techniques – Through-Transmission

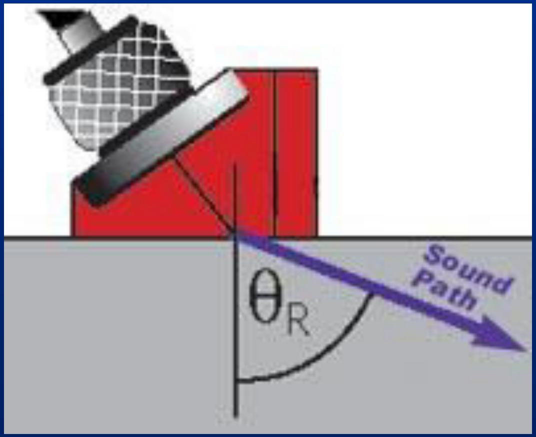
Digital display showing received sound through material thickness.



Digital display showing loss of received signal due to presence of a discontinuity in the sound field.

Test Techniques – Normal and Angle Beam

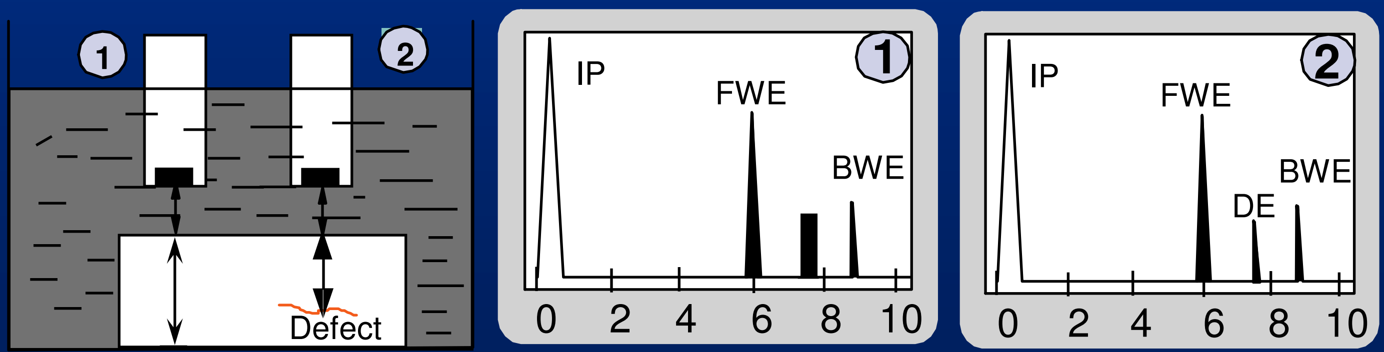




- In normal beam testing, the sound beam is introduced into the test article at 90 degree to the surface.
- In angle beam testing, the sound beam is introduced into the test article at some angle other than 90.
- The choice between normal and angle beam inspection usually depends on two considerations:
  - The orientation of the feature of interest – the sound should be directed to produce the largest reflection from the feature.
  - Obstructions on the surface of the part that must be worked around.

Test Techniques – Contact Vs Immersion

- To get useful levels of sound energy into a material, the air between the transducer and the test article must be removed. This is referred to as coupling.
- In contact testing (shown on the previous slides) a couplant such as water, oil or a gel is applied between the transducer and the part.
- In immersion testing, the part and the transducer are place in a water bath. This arrangement allows better movement of the transducer while maintaining consistent coupling.
- With immersion testing, an echo from the front surface of the part is seen in the signal but otherwise signal interpretation is the same for the two techniques.



IP = Initial Pulse
FWE = Front Wall Echo
DE = Defect Echo
BWE = Back Wall Echo

Inspection Applications

Some of the applications for which ultrasonic testing may be employed include:

- Flaw detection (cracks, inclusions, porosity, etc.)
- Erosion & corrosion thickness gauging
- Assessment of bond integrity in adhesively joined and brazed components
- Estimation of void content in composites and plastics
- Measurement of case hardening depth in steels
- Estimation of grain size in metals

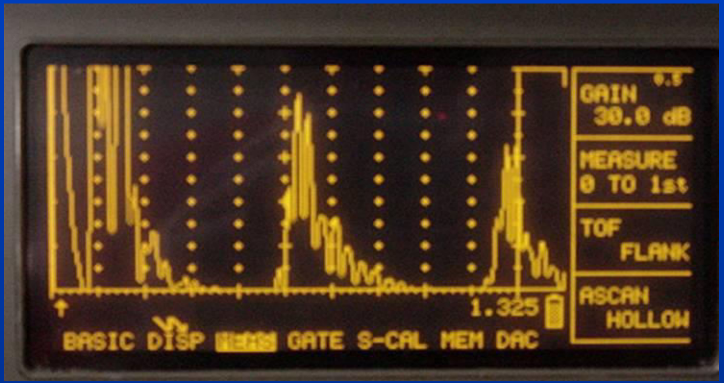
On the following slides are examples of some common applications of ultrasonic inspection.

