Monograph of

NON-DESTRUCTIVE EVALUATION AND TESTING

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UNIT 1

INTRODUCTION AND VISUAL METHODS

What is NDT?

The field of Nondestructive Testing (NDT) is a very broad, interdisciplinary field that plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. NDT technicians and engineers define and implement tests that locate and characterize material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and a variety of less visible, but equally troubling events. These tests are performed in a manner that does not affect the future usefulness of the object or material. In other words, NDT allows parts and material to be inspected and measured without damaging them. Because it allows inspection without interfering with a product's final use, NDT provides an excellent balance between quality control and cost-effectiveness. Generally speaking, NDT applies to industrial inspections. The technologies that are used in NDT are similar to those used in the medical industry, but nonliving objects are the subjects of the inspections.

What is NDE?

Nondestructive evaluation (NDE) is a term that is often used interchangeably with NDT. However, technically, NDE is used to describe measurements that are more quantitative in nature. For example, an NDE method would not only locate a defect, but it would also be used to measure something about that defect such as its size, shape, and orientation. NDE may be used to determine material properties, such as fracture toughness, formability, and other physical characteristics.

Some NDT/NDE Technologies:

Many people are already familiar with some of the technologies that are used in NDT and NDE from their uses in the medical industry. Most people have also had an X-ray taken and many mothers have had ultrasound used by doctors to give their baby a checkup while still in the womb. X-rays and ultrasound are only a few of the technologies used in the field of NDT/NDE. The number of inspection methods seems to grow daily

Visual and Optical Testing (VT):

Visual inspection involves using an inspector’s eyes to look for defects, such as scratches, presence of debris, corrosion or oxidation. The inspector may also use special tools such as magnifying glasses, mirrors, or borescopes to gain access and more closely inspect the subject area. In nuclear power plants, an extensive fuel inspection programme (including e.g., visual inspections, oxide layer measurements, eddy-current tests of control rods), is carried out under water and supervised by the regulatory body. So that visual testing is usually a part of the Post Irradiation Examination. Visual examinations are also very common in aircraft industry, where over 80 percent of the inspections done to an aircraft are visual inspections, being often used as an initial screening method to detect gross defects and target subsequent testing by other methods.

In-Situ Metallography:

Field **metallography** is also called in **situ metallography**, and it is sometimes called nondestructive **metallography**. The major application areas are power plants, petroleum and natural gas pipelines, and welding quality inspection for metal constructions etc.

The technique of in situ metallography involves location selection, mechanical grinding & polishing / electrolytic polishing, electrolytic etching or chemical etching, replication and micro structural observation. The kit of in-situ metallography comprises of portable grinder, light grinder with variable speed controller, electrolytic etcher/polisher, microscope and variety of consumables. The consumables can be listed as self-adhesive polishing papers of different grit size, self-adhesive velvet cloth, solvents, water bottles, diamond paste, and suspended alumina, electrolytes and replica films.

2.1) Location Selection:

The location is selected on the basis of a careful analysis of the involved components. Because of the local nature of replica inspection, the selected position must be most critically representative one in the anticipated damage mechanism. There are two types of considerations mentioned hereunder.

a. Mechanical consideration, where parameters like stress, vibrations, bends, weld and stress generated from due to self-weight of components in addition to the operating stresses.
b. Process considerations; where parameters like Temperature, Pressure, Flow rate and reaction with the environment are taken in to account.

2.2) Visual Examination and General Requirements:

Visual examination is done to assess the surface condition and accessibility for the person with equipments. It must be possible to keep the test position clean, dry and free of dust. The temperature of the examined metal must be ambient. When the dimensions and the wall thickness are critical, precautions must be taken to avoid excessive removal of metal surface to the examined component.

2.3) Mechanical Grinding & Polishing:

Small area of 1 sq. inch is rough ground to remove oxide scale or decarburized layer formed in operation. To keep in-situ metallography investigation non destructive, the total material removed by grinding must not exceed 0.5 to 1 mm. On a small rotating shaft, abrasive papers at least in three steps with successively finer grits of paper ending with emery paper No 600 are attached.

On each type of emery paper, the grinding time must be three times the time needed to remove the traces from the previous grinding.

The polishing is done in one of the following two ways

1. Electro polishing with portable electro polishing equipment
2. Mechanical polishing with polishing disk via 800, 1000 grit finish and with the help of diamond paste to achieve 5 micron and 1 micron finish. Then suspended alumina is used in final polishing.

When macro cracks are detected, mechanical polishing is preferred as it does not affect the crack faces strongly. If electro polishing is carried out it should be preformed after examination of the mechanically polished surface.

2.4) Etching:

The prepared surface is etched either chemically or electrolytically. Optimum care is necessary in etching the surface. Over etching or under etching will mislead the result. In chemical etching with the help of the cotton swab, etchant is applied on prepared surface; where as in electrolytic etching etchant is circulated or kept in a soaked cloth and necessary voltage is applied between anode (material to be etched) and auxiliary cathode.

2.5) Microstructure Examination:

Stage wise examination right from the fine polishing can result into true microstructure development. Final judgment of microstructure is arrived at with the help of portable microscope in which the magnification can be as high as 400 to 500 times.

2.6) Replication:

After ensuring the properly developed microstructure, a plastic tape made of Cellulose acetate material is soaked in Acetone and kept on prepared surface. By gentle pressure the microstructure features can be replicated on plastic tape. A tape can be self-refractive or if not, it can be painted. There are various methods of replica technique like, Cast resin technique or extraction replica. For further enhancement in the contrast, sputtering with gold is done sometimes to study under the electron microscope for high resolution. With the extraction replica, analysis of carbon precipitated at elevated temperature can be found out.

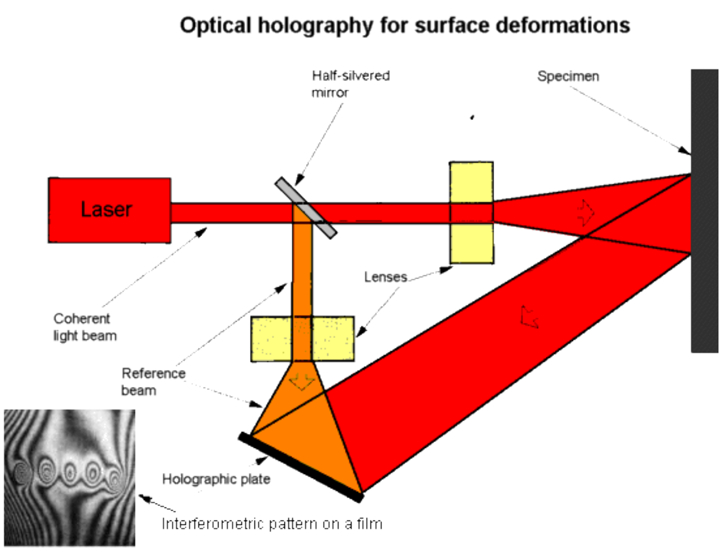
2.7) After Care of Replica

After the preparation of replicas these may be coated with gold or other light reflecting and conductive material under vacuum to improve the contrast in the light optical microscope. It also makes it possible to use the coated replica in the scanning electron microscope. While being coated and examined in SEM, the replica should be exposed to a minimum of heat.

Optical Holographic Method:

Optical Holographic techniques can be used for nondestructive testing of materials (HNDT). Non-optical Holography techniques include Acoustical, Microwave, X-Ray and Electron beam Holography. HNDT essentially measures deformations on the surface of the object. However, there is sufficient sensitivity to detect sub- surface and internal defects in metallic and composite specimens.

In HNDT techniques, the test sample is interferometrically compared with the sample after it has been stressed (loaded). A flaw can be detected if by stressing the object it creates an anomalous deformation of the surface around the flaw.



Optical holography is an imaging method, which records the amplitude and phase of light reflected from an object as an interferometric pattern on film. It thus allows reconstruction of the full 3-D image of the object. In HNDT, the test sample is interferometrically compared in two different stressed states. Stressing can be mechanical, thermal, vibration etc. The resulting interference pattern contours the deformation undergone by the specimen in between the two recordings. Surface as well as sub-surface defects show distortions in the otherwise uniform pattern.

In addition, the characteristics of the component, such as vibration modes, mechanical properties, residual stress etc. can be identified through holographic inspection. Applications in fluid mechanics and gas dynamics also abound.

The light used to illuminate the surface of the specimen must be coherent, which means that it must also be monochromatic, and the only practical source is a laser. Each type of laser emits a characteristic wavelength, e.g. a helium-neon laser emits 632.8nm; a ruby laser emits 694.3nm. Laser diodes are nowadays an exciting and compact alternative. Indeed, holography using laser pointers have also been demonstrated.

High-resolution films are another necessity for holography. With the advent of CCD and digital image processing, digital holographic interferometry offers tremendous flexibility and real-time visualization. Furthermore, image-processing schemes can provide computerized analysis of patterns for automated defect detection and analysis.

Finally since intricate interferometric patterns have to be recorded, vibration isolation is also required. Novel schemes have been proposed, including use of pulsed lasers to record holograms in factory environments. Advances and developments in lasers, computers, and recording materials introduce new techniques such as electronic (or TV) holography, multi-wavelength recording, thermoplastic medium, time-averaged holography, dynamic holographic interferometry, cineholography, and digital holography with each new development. Methods that once held only academic interest often become practically viable with these developments in hardware and software.

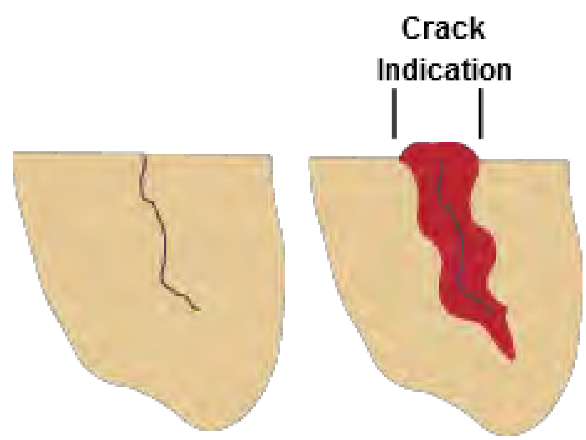
HNDT is widely applied in aerospace to find impact damage, corrosion, delamination, debonds, and cracks in high performance composite aircraft parts as well as turbine blades, solid propellant rocket motor casings, tyre and air foils. But Holography is also finding new applications in commercial and defense related industries to investigate and test object ranging from microscopic computer chips and circuits to cultural articles, paintings and restoration.

DYNAMIC INSPECTION TECHNIQUE:

Penetrant Flaw Detection:

Principle: Liquid penetrant inspection is a method that is used to reveal surface breaking flaws by bleedout of a colored or fluorescent dye from the flaw. The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. After a period of time called the "dwell," excess surface penetrant is removed and a developer applied. This acts as a blotter. It draws the penetrant from the flaw to reveal its presence. Colored (contrast) penetrants require good white light while fluorescent penetrants need to be used in darkened conditions with an ultraviolet "black light".

The advantage that a liquid penetrant inspection (LPI) offers over an unaided visual inspection is that it makes defects easier to see for the inspector. There are basically two ways that a penetrant inspection process makes flaws more easily seen. First, LPI produces a flaw indication that is much larger and easier for the eye to detect than the flaw itself. Many flaws are so small or narrow that they are undetectable by the unaided eye. Due to the physical features of the eye, there is a threshold below which objects cannot be resolved.

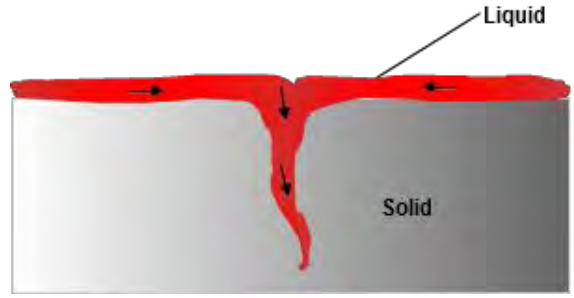


Basic Processing Steps of a Liquid Penetrant Inspection

1. **Surface Preparation:** One of the most critical steps of a liquid penetrant inspection is the surface preparation. The surface must be free of oil, grease, water, or other contaminants that may prevent penetrant from entering flaws. The sample may also require etching if mechanical operations such as

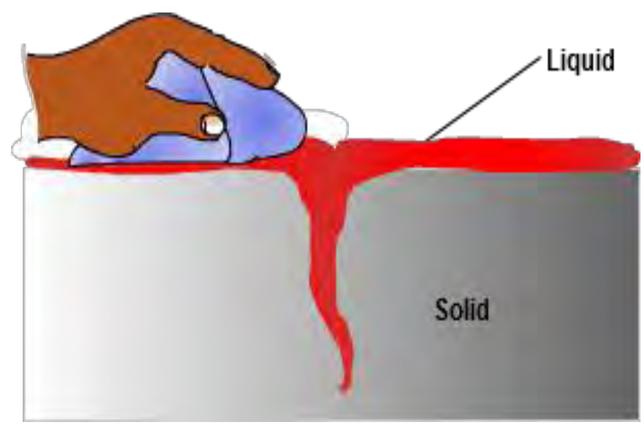
machining, sanding, or grit blasting have been performed. These and other mechanical operations can smear metal over the flaw opening and prevent the penetrant from entering.

2. **Penetrant Application:** Once the surface has been thoroughly cleaned and dried, the penetrant material is applied by spraying, brushing, or immersing the part in a penetrant bath.

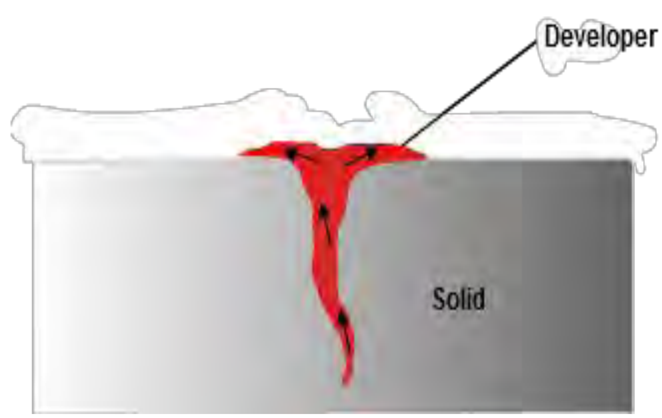


3. **Penetrant Dwell:** The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn from or to seep into a defect. Penetrant dwell time is the total time that the penetrant is in contact with the part surface. Dwell times are usually recommended by the penetrant producers or required by the specification being followed. The times vary depending on the application, penetrant materials used, the material, the form of the material being inspected, and the type of defect being inspected for. Minimum dwell times typically range from five to 60 minutes. Generally, there is no harm in using a longer penetrant dwell time as long as the penetrant is not allowed to dry. The ideal dwell time is often determined by experimentation and may be very specific to a particular application.

4. **Excess Penetrant Removal:** This is the most delicate part of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects. Depending on the penetrant system used, this step may involve cleaning with a solvent, direct rinsing with water, or first treating the part with an emulsifier and then rinsing with water.



5. **Developer Application:** A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. Developers come in a variety of forms that may be applied by dusting (dry powdered), dipping, or spraying (wet developers).



6. **Indication Development:** The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws. This development time is usually a minimum of 10 minutes. Significantly longer times may be necessary for tight cracks.
7. **Inspection:** Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.
8. **Clean Surface:** The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.

Liquid Penetrant Materials:

The industry and military specifications that control penetrant materials and their use, all stipulate certain physical properties of the penetrant materials that must be met. Some of these requirements address the safe use of the materials, such as toxicity, flash point, and corrosiveness, and other requirements address storage and contamination issues. Still others delineate properties that are thought to be primarily responsible for the performance or sensitivity of the penetrants. The properties of penetrant materials that are controlled by AMS 2644 and MIL-I-25135E include flash point, surface wetting capability, viscosity, color, brightness, ultraviolet stability, thermal stability, water tolerance, and removability.

Emulsifiers

When removal of the penetrant from a defect due to over-washing of the part is a concern, a post-emulsifiable penetrant system can be used. Post-emulsifiable penetrants require a separate emulsifier to break the penetrant down and make it water-washable. Most penetrant inspection specifications classify penetrant systems into four methods of excess penetrant removal. These are listed below:

1. Method A: Water-Washable
2. Method B: Post-Emulsifiable, Lipophilic
3. Method C: Solvent Removable
4. Method D: Post-Emulsifiable, Hydrophilic

Method C relies on a solvent cleaner to remove the penetrant from the part being inspected. Method A has emulsifiers built into the penetrant liquid that makes it possible to remove the excess penetrant with a simple water wash. Method B and D penetrants require an additional processing step where a separate emulsification agent is applied to make the excess penetrant more removable with a water wash. Lipophilic emulsification systems are oil-based materials that are supplied in ready-to-use form. Hydrophilic systems are water-based and supplied as a concentrate that must be diluted with water prior to use.

Lipophilic emulsifiers (Method B) were introduced in the late 1950's and work with both a chemical and mechanical action. After the emulsifier has coated the surface of the object, mechanical action starts to remove some of the excess penetrant as the mixture drains from the part. During the emulsification time, the emulsifier diffuses into the remaining penetrant and the resulting mixture is easily removed with a water spray.

Hydrophilic emulsifiers (Method D) also remove the excess penetrant with mechanical and chemical action but the action is different because no diffusion takes place. Hydrophilic emulsifiers are basically detergents that contain solvents and surfactants. The hydrophilic emulsifier breaks up the penetrant into small quantities and prevents these pieces from recombining or reattaching to the surface of the part. The mechanical action of the rinse water removes the displaced penetrant from the part and causes fresh remover to contact and lift newly exposed penetrant from the surface.