Thickness Gauging

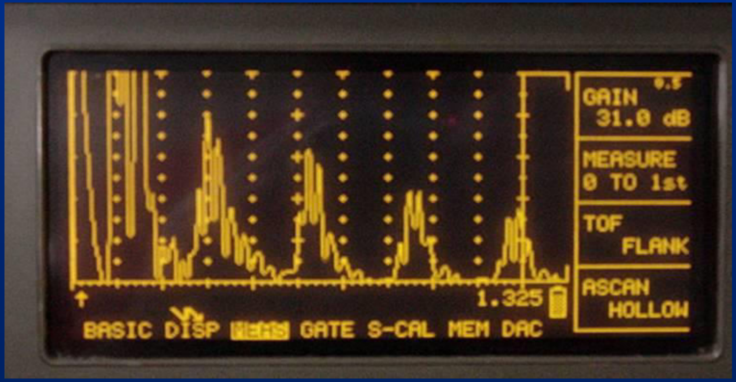
- Ultrasonic thickness gauging is routinely utilized in the petrochemical and utility industries to determine various degrees of corrosion/erosion.
- Applications include piping systems, storage and containment facilities, and pressure vessels.

Flaw Detection - Delaminations

Contact, pulse-echo inspection for delaminations on 36” rolled beam.



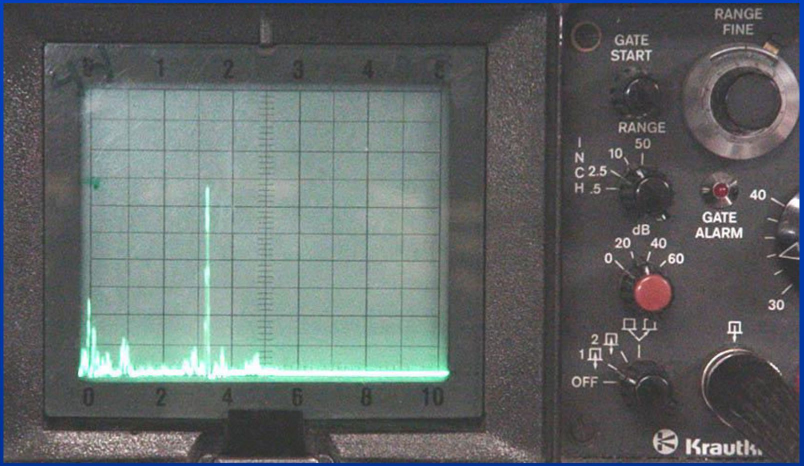
Signal showing multiple back surface echoes in an unflawed area.

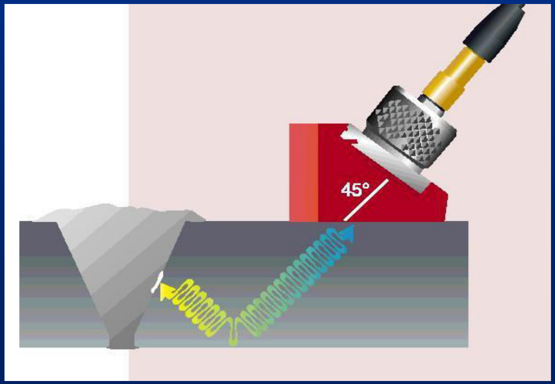


Additional echoes indicate delaminations in the member.

Flaw Detection in Welds

- One of the most widely used methods of inspecting weldments is ultrasonic inspection.
- Full penetration groove welds lend themselves readily to angle beam shear wave examination.





Equipment

Equipment for ultrasonic testing is very diversified. Proper selection is important to insure accurate inspection data as desired for specific applications.

In general, there are three basic components that comprise an ultrasonic test system:

- Instrumentation
- Transducers
- Calibration Standards

Transducers

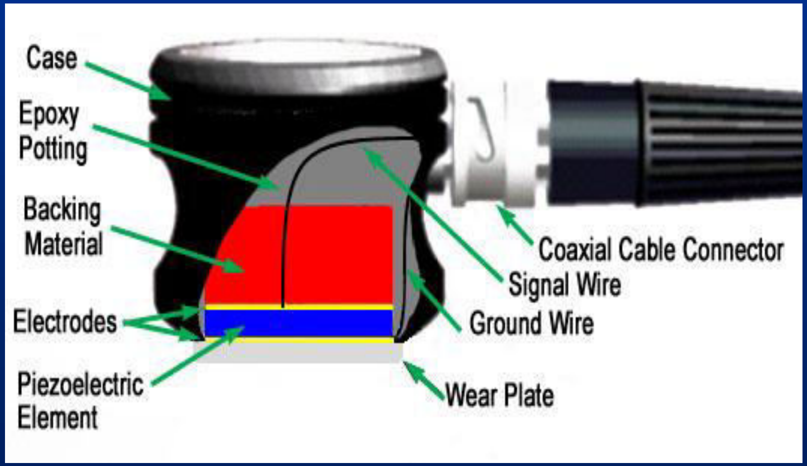
- Transducers are manufactured in a variety of forms, shapes and sizes for varying applications.
- Transducers are categorized in a number of ways which include:
  - Contact or immersion
  - Single or dual element
  - Normal or angle beam

- In selecting a transducer for a given application, it is important to choose the desired frequency, bandwidth, size, and in some cases focusing which optimizes the inspection capabilities.