Contaminants and Cleaners:

Coatings, such as paint, are much more elastic than metal and will not fracture even though a large defect may be present just below the coating. The part must be thoroughly cleaned as surface contaminates can prevent the penetrant from entering a defect. Surface contaminants can also lead to a higher level of background noise since the excess penetrant may be more difficult to remove.

Common coatings and contaminates that must be removed include: paint, dirt, flux, scale, varnish, oil, etchant, smut, plating, grease, oxide, wax, decals, machining fluid, rust, and residue from previous penetrant inspections.

Some of these contaminants would obviously prevent penetrant from entering defects, so it is clear they must be removed. However, the impact of other contaminants such as the residue from previous penetrant inspections is less clear, but they can have a disastrous effect on the inspection.

A good cleaning procedure will remove all contamination from the part and not leave any residue that may interfere with the inspection process. It has been found that some alkaline cleaners can be detrimental to the penetrant inspection process if they have silicates in concentrations above 0.5 percent. Sodium metasilicate, sodium silicate, and related compounds can adhere to the surface of parts and form a coating that prevents penetrant entry into cracks. Researchers in Russia have also found that some domestic soaps and commercial detergents can clog flaw cavities and reduce the wettability of the metal surface, thus reducing the sensitivity of the penetrant. Conrad and Caudill found that media from plastic media blasting was partially responsible for loss of LPI indication strength. Microphotographs of cracks after plastic media blasting showed media entrapment in addition to metal smearing.

It is very important that the material being inspected has not been smeared across its own surface during machining or cleaning operations. It is well recognized that machining, honing, lapping, hand sanding, hand scraping, grit blasting, tumble deburring, and peening operations can cause some materials to smear. It is perhaps less recognized that some cleaning operations, such as steam cleaning, can also cause metal smearing in the softer materials.

Developers

The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector. The fine developer particles both reflect and refract the incident ultraviolet light, allowing more of it to interact with the penetrant, causing more efficient fluorescence. The developer also allows more light to be emitted through the same mechanism. This is why indications are brighter than the penetrant itself under UV light. Another function that some developers perform is to create a white background so there is a greater degree of contrast between the indication and the surrounding background.

Developer Forms

The AMS 2644 and Mil-I-25135 classify developers into six standard forms. These forms are listed below:

1. Form a - Dry Powder
2. Form b - Water Soluble
3. Form c - Water Suspendable
4. Form d - Nonaqueous Type 1 Fluorescent (Solvent Based)
5. Form e - Nonaqueous Type 2 Visible Dye (Solvent Based)
6. Form f - Special Applications

The developer classifications are based on the method that the developer is applied. The developer can be applied as a dry powder, or dissolved or suspended in a liquid carrier. Each of the developer forms has advantages and disadvantages.

Dry Powder

Dry powder developer is generally considered to be the least sensitive but it is inexpensive to use and easy to apply. Dry developers are white, fluffy powders that can be applied to a thoroughly dry surface in a number of ways. The developer can be applied by dipping parts in a container of developer, or by using a puffer to dust parts with the developer. Parts can also be placed in a dust cabinet where the developer is blown around and allowed to settle on the part. Electrostatic powder spray guns are also available to apply the developer. The goal is to allow the developer to come in contact with the whole inspection area.

Unless the part is electrostatically charged, the powder will only adhere to areas where trapped penetrant has wet the surface of the part. The penetrant will try to wet the surface of the penetrant particle and fill the voids between the particles, which brings more penetrant to the surface of the part where it can be seen. Since dry powder developers only stick to the area where penetrant is present, the dry developer does not provide a uniform white background as the other forms of developers do. Having a uniform light background is very important for a visible inspection to be effective and since dry developers do not provide one, they are seldom used for visible inspections. When a dry developer is used, indications tend to stay bright and sharp since the penetrant has a limited amount of room to spread.

Water Soluble

As the name implies, water soluble developers consist of a group of chemicals that are dissolved in water and form a developer layer when the water is evaporated away. The best method for applying water soluble developers is by spraying it on the part. The part can be wet or dry. Dipping, pouring, or brushing the solution on to the surface is sometimes used but these methods are less desirable. Aqueous developers contain wetting agents that cause the solution to function much like dilute hydrophilic emulsifier and can lead to additional removal of entrapped penetrant. Drying is achieved by placing the wet but well drained part in a recirculating, warm air dryer with the temperature held between 70 and 75°F. If the parts are not dried quickly, the indications will will be blurred and indistinct. Properly developed parts will have an even, pale white coating over the entire surface.

Water Suspendable

Water suspendable developers consist of insoluble developer particles suspended in water. Water suspendable developers require frequent stirring or agitation to keep the particles from settling out of suspension. Water suspendable developers are applied to parts in the same manner as water soluble developers. Parts coated with a water suspendable developer must be forced dried just as parts coated with a water soluble developer are forced dried. The surface of a part coated with a water suspendable developer will have a slightly translucent white coating.

Nonaqueous

Nonaqueous developers suspend the developer in a volatile solvent and are typically applied with a spray gun. Nonaqueous developers are commonly distributed in aerosol spray cans for portability. The solvent tends to pull penetrant from the indications by solvent action. Since the solvent is highly volatile, forced drying is not required. A nonaqueous developer should be applied to a thoroughly dried part to form a slightly translucent white coating.

Special Applications

Plastic or lacquer developers are special developers that are primarily used when a permanent record of the inspection is required.

Advantages and Limitations of Penetrant Testing

Like all nondestructive inspection methods, liquid penetrant inspection has both advantages and disadvantages. The primary advantages and disadvantages when compared to other NDE methods are summarized below.

Primary Advantages

- The method has high sensitivity to small surface discontinuities.
- The method has few material limitations, i.e. metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected.
- Large areas and large volumes of parts/materials can be inspected rapidly and at low cost.
- Parts with complex geometric shapes are routinely inspected.
- Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
- Aerosol spray cans make penetrant materials very portable.
- Penetrant materials and associated equipment are relatively inexpensive.

Primary Limitations

- Only surface breaking defects can be detected.
- Only materials with a relatively nonporous surface can be inspected.
- Precleaning is critical since contaminants can mask defects.
- Metal smearing from machining, grinding, and grit or vapor blasting must be removed prior to LPI.
- The inspector must have direct access to the surface being inspected.
- Surface finish and roughness can affect inspection sensitivity.
- Multiple process operations must be performed and controlled.
- Post cleaning of acceptable parts or materials is required.
- Chemical handling and proper disposal is required.

Applications of Penetrant Testing

Liquid penetrant inspection (LPI) is one of the most widely used nondestructive evaluation (NDE) methods. Its popularity can be attributed to two main factors: its relative ease of use and its flexibility. LPI can be used to inspect almost any material provided that its surface is not extremely rough or porous. Materials that are commonly inspected using LPI include the following:

- Metals (aluminum, copper, steel, titanium, etc.)
- Glass
- Many ceramic materials

- Rubber
- Plastics

LPI offers flexibility in performing inspections because it can be applied in a large variety of applications ranging from automotive spark plugs to critical aircraft components. Penetrant materials can be applied with a spray can or a cotton swab to inspect for flaws known to occur in a specific area or it can be applied by dipping or spraying to quickly inspect large areas. In the image above, visible dye penetrant is being locally applied to a highly loaded connecting point to check for fatigue cracking.

Penetrant inspection systems have been developed to inspect some very large components. In the image shown right, DC-10 banjo fittings are being moved into a penetrant inspection system at what used to be the Douglas Aircraft Company's Long Beach, California facility. These large machined aluminum forgings are used to support the number two engine in the tail of a DC-10 aircraft.

Liquid penetrant inspection can only be used to inspect for flaws that break the surface of the sample. Some of these flaws are listed below:

- Fatigue cracks
- Quench cracks
- Grinding cracks
- Overload and impact fractures
- Porosity
- Laps
- Seams
- Pin holes in welds
- Lack of fusion or braising along the edge of the bond line

UNIT 2

RADIOGRAPHIC AND ULTRASONIC METHODS IN NDT

RADIOGRAPHIC METHOD OF TESTING

Principle of Radiography:

Radiography captures a shadow image on film. However, we are able to generate images of higher quality and greater sensitivity through the use of higher quality films with a larger variety of film grain sizes. Film processing has evolved to an automated state, producing more consistent film quality by removing manual processing variables. Electronics and computers allow technicians to now capture images digitally. The use of "filmless radiography" provides a means of capturing an image, digitally enhancing, sending the image anywhere in the world, and archiving an image that will not deteriorate with time. Technological advances have provided industry with smaller, lighter, and very portable equipment that produce high quality X-rays. The use of linear accelerators provides a means of generating extremely short wavelength, highly penetrating radiation.

Radiography is used in numerous areas of inspection. Radiography has seen expanded usage in industry to inspect not only welds and castings, but to radiographically inspect items such as airbags and canned food products. Radiography has found use in metallurgical material identification and security systems at airports and other facilities.

Gamma ray inspection has also been in use since the Curies' discovery of radium. Man-made isotopes of today are far stronger and offer the technician a wide range of energy levels and half-lives. The technician can select Co-60 which will effectively penetrate very thick materials, or select a lower energy isotope, such as Tm-170, which can be used to inspect plastics and very thin or low density materials. Today gamma rays find wide application in industries such as petrochemical, casting, welding, and aerospace.

Limitation:

Today, it can be said that radiation ranks among the most thoroughly investigated causes of disease. Although much still remains to be learned, more is known about the mechanisms of radiation damage on the molecular, cellular, and organ system than is known for most other health stressing agents. Indeed, it is precisely this vast accumulation of quantitative dose-response data that enables health physicists to specify radiation levels so that medical, scientific, and industrial uses of radiation may continue at levels of risk no greater than, and frequently less than, the levels of risk associated with any other technology.

Sources of Radiation:

X-rays and gamma rays differ only in their source of origin. X-rays are produced by an x-ray generator and gamma radiation is the product of radioactive atoms. They are both part of the **electromagnetic spectrum.** They are waveforms, as are light rays, microwaves, and radio waves. X-rays and gamma rays cannot be seen, felt, or heard. They possess no charge and no mass and, therefore, are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light.

Both X-rays and gamma rays can be characterized by frequency, wavelength, and velocity. However, they act somewhat like a particle at times in that they occur as small "packets" of energy and are referred to as "**photons."** Electromagnetic radiation has also been described in terms of a stream of photons (massless particles) each traveling in a wave-like pattern and moving at the speed of light.

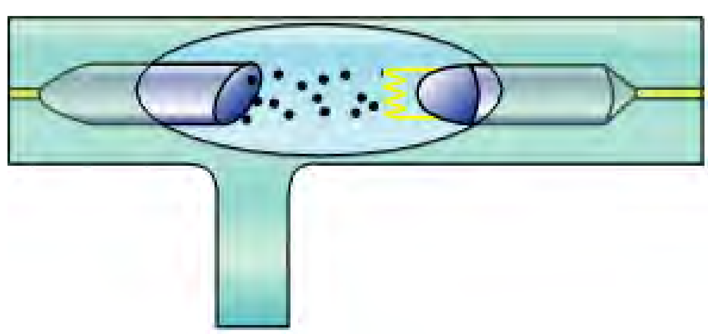
Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons. The only difference between the various types of electromagnetic radiation is the amount of energy found in the photons. Due to their short wavelength they have more energy to pass through matter than do the other forms of energy in the electromagnetic spectrum. As they pass through matter, they are scattered and absorbed and the degree of penetration depends on the kind of matter and the energy of the rays.

Properties of X-Rays and Gamma Rays

- They are not detected by human senses (cannot be seen, heard, felt, etc.).
- They travel in straight lines at the speed of light.
- Their paths cannot be changed by electrical or magnetic fields.
- They can be diffracted to a small degree at interfaces between two different materials.
- They pass through matter until they have a chance encounter with an atomic particle.
- Their degree of penetration depends on their energy and the matter they are traveling through.
- They have enough energy to ionize matter and can damage or destroy living cells.

X-Radiation

X-rays are just like any other kind of electromagnetic radiation. They can be produced in parcels of energy called photons, just like light. There are two different atomic processes that can produce X-ray photons. One is called Bremsstrahlung and is a German term meaning "braking radiation." The other is called K-shell emission. They can both occur in the heavy atoms of tungsten. Tungsten is often the material chosen for the target or anode of the x-ray tube.



Both ways of making X-rays involve a change in the state of electrons. However, Bremsstrahlung is easier to understand using the classical idea that radiation is emitted when the velocity of the electron shot at the tungsten changes. The negatively charged electron slows down after swinging around the nucleus of a positively charged tungsten atom. This energy loss produces X-radiation. Electrons are scattered elastically and inelastically by the positively charged nucleus. The inelastically scattered electron loses energy, which appears as Bremsstrahlung. Elastically scattered electrons (which include backscattered electrons) are generally scattered through larger angles. In the interaction, many photons of different wavelengths are produced, but none of the photons have more energy than the electron had to begin with. After emitting the spectrum of X-ray radiation, the original electron is slowed down or stopped.

Gamma Radiation

Gamma radiation is one of the three types of natural radioactivity. Gamma rays are electromagnetic radiation, like X-rays. The other two types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation, with a very short wavelength of less than one-tenth of a nanometer.

Gamma radiation is the product of radioactive atoms. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as radioactive decay. Various types of penetrating radiation may be emitted from the nucleus and/or its surrounding electrons. Nuclides which undergo radioactive decay are called radionuclides. Any material which contains measurable amounts of one or more radionuclides is a radioactive material.

Types Radiation Produced by Radioactive Decay

<u>Alpha Particles</u>

Certain radionuclides of high atomic mass (Ra226, U238, and Pu239) decay by the emission of alpha particles. These alpha particles are tightly bound units of two neutrons and two protons each (He4 nucleus) and have a positive charge. Emission of an alpha particle from the nucleus results in a decrease of two units of atomic number (Z) and four units of mass number (A). Alpha particles are emitted with discrete energies characteristic of the particular transformation from which they originate. All alpha particles from a particular radionuclide transformation will have identical energies.

<u>Beta Particles</u>

A nucleus with an unstable ratio of neutrons to protons may decay through the emission of a high-speed electron called a beta particle. This results in a net change of one unit of atomic number (Z). Beta particles have a negative charge and the beta particles emitted by a specific radionuclide will range in energy from near zero up to a maximum value, which is characteristic of the particular transformation.

Gamma-rays

A nucleus which is in an excited state may emit one or more photons (packets of electromagnetic radiation) of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state (unstable to stable). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

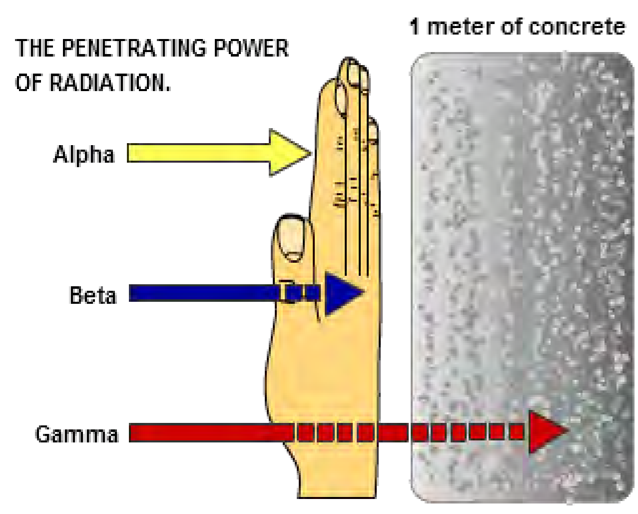
Ionizing Radiation

As penetrating radiation moves from point to point in matter, it loses its energy through various interactions with the atoms it encounters. The rate at which this energy loss occurs depends upon the type and energy of the radiation and the density and atomic composition of the matter through which it is passing.

The various types of penetrating radiation impart their energy to matter primarily through excitation and ionization of orbital electrons. Excited electrons may subsequently emit energy in the form of x-rays during the process of returning to a lower energy state. The term "ionization" refers to the complete removal of an electron from an atom following the transfer of energy from a passing charged particle.

Gamma-rays, x-rays, and neutrons are referred to as indirectly ionizing radiation since, having no charge; they do not directly apply impulses to orbital electrons as do alpha and beta particles. Electromagnetic radiation proceeds through matter until there is a chance of interaction with a particle.

If the particle is an electron, it may receive enough energy to be ionized, whereupon it causes further ionization by direct interactions with other electrons. As a result, indirectly ionizing radiation (e.g. gamma, x-rays, and neutrons) can cause the liberation of directly ionizing particles (electrons) deep inside a medium. Because these neutral radiations undergo only chance encounters with matter, they do not have finite ranges, but rather are attenuated in an exponential manner. In other words, a given gamma ray has a definite probability of passing through any medium of any depth.



Neutrons lose energy in matter by collisions which transfer kinetic energy. This process is called moderation and is most effective if the matter the neutrons collide with has about the same mass as the neutron. Once slowed down to the same average energy as the matter being interacted with (thermal energies), the neutrons have a much greater chance of interacting with a nucleus. Such interactions can result in material becoming radioactive or can cause radiation to be given off.

Recording of Radiations

Personnel dosimetry film badges are commonly used to measure and record radiation exposure due to gamma rays, X-rays and beta particles. The detector is, as the name implies, a piece of radiation sensitive film. The film is packaged in a light proof, vapor proof envelope preventing light, moisture or chemical vapors from affecting the film.

A special film is used which is coated with two different emulsions. One side is coated with a large grain, fast emulsion that is sensitive to low levels of exposure. The other side of the film is coated with a fine grain, slow emulsion that is less sensitive to exposure. If the radiation exposure causes the fast emulsion in the processed film to be darkened to a degree that it cannot be interpreted, the fast emulsion is removed and the dose is computed using the slow emulsion.