Contact Transducers

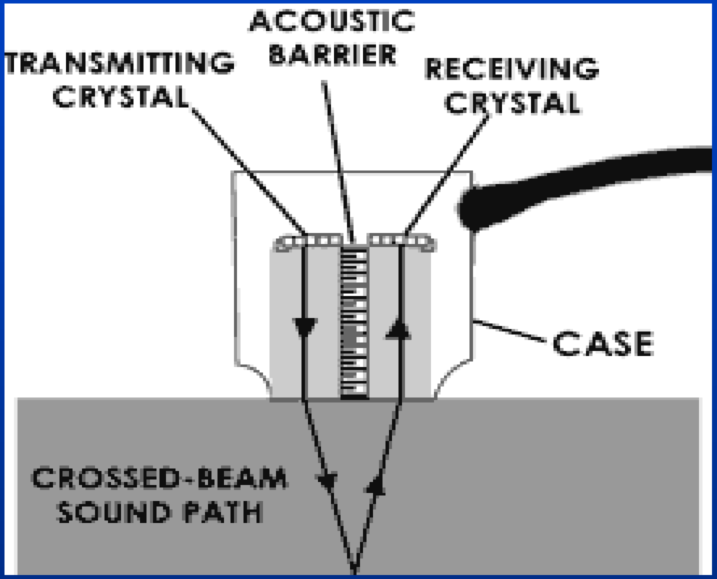
Contact transducers are designed to withstand rigorous use, and usually have a wear plate on the bottom surface to protect the piezoelectric element from contact with the surface of the test article.

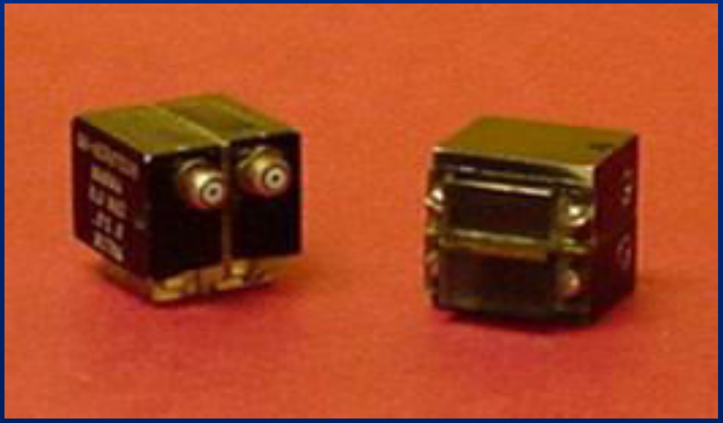
Many incorporate ergonomic designs for ease of grip while scanning along the surface.



Contact Transducers (cont.)

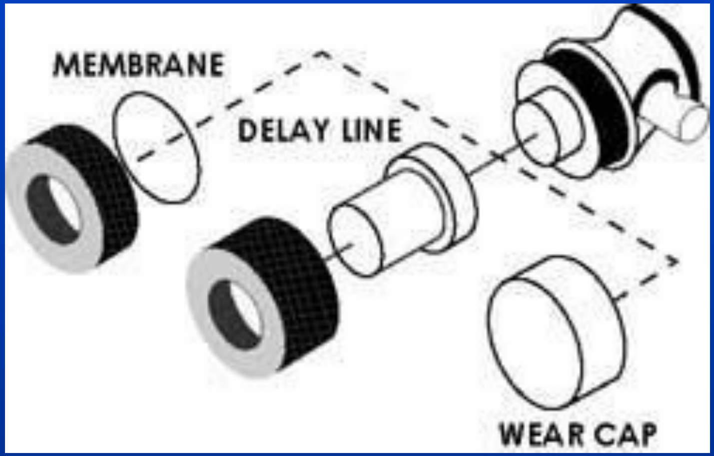
- Contact transducers are available with two piezoelectric crystals in one housing. These transducers are called dual element transducers.
- One crystal acts as a transmitter, the other as a receiver.
- This arrangement improves near surface resolution because the second transducer does not need to complete a transmit function before listening for echoes.
- Dual elements are commonly employed in thickness gauging of thin materials.

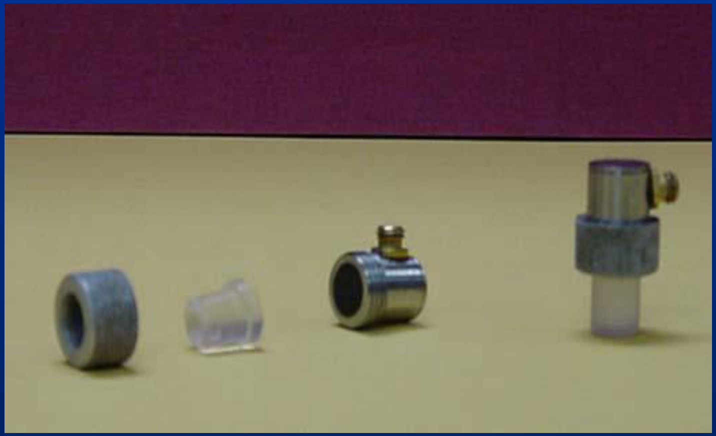




Contact Transducers (cont.)

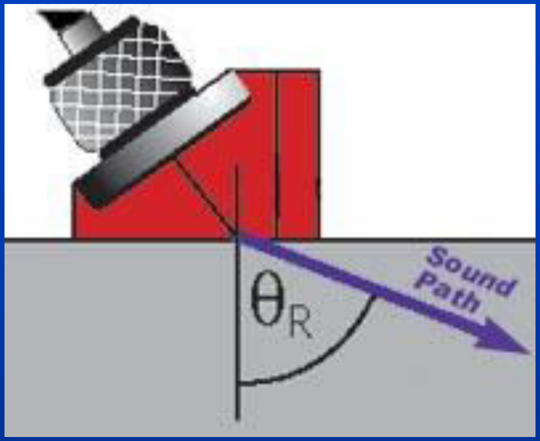
- A way to improve near surface resolution with a single element transducer is through the use of a delay line.
- Delay line transducers have a plastic piece that is a sound path that provides a time delay between the sound generation and reception of reflected energy.
- Interchangeable pieces make it possible to configure the transducer with insulating wear caps or flexible membranes that conform to rough surfaces.
- Common applications include thickness gauging and high temperature measurements.

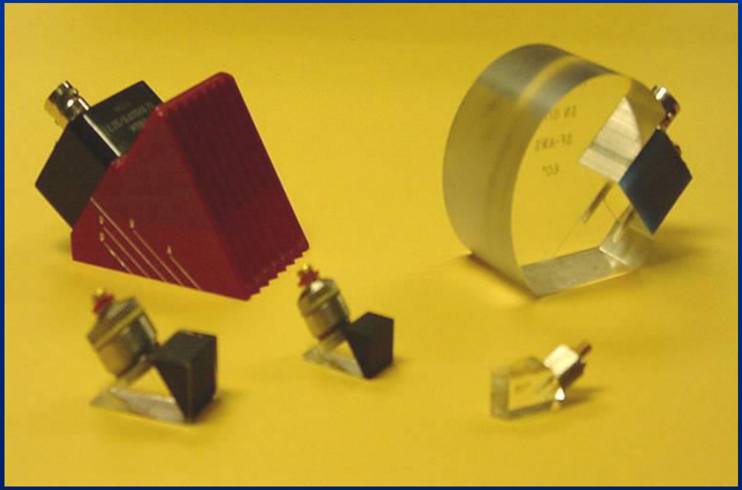




Transducers (cont.)

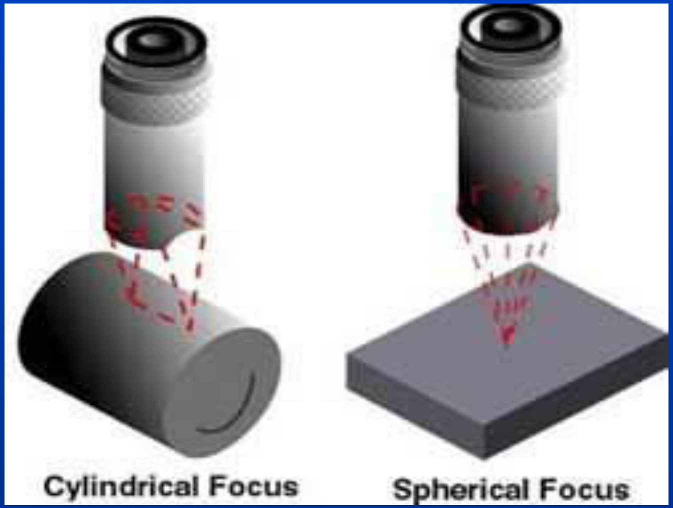
- Angle beam transducers incorporate wedges to introduce a refracted shear wave into a material.
- The incident wedge angle is used with the material velocity to determine the desired refracted shear wave according to Snell's Law)
- Transducers can use fixed or variable wedge angles.
- Common application is in weld examination.