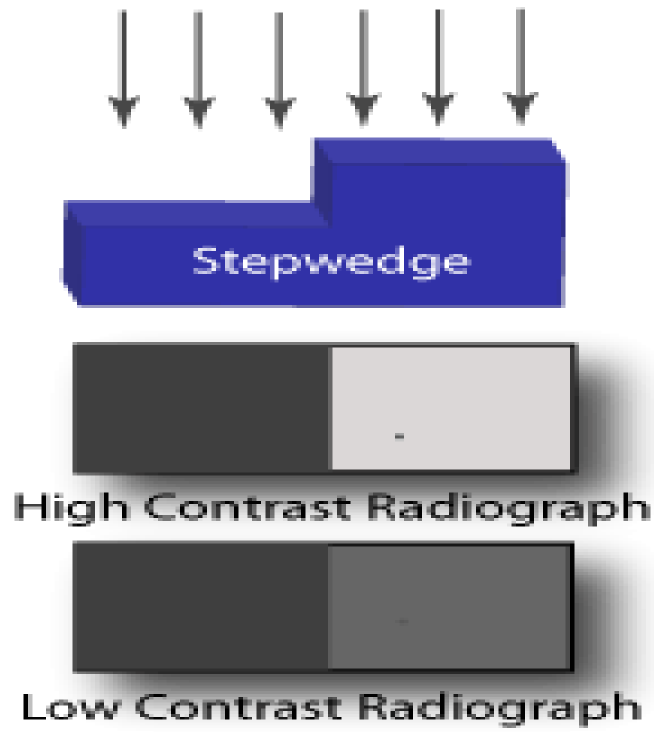
The film is contained inside a film holder or badge. The badge incorporates a series of filters to determine the quality of the radiation. Radiation of a given energy is attenuated to a different extent by various types of absorbers. Therefore, the same quantity of radiation incident on the badge will produce a different degree of darkening under each filter. By comparing these results, the energy of the radiation can be determined and the dose can be calculated knowing the film response for that energy. The badge holder also contains an open window to determine radiation exposure due to beta particles. Beta particles are effectively shielded by a thin amount of material.

The major advantages of a film badge as a personnel monitoring device are that it provides a permanent record, it is able to distinguish between different energies of photons, and it can measure doses due to different types of radiation.

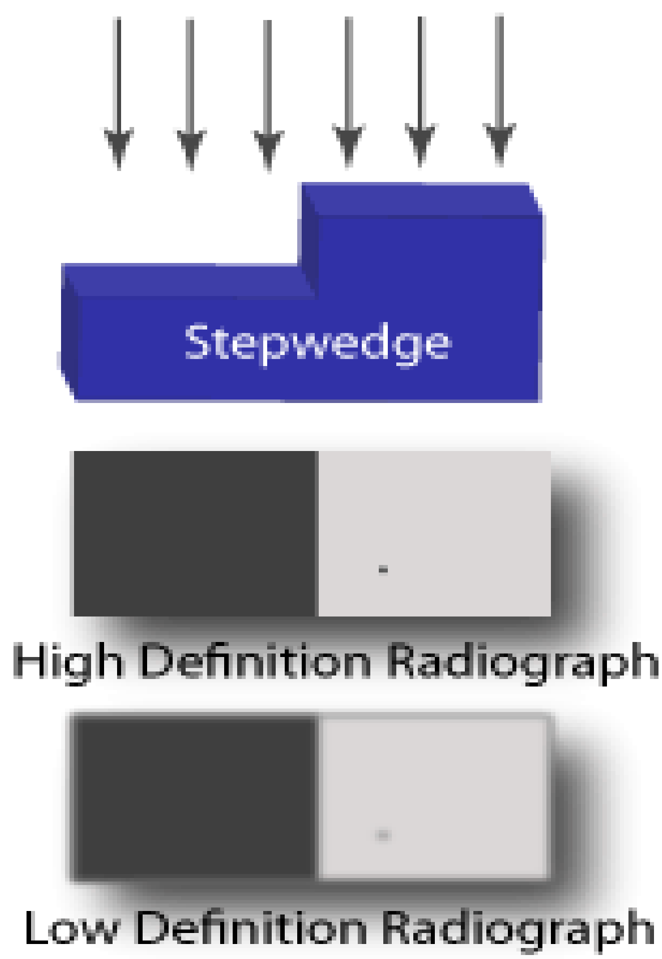
Radiographic Sensitivity

Radiographic sensitivity is a measure of the quality of an image in terms of the smallest detail or discontinuity that may be detected. Radiographic sensitivity is dependent on the combined effects of two independent sets of variables. One set of variables affects the contrast and the other set of variables affects the definition of the image.

Radiographic contrast is the degree of density difference between two areas on a radiograph. Contrast makes it easier to distinguish features of interest, such as defects, from the surrounding area. The image to the right shows two radiographs of the same stepwedge. The upper radiograph has a high level of contrast and the lower radiograph has a lower level of contrast. While they are both imaging the same change in thickness, the high contrast image uses a larger change in radiographic density to show this change. In each of the two radiographs, there is a small circle, which is of equal density in both radiographs. It is much easier to see in the high contrast radiograph.



Radiographic definition is the abruptness of change in going from one area of a given radiographic density to another. Like contrast, definition also makes it easier to see features of interest, such as defects, but in a totally different way. In the image to the right, the upper radiograph has a high level of definition and the lower radiograph has a lower level of definition. In the high definition radiograph, it can be seen that a change in the thickness of the stepwedge translates to an abrupt change in radiographic density. It can be seen that the details, particularly the small circle, are much easier to see in the high definition radiograph. It can be said that the detail portrayed in the radiograph is equivalent to the physical change present in the stepwedge. The edge line between the steps is blurred. This is evidenced by the gradual transition between the high- and low-density areas on the radiograph.



Radiation Safety

Ionizing radiation is an extremely important NDT tool but it can pose a hazard to human health. For this reason, special precautions must be observed when using and working around ionizing radiation. The possession of radioactive materials and use of radiation producing devices are governed by strict regulatory controls.

For most situations, the types and maximum quantities of radioactive materials possessed, the manner in which they may be used, and the individuals authorized to use radioactive materials are stipulated in the form of a "specific" license from the appropriate regulatory authority. In Iowa, this authority is the Iowa Department of Public Health. However, for certain institutions which routinely use large quantities of numerous types of radioactive materials, the exact quantities of materials and details of use may not be specified in the license. Instead, the license grants the institution the authority and responsibility for setting the specific requirements for radioactive material use within its facilities. These licensees are termed "broadscope" and require a Radiation Safety Committee and usually a full-time Radiation Safety Officer.

Fluoroscopic Techniques

Fluoroscopy involves the real time viewing of X-Rayed parts. The quality of inspection technique depends on the resolution of the system and skill of the operator/Interpreter. The X-Ray Fluoroscope is a fixed machine operating under typical dark room lighting conditions. To obtain satisfactory results geometry, scatter radiation and source kilo-voltage must be carefully controlled. Advantages of fluoroscopic inspection include the immediate viewing of the subject from a multitude of angles, the illusion of a three-dimensional presentation and the ability to study moving parts in action.

ULTRASONIC TESTING OF MATERIALS

Introduction Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more.

Advantages: Ultrasonic Inspection is a very useful and versatile NDT method. Some of the advantages of ultrasonic inspection that are often cited include:

- It is sensitive to both surface and subsurface discontinuities.
- The depth of penetration for flaw detection or measurement is superior to other NDT methods.
- Only single-sided access is needed when the pulse-echo technique is used.
- It is highly accurate in determining reflector position and estimating size and shape.
- Minimal part preparation is required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- It has other uses, such as thickness measurement, in addition to flaw detection.

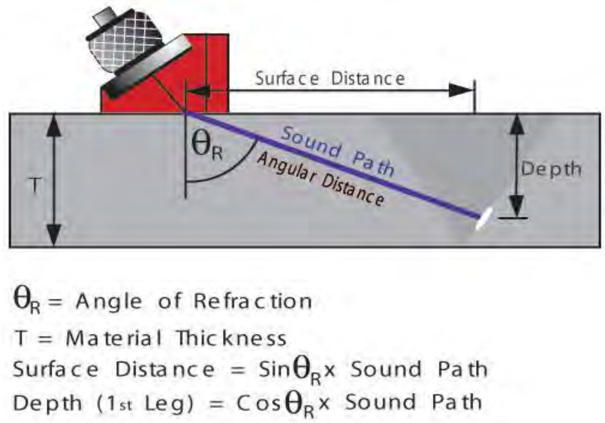
Limitations: As with all NDT methods, ultrasonic inspection also has its limitations, which include:

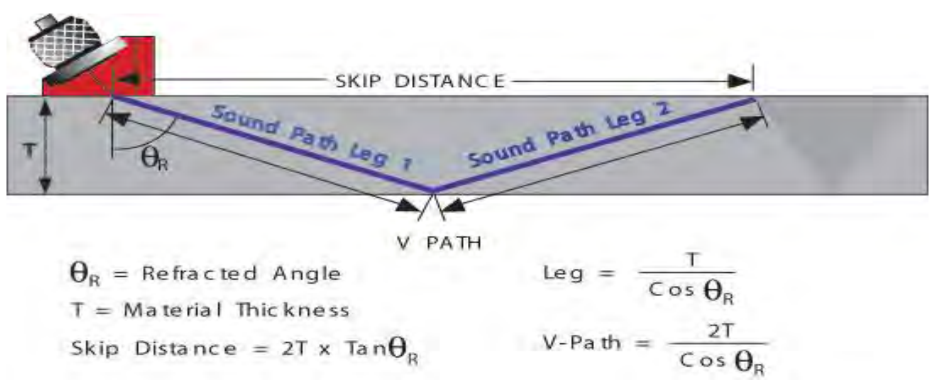
- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally 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 the characterization of flaws.