Transducers (cont.)

- Immersion transducers are designed to transmit sound whereby the transducer and test specimen are immersed in a liquid coupling medium (usually water).
- Immersion transducers are manufactured with planar, cylindrical or spherical acoustic lenses (focusing lens).



Instrumentation

- Ultrasonic equipment is usually purchased to satisfy specific inspection needs, some users may purchase general purpose equipment to fulfill a number of inspection applications.
- Test equipment can be classified in a number of different ways, this may include portable or stationary, contact or immersion, manual or automated.
- Further classification of instruments commonly divides them into four general categories: D-meters, Flaw detectors, Industrial and special application.

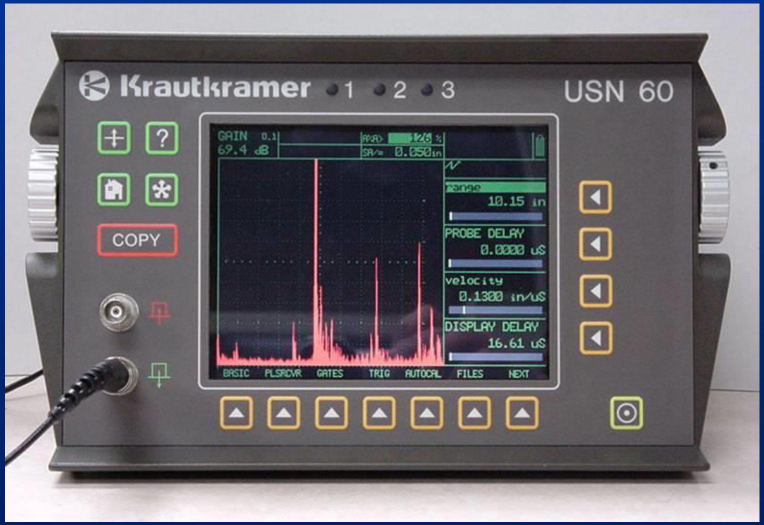
Instrumentation (cont.)

- D-meters or digital thickness gauge instruments provide the user with a digital (numeric) readout.
- They are designed primarily for corrosion/erosion inspection applications.

- Some instruments provide the user with both a digital readout and a display of the signal. A distinct advantage of these units is that they allow the user to evaluate the signal to ensure that the digital measurements are of the desired features.

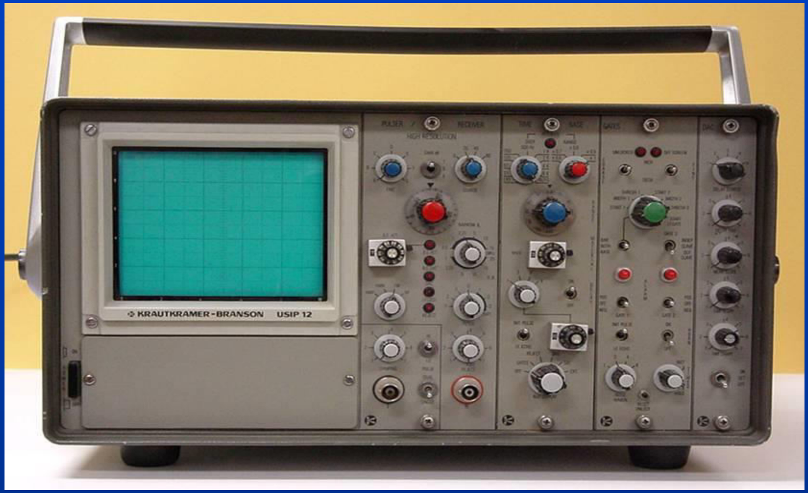
Instrumentation (cont.)

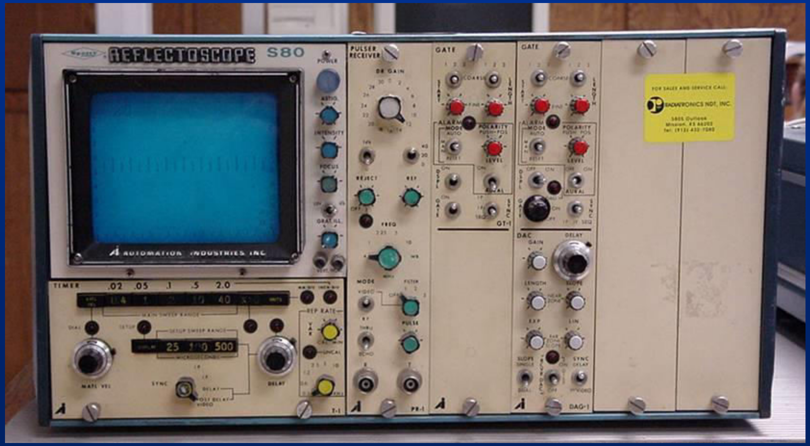
- Flaw detectors are instruments designed primarily for the inspection of components for defects.
- However, the signal can be evaluated to obtain other information such as material thickness values.
- Both analog and digital display.
- Offer the user options of gating horizontal sweep and amplitude threshold.



Instrumentation (cont.)

- Industrial flaw detection instruments, provide users with more options than standard flaw detectors.
- May be modulated units allowing users to tailor the instrument for their specific needs.
- Generally not as portable as standard flaw detectors.





Instrumentation (cont.)

- Immersion ultrasonic scanning systems are used for automated data acquisition and imaging.
- They integrate an immersion tank, ultrasonic instrumentation, a scanning bridge, and computer controls.
- The signal strength and/or the time-of-flight of the signal is measured for every point in the scan plan.
- The value of the data is plotted using colors or shades of gray to produce detailed images of the surface or internal features of a component.

Images of a Quarter Produced With an Ultrasonic Immersion Scanning System

Gray scale image produced using the sound reflected from the front surface of the coin

Gray scale image produced using the sound reflected from the back surface of the coin (inspected from “heads” side)

Calibration Standards

Calibration is a operation of configuring the ultrasonic test equipment to known values. This provides the inspector with a means of comparing test signals to known measurements.

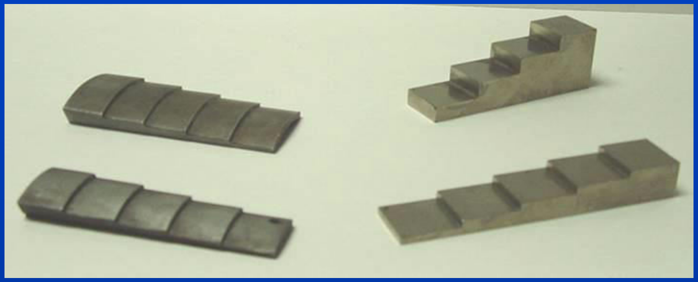
Calibration standards come in a wide variety of material types, and configurations due to the diversity of inspection applications.

Calibration standards are typically manufactured from materials of the same acoustic properties as those of the test articles.

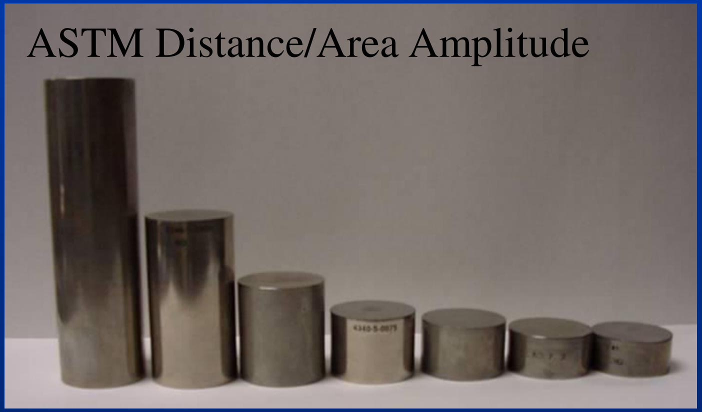
The following slides provide examples of specific types of standards.

Calibration Standards (cont.)

Thickness calibration standards may be flat or curved for pipe and tubing applications, consisting of simple variations in material thickness.

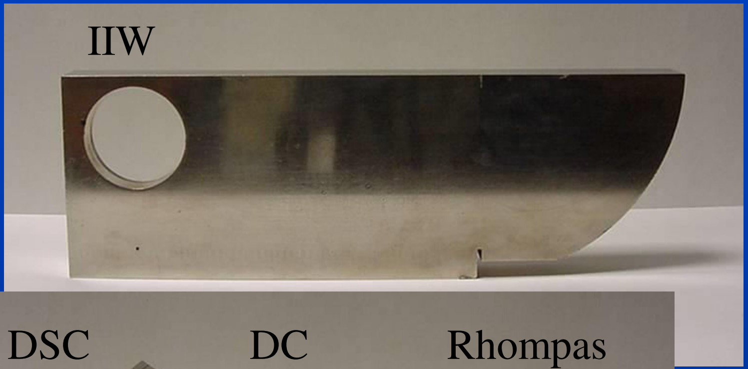


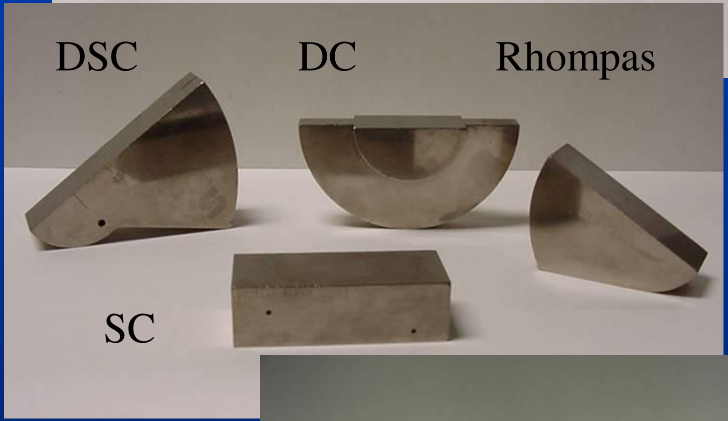
Distance/Area Amplitude standards utilize flat bottom holes or side drilled holes to establish known reflector size with changes in sound path form the entry surface.