Applications: There are many applications of ultrasonic testing some of them are as follows:

- ***Forging Testing:*** Large forgings, e.g. generator shafts, undergo a 100% ultrasonic inspection, either manually or automatically on specific installations. The instrument setup requires the range calibration and sensitivity setting to be made according to given standards, using defined calibration blocks. Due to the fact that very small defects have to be detected, the instrument gain is set to a very high value causing increased noise indications on the screen.

- ***Tube testing:*** In high speed automatic tube testing the system is setup with test pieces having defined defects. The visualization of transversal/ longitudinal or inside/ outside defects at a scanning speed of up to 10 m/s or more is very difficult, as these defects are only hit with a few ultrasonic shots, nevertheless, when the system is set to automatic testing, the evaluation, is done with pulse repetition frequency.
- ***Rail Inspection:*** Both normal- and angle-beam techniques are used, as are both pulse-echo and pitch-catch techniques. The different transducer arrangements offer different inspection capabilities. Manual contact testing is done to evaluate small sections of rail but the ultrasonic inspection has been automated to allow inspection of large amounts of rail.
- ***Weldments Inspection:*** Ultrasonic weld inspections are typically performed using a straight beam transducer in conjunction with an angle beam transducer and wedge. A straight beam transducer, producing a longitudinal wave at normal incidence into the test piece, is first used to locate any laminations in or near the heat-affected zone. This is important because an angle beam transducer may not be able to provide a return signal from a laminar flaw.





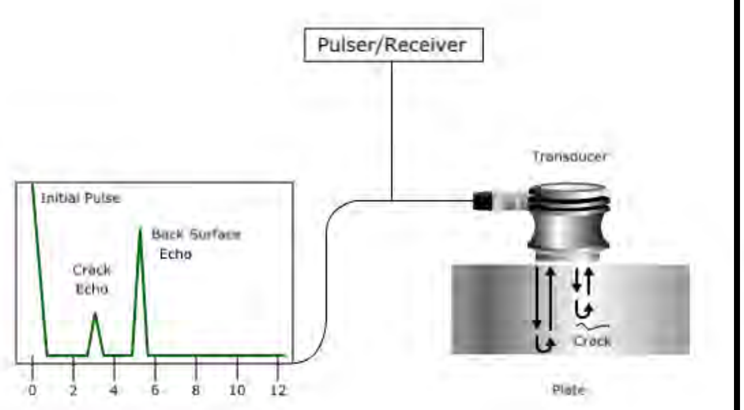
Generation of Ultrasonic Waves: In order to duplicate ultrasonic frequencies, humans have harnessed the electrical properties of materials. When an especially cut piezoelectric quartz crystal is compressed, the crystal becomes electrically charged and an electric current is generated: the greater the pressure, the greater the electric current. If the crystal is suddenly stretched rather than being compressed, the direction of the current will reverse itself. Alternately compressing and stretching the crystal has the effect of producing an alternating current. It follows that by applying an alternating current that matches the natural frequency of the crystal, the crystal can be made to expand and contract with the alternating current. When such a current is applied to the crystal, ultrasonic waves are produced.

Depending on which way the crystal is cut, the waves can be focused along the direction of ultrasound propagation or at right angles to the direction of propagation. Waves that travel along the direction of propagation are called longitudinal waves; as noted above, these waves travel in the direction in which molecules in the surrounding medium move back and forth. Waves that travel at right angles to the propagation direction are called transverse waves; the molecules in the surrounding medium move up and down with respect to the direction that the waves propagate. Ultrasound waves can also propagate as surface waves; in this case, molecules in the surrounding medium experience up-and-down motion as well as expanding and contracting motion.

In most applications, ultrasonic waves are generated by a transducer that includes a piezoelectric crystal that converts electrical energy (electric current) to mechanical energy (sound waves). These sound waves are reflected and return to the transducer as echoes and are converted back to electrical signals by the same transducer or by a separate one. Alternately, one can generate ultrasonic waves by means of magnetostriction (from magneto, meaning magnetic, and striction, meaning drawing together.) In this case an iron or nickel element is magnetized to change its dimensions, thereby producing ultrasonic waves. Ultrasound may also be produced by a whistle or siren-type generator. In this method, gas or liquid streams are passed through a resonant cavity or reflector with the result that ultrasonic vibrations characteristic of the particular gas or liquid are produced.

General characteristics of Ultrasonic Waves: A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface.

The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. In the applet below, the reflected signal strength is displayed versus the time from signal generation to when a echo was received. Signal travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.



Methods and instruments for ultrasonic materials testing: Ultrasonic testing (UT) has been practiced for many decades. Initial rapid developments in instrumentation spurred by the technological advances from the 1950's continue today. Through the 1980's and continuing through the present, computers have provided technicians with smaller and more rugged instruments with greater capabilities.

Thickness gauging is an example application where instruments have been refined make data collection easier and better. Built-in data logging capabilities allow thousands of measurements to be recorded and eliminate the need for a "scribe." Some instruments have the capability to capture waveforms as well as thickness readings. The waveform option allows an operator to view or review the A-scan signal of thickness measurement long after the completion of an inspection. Also, some instruments are capable of modifying the measurement based on the surface conditions of the material. For example, the signal from a pitted or eroded inner surface of a pipe would be treated differently than a smooth surface. This has led to more accurate and repeatable field measurements.

Many ultrasonic flaw detectors have a trigonometric function that allows for fast and accurate location determination of flaws when performing shear wave inspections. Cathode ray tubes, for the most part, have been replaced with LED or LCD screens. These screens, in most cases, are extremely easy to view in a wide range of ambient lighting. Bright or low light working conditions encountered by technicians have little effect on the technician's ability to view the screen. Screens can be adjusted for brightness, contrast, and on some instruments even the color of the screen and signal can be selected. Transducers can be programmed with predetermined instrument settings. The operator only has to connect the transducer and the instrument will set variables such as frequency and probe drive.

Along with computers, motion control and robotics have contributed to the advancement of ultrasonic inspections. Early on, the advantage of a stationary platform was recognized and used in industry. Computers can be programmed to inspect large, complex shaped components, with one or multiple transducers collecting information. Automated systems typically consisted of an immersion tank, scanning system, and recording system for a printout of the scan. The immersion tank can be replaced with a squirter systems, which allows the sound to be transmitted through a water column. The resultant C-scan provides a plan or top view of the component. Scanning of components is considerably faster than contact hand scanning, the coupling is much more consistent. The scan information is collected by a computer for evaluation, transmission to a customer, and archiving.

UNIT 3

MAGNETIC AND ELECTRICAL METHODS IN NDT

Magnetic Particle Inspection Method:

Magnetic particle inspection (MPI) is a nondestructive testing method used for defect detection. MPI is fast and relatively easy to apply, and part surface preparation is not as critical as it is for some other NDT methods. These characteristics make MPI one of the most widely utilized nondestructive testing methods.

MPI uses magnetic fields and small magnetic particles (i.e. Iron filings) to detect flaws in components. The only requirement from an inspectability standpoint is that the component being inspected must be made of a ferromagnetic material such as iron, nickel, cobalt, or some of their alloys. Ferromagnetic materials are materials that can be magnetized to a level that will allow the inspection to be effective.

The method is used to inspect a variety of product forms including castings, forgings, and weldments. Many different industries use magnetic particle inspection for determining a component's fitness-for-use. Some examples of industries that use magnetic particle inspection are the structural steel, automotive, petrochemical, power generation, and aerospace industries. Underwater inspection is another area where magnetic particle inspection may be used to test items such as offshore structures and underwater pipelines.

Advantages of Magnetic Particle Inspection: Advantages of the Magnetic Particle method of Non-Destructive Examination are:

- It is quick and relatively uncomplicated
- It gives immediate indications of defects
- It shows surface and near surface defects, and these are the most serious ones as they concentrate stresses
- The method can be adapted for site or workshop use
- It is inexpensive compared to radiography
- Large or small objects can be examined
- Elaborate pre-cleaning is not necessary

Limitations of Magnetic Particle Inspection: Limitations of the Magnetic Particle method of Non-Destructive Examination are:

- It is restricted to ferromagnetic materials - usually iron and steel, and cannot be used on austenitic stainless steel
- It is messy

- Most methods need a supply of electricity
- It is sometimes unclear whether the magnetic field is sufficiently strong to give good indications
- The method cannot be used if a thick paint coating is present
- Spurious, or non-relevant indications, are probable, and thus interpretation is a skilled task
- Some of the paints and particle suspension fluids can give a fume or fire problem, particularly in a confined space

Methods of Generating fields:

There are several methods of magnetising the test parts.

A current flow method through contact heads, encircling coil magnetising, threaded bard magnetising are the examples of magnetising methods on a magnetic particle bench. The most common method utilised in general industries is the magnetic flow method using electromagnetic yoke. The particles are often coloured and usually coated with fluorescent dyes that are made visible with a hand-held ultraviolet (UV) light (black light). The test method using fluorescent coated particles is called as Fluorescent Magnetic Particle Inspection or test (FMPI) and the usage of other coloured particles is termed as colour contrast Magnetic Particle Inspection or test (MPI).

Magnetic Particle Magnetography:

In this magnetic particle testing technique, dry particles are dusted onto the surface of the test object as the item is magnetized. Dry particle inspection is well suited for the inspections conducted on rough surfaces. When an electromagnetic yoke is used, the AC or half wave DC current creates a pulsating magnetic field that provides mobility to the powder. The primary applications for dry powders are unground welds and rough as-cast surfaces.

Dry particle inspection is also used to detect shallow subsurface cracks. Dry particles with half wave DC is the best approach when inspecting for lack of root penetration in welds of thin materials. Half wave DC with prods and dry particles is commonly used when inspecting large castings for hot tears and cracks.

Steps in performing an inspection using dry particles

Prepare the part surface - the surface should be relatively clean but this is not as critical as it is with liquid penetrant inspection. The surface must be free of grease, oil or other moisture that could keep particles from moving freely. A thin layer of paint, rust or scale will reduce test sensitivity but can sometimes be left in place with adequate results. Specifications often allow up to 0.003 inch (0.076 mm) of a nonconductive coating (such as paint) and 0.001-inch max (0.025 mm) of a ferromagnetic coating (such as nickel) to be left on the surface. Any loose dirt, paint, rust or scale must be removed.

Apply the magnetizing force - Use permanent magnets, an electromagnetic yoke, prods, a coil or other means to establish the necessary magnetic flux.

***Dust on the dry magnetic particles* -** Dust on a light layer of magnetic particles.

***Gently blow off the excess powder* -** With the magnetizing force still applied, remove the excess powder from the surface with a few gentle puffs of dry air. The force of the air needs to be strong enough to remove the excess particles but not strong enough to dislodge particles held by a magnetic flux leakage field**.**

***Terminate the magnetizing force* -** If the magnetic flux is being generated with an electromagnet or an electromagnetic field, the magnetizing force should be terminated. If permanent magnets are being used, they can be left in place.

***Inspect for indications* -** Look for areas where the magnetic particles are clustered.

Suspending Liquid Magnetography:

Wet suspension magnetic particle inspection, more commonly known as wet magnetic particle inspection, involves applying the particles while they are suspended in a liquid carrier. Wet magnetic particle inspection is most commonly performed using a stationary, wet, horizontal inspection unit but suspensions are also available in spray cans for use with an electromagnetic yoke. A wet inspection has several advantages over a dry inspection. First, all of the surfaces of the component can be quickly and easily covered with a relatively uniform layer of particles. Second, the liquid carrier provides mobility to the particles for an extended period of time, which allows enough particles to float to small leakage fields to form a visible indication. Therefore, wet inspection is considered best for detecting very small discontinuities on smooth surfaces. On rough surfaces, however, the particles (which are much smaller in wet suspensions) can settle in the surface valleys and lose mobility, rendering them less effective than dry powders under these conditions.

Steps in performing an inspection using wet suspensions

Prepare the part surface - Just as is required with dry particle inspections, the surface should be relatively clean. The surface must be free of grease, oil and other moisture that could prevent the suspension from wetting the surface and preventing the particles from moving freely. A thin layer of paint, rust or scale will reduce test sensitivity, but can sometimes be left in place with adequate results. Specifications often allow up to 0.003 inch (0.076 mm) of a nonconductive coating (such as paint) and 0.001-inch max (0.025 mm) of a ferromagnetic coating (such as nickel) to be left on the surface. Any loose dirt, paint, rust or scale must be removed.

Apply the suspension - The suspension is gently sprayed or flowed over the surface of the part. Usually, the stream of suspension is diverted from the part just before the magnetizing field is applied.

Apply the magnetizing force - The magnetizing force should be applied immediately after applying the suspension of magnetic particles. When using a wet horizontal inspection unit, the current is applied in two or three short busts (1/2 second) which helps to improve particle mobility.

***Inspect for indications* -** Look for areas where the magnetic particles are clustered. Surface discontinuities will produce a sharp indication. The indications from subsurface flaws will be less defined and lose definition as depth increases.

Field Sensitive Probes:

Eddy current probes are available in a large variety of shapes and sizes. In fact, one of the major advantages of eddy current inspection is that probes can be custom designed for a wide variety of applications. Eddy current probes are classified by the configuration and mode of operation of the test coils. The configuration of the probe generally refers to the way the coil or coils are packaged to best "couple" to the test area of interest. An example of different configurations of probes would be bobbin probes, which are inserted into a piece of pipe to inspect from the inside out, versus encircling probes, in which the coil or coils encircle the pipe to inspect from the outside in. The mode of operation refers to the way the coil or coils are wired and interface with the test equipment. The mode of operation of a probe generally falls into one of four categories: absolute, differential, reflection and hybrid. Each of these classifications will be discussed in more detail below.

Absolute probes generally have a single test coil that is used to generate the eddy currents and sense changes in the eddy current field. As discussed in the physics section, AC is passed through the coil and this sets up an expanding and collapsing magnetic field in and around the coil. When the probe is positioned next to a conductive material, the changing magnetic field generates eddy currents within the material. The generation of the eddy currents take energy from the coil and this appears as an increase in the electrical resistance of the coil. The eddy currents generate their own magnetic field that opposes the magnetic field of the coil and this changes the inductive reactance of the coil. By measuring the absolute change in impedance of the test coil, much information can be gained about the test material.

Absolute coils can be used for flaw detection, conductivity measurements, liftoff measurements and thickness measurements. They are widely used due to their versatility. Since absolute probes are sensitive to things such as conductivity, permeability liftoff and temperature, steps must be taken to minimize these variables when they are not important to the inspection being performed. It is very common for commercially available absolute probes to have a fixed "air loaded" reference coil that compensates for ambient temperature variations.

Differential probes have two active coils usually wound in opposition, although they could be wound in addition with similar results. When the two coils are over a flaw-free area of test sample, there is no differential signal developed between the coils since they are both inspecting identical material. However, when one coil is over a defect and the other is over good material, a differential signal is produced. They have the advantage of being very sensitive to defects yet relatively insensitive to slowly varying properties such as gradual dimensional or temperature variations. Probe wobble signals are also reduced with this probe type. There are also disadvantages to using differential probes. Most notably, the signals may be difficult to interpret. For example, if a flaw is longer than the spacing between the two coils, only the leading and trailing edges will be detected due to signal cancellation when both coils sense the flaw equally.

Reflection probes have two coils similar to a differential probe, but one coil is used to excite the eddy currents and the other is used to sense changes in the test material. Probes of this arrangement are often referred to as driver/pickup probes. The advantage of reflection probes is that the driver and pickup coils can be separately optimized for their intended purpose. The driver coil can be made so as to produce a strong and uniform flux field in the vicinity of the pickup coil, while the pickup coil can be made very small so that it will be sensitive to very small defects. The through-transmission method is sometimes used when complete penetration of plates and tube walls is required.

Hybrid probe: An example of a ***hybrid probe*** is the split D, differential probe shown to the right. This probe has a driver coil that surrounds two D shaped sensing coils. It operates in the reflection mode but additionally, its sensing coils operate in the differential mode. This type of probe is very sensitive to surface cracks. Another example of a hybrid probe is one that uses a conventional coil to generate eddy currents in the material but then uses a different type of sensor to detect changes on the surface and within the test material. An example of a hybrid probe is one that uses a Hall effect sensor to detect changes in the magnetic flux leaking from the test surface. Hybrid probes are usually specially designed for a specific inspection application.

Electrical methods or Alternating Current Field Measurement (ACFM) is an electromagnetic technique for detection and sizing of surface breaking discontinuities.

It can be used on conductive materials coated with conductive or non-conductive coatings with the surface temperature up to 400 degree Celsius.

The ACFM probe induces a uniform alternating current in the area under test and detects the resulting current flow near to the surface.

This current flow will be distorted around the discontinuity and flow around the ends and faces of the discontinuity.

The ACFM instrument measures these disturbances in the field and uses mathematical modelling to estimate discontinuity size (length and depth).

Scanning data can be captured and stored on electronic storage devices.

This non-destructive test technique is very useful for the sub-sea and offshore industry because there is no need to remove the thick protective coating.

This test method can be applied on any in-service structures and pressure equipment’s, pressure vessels and pressure piping.

This test method is not recommended for short sections or small items.

Weld repairs and localised grinding can cause spurious indications. The minimum discontinuity length that can be detected is 5mm and the accuracy can reduce when multiple discontinuities are clustered.