Calibration Standards (cont.)

- There are also calibration standards for use in angle beam inspections when flaws are not parallel to entry surface.
- These standards utilized side drilled holes, notches, and geometric configuration to establish time distance and amplitude relationships.





Qualification Standards

Qualification standards differ from calibration standards in that their use is for purposes of varying proper equipment operation and qualification of equipment use for specific codes and standards.

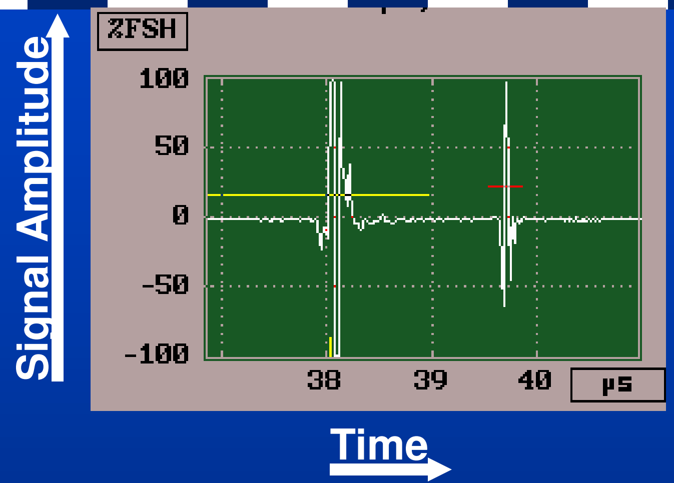
Data Presentation

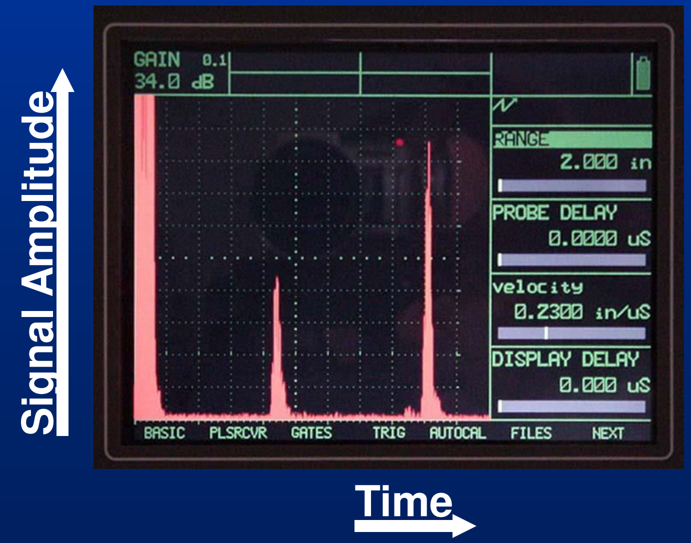
- **Information from ultrasonic testing can be presented in a number of differing formats.**
- **Three of the more common formats include:**
  - A-scan
  - B-scan
  - C-scan

These three formats will be discussed in the next few slides.

Data Presentation - A-scan

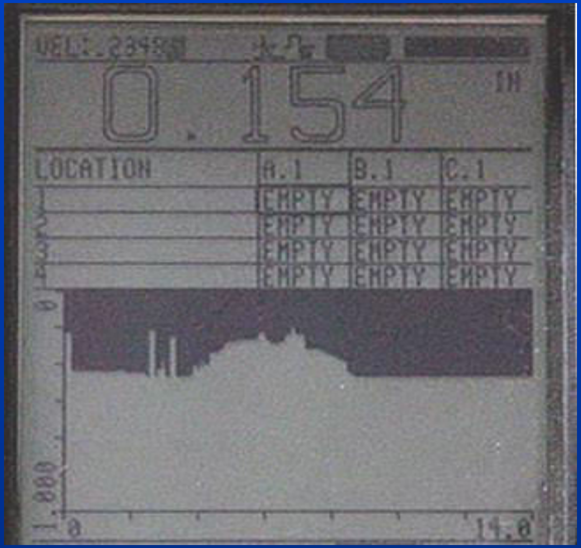
- A-scan presentation displays the amount of received ultrasonic energy as a function of time.
- Relative discontinuity size can be estimated by comparing the signal amplitude to that from a known reflector.
- Reflector depth can be determined by the position of the signal on the horizontal sweep.





Data Presentation - B-scan

- B-scan presentations display a profile view (cross-sectional) of a test specimen.
- Only the reflector depth in the cross-section and the linear dimensions can be determined.
- A limitation to this display technique is that reflectors may be masked by larger reflectors near the surface.



Data Presentation - C-scan

- The C-scan presentation displays a plan type view of the test specimen and discontinuities.
- C-scan presentations are produced with an automated data acquisition system, such as in immersion scanning.
- Use of A-scan in conjunction with C-scan is necessary when depth determination is desired.

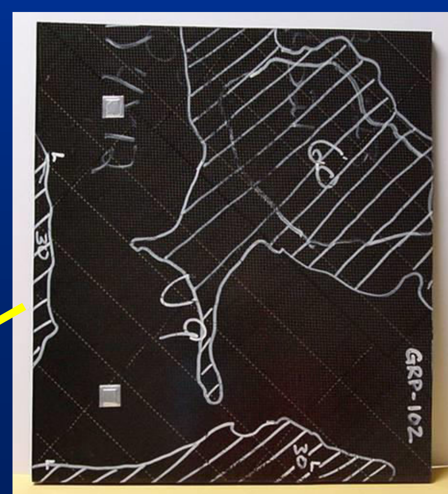
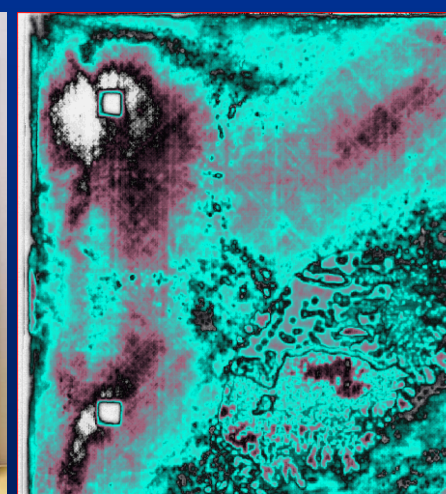


Photo of a Composite Component



C-Scan Image of Internal Features

Advantage of Ultrasonic Testing

- Sensitive to small discontinuities both surface and subsurface.
- Depth of penetration for flaw detection or measurement is superior to other methods.
- Only single-sided access is needed when pulse-echo technique is used.
- High accuracy in determining reflector position and estimating size and shape.
- Minimal part preparation required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- Has other uses such as thickness measurements, in addition to flaw detection.

Limitations of Ultrasonic Testing

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- Normally requires a coupling medium to promote transfer of sound energy into test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration, and characterization of flaws.

Glossary of Terms

- **Acoustical properties:** ultrasonic material characteristics such as velocity, impedance, and attenuation.
- **ASTM:** acronym for American Society for Testing and Materials. This society is extensively involved in establishing standards for materials and the testing of materials.
- **Back reflection:** a display signal that corresponds to the far surface of a test specimen, side opposite to transducer when testing with longitudinal waves.
- **Band width:** a range of frequencies either transmitted or received, may be narrow or broad range.
- **B-scan:** presentation technique displaying data in a cross-sectional view.

Glossary of Terms

- **Calibration:** a sequence of instrument control adjustments/instrument responses using known values to verify instrument operating characteristics. Allows determination of unknown quantities from test materials.
- **CRT:** acronym for Cathode Ray Tube. Vacuum tube that utilizes one or more electron guns for generating an image.
- **C-scan:** presentation technique that displays specimen data in a plan type view.
- **DAC (Distance Amplitude Correction-curves):** a graphical method of allowing for material attenuation. Percentage of DAC is often used as a means of acceptance criteria.
- **Discontinuity:** an interruption in the physical structure of a material, examples include fissures, cracks, and porosity.

Glossary of Terms

- **IIW:** calibration standard meeting the specification of the International Institute of Welding.
- **Longitudinal (Compression) waves:** ultrasonic mode of propagation in which the particle vibration is parallel to the direction of propagation.
- **Near Surface Resolution:** the ability of an ultrasonic system to display reflectors located close to the entry surface.
- **Pulse-echo:** ultrasonic test method that utilizes reflected sound as a means of collecting test data.
- **Rayleigh (Surface) waves:** ultrasonic mode of propagation where the sound travels along the surface, particle vibration is elliptical.

Glossary of Terms

- **Reflection:** the changing in direction of sound waves as they strike a surface.
- **Snell's Law:** an equation of ratios used to determine incident or refracted angle of sound, denotes angle/velocity relationship.
- **Sweep display:** horizontal line on the lower portion of the display, often called the time base line.
- **Through transmission:** test technique in which ultrasound is transmitted from one transducer and received by a separate transducer on the opposite side of the test specimen.
- **Wavelength:** the distance that a sound wave travels as it completes one cycle, normally measured in inches or millimeters.