Compared to other surface flaw detection methods, Alternating Current Field Measurement (ACFM) test requires highly trained, skilled and experienced technicians.

Eddy-current test uses electromagnetic induction to detect flaws in conductive materials. The eddy current test set-up consists of a circular coil which is placed on the test surface. The alternating current in the coil generates changing magnetic field which interacts with the conductive test surface and generates eddy current. The flow of eddy current can be disrupted due to change in resistivity or conductivity, magnetic permeability, any physical discontinuities. The change in eddy current flow and a corresponding change in the phase and amplitude is measured against known values.

Eddy current test method can detect very small cracks in or near the surface of the material, the surfaces need minimum preparation. The biggest advantage of the eddy current test method is that is can be employed to determine surface flaws on painted or coated surface. Eddy current flaw detection is commonly used in the aerospace industry, crane industry, concrete pumping industry and other general industries where the protective surface coating cannot be removed.

The crane industry and crane owners benefit most from the application of eddy current test method to detect surface flaws underneath the protective coating (paint). The exorbitant cost of paint removal and repainting is eliminated by applying eddy current flaw detection method as compared to magnetic particle test. It is also useful for making electrical conductivity and coating thickness measurements. Eddy current test is commonly employed for rapid thickness testing of coatings - conductive and non-conductive.

The principle of eddy current test which measures the change in resistivity in the conductive material makes it useful in wide range of applications such as conductivity measurement, sorting of material, assessment of heat treatment condition, sorting of materials on the basis of hardness and strength, thickness measurement of thin components.

Compared to other surface flaw detection methods, eddy current test requires highly trained, skilled and experienced technicians.

Potential drop methods

A special electrical resistance testing method applies an electrical potential between two prods attached to a specimen surface and then measures the difference in resistance across a second pair of prods placed successively across a crack and across adjacent sound material. The increase in resistance due to the crack is a direct measure of the through-thickness dimension of the crack from the surface (the crack height).

The method is used mostly for sizing cracks which have been found by other techniques. It can be applied to any electrically conductive material. The instruments required can be small and portable. The applied electrical potential may be AC or DC.

Accuracy of results depends on the crack not containing any conductive bridging material, which would shorten the electrical path length.

Applications of potential drop methods:

Alternating Current Potential Drop (ACPD) test method is one of the non-destructive test surface methods used to determine material thickness, electrical conductivity, resistivity due to material discontinuities and linear effective magnetic permeability.

The Direct Current Potential Drop (ACPD) test method is one of the non-destructive test surface methods used to determine electrical conductivity, resistivity due to material discontinuities such as cracks and manufacturing linear discontinuities.

UNIT 4

ELECTROMAGNETIC TESTING

Magnetism: Magnetism is a class of physical phenomena that are mediated by magnetic fields. Electric currents and the magnetic moments of elementary particles give rise to a magnetic field, which acts on other currents and magnetic moments. The most familiar effects occur in ferromagnetic materials, which are strongly attracted by magnetic fields and can be magnetized to become permanent magnets, producing magnetic fields themselves.

Magnetic Domain: The magnetic moments of atoms in a ferromagnetic material cause them to behave something like tiny permanent magnets. They stick together and align themselves into small regions of more or less uniform alignment called magnetic domains or Weiss domains. Magnetic domains can be observed with a magnetic force microscope to reveal magnetic domain boundaries that resemble white lines in the sketch. There are many scientific experiments that can physically show magnetic fields.

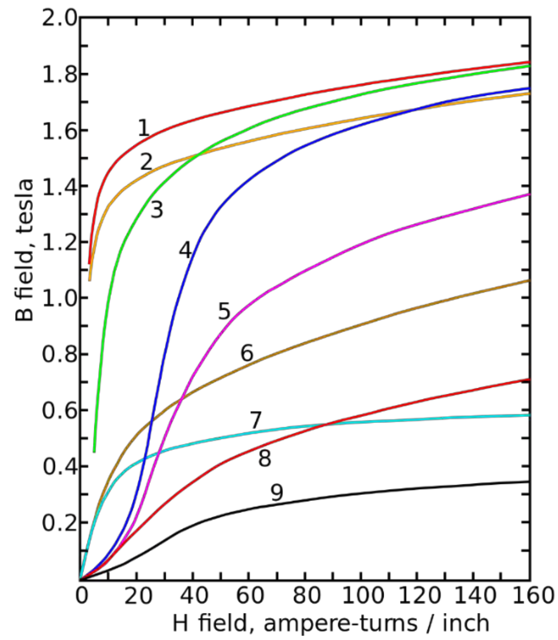
When a domain contains too many molecules, it becomes unstable and divides into two domains aligned in opposite directions, so that they stick together more stably.

When exposed to a magnetic field, the domain boundaries move, so that the domains aligned with the magnetic field grow and dominate the structure. When the magnetizing field is removed, the domains may not return to an unmagnetized state. This results in the ferromagnetic material's being magnetized, forming a permanent magnet.

When magnetized strongly enough that the prevailing domain overruns all others to result in only one single domain, the material is magnetically saturated. When a magnetized ferromagnetic material is heated to the Curie point temperature, the molecules are agitated to the point that the magnetic domains lose the organization, and the magnetic properties they cause cease. When the material is cooled, this domain alignment structure spontaneously returns, in a manner roughly analogous to how a liquid can freeze into a crystalline solid.

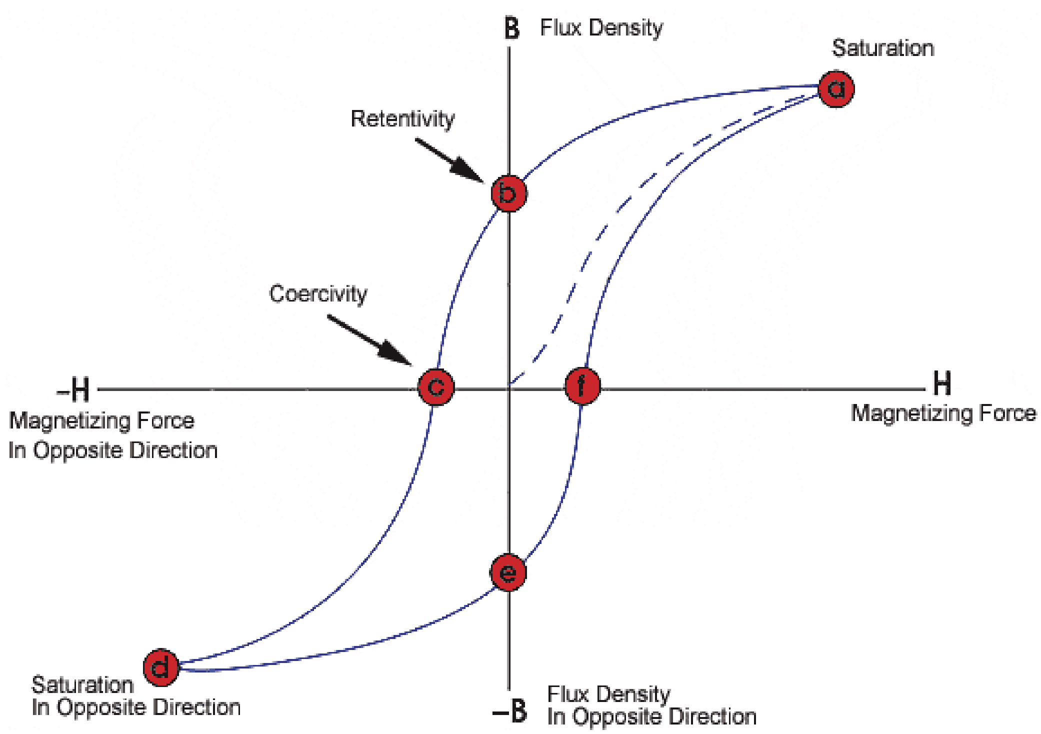
Magnetization curves: A graph representing changes in the condition of a magnetizable substance with magnetizing force H as abscissa and either magnetization I or induction B as ordinate. Magnetization curves of 9 ferromagnetic substances; a plot of the flux density B as a function of magnetizing field H. They all show saturation, the levelling off of B with increasing H that is characteristic of ferromagnetic substances. The graph was traced from a 1917 electronics book, so the accuracy of the data may not be equal to modern measurements. the substances are:

1. Standard sheet steel, annealed,
2. Silicon sheet steel, annealed, Si 2.5%,
3. Soft steel casting,
4. Tungsten steel,
5. Magnet steel,
6. Cast iron,
7. Nickel, 99%,
8. Cast cobalt,
9. Magnetite, Fe_2O_3.



Magnetic Hysteresis:

The Hysteresis Loop and Magnetic Properties: A great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density **(B)** and the magnetizing force **(H).** It is often referred to as the B-H loop. An example hysteresis loop is shown below.



The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H** is increased. As the line demonstrates, the greater the amount of current applied **(H+)**, the stronger the magnetic field in the component **(B+)**. At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When **H** is reduced to zero, the curve will move from point "a" to point "b." At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to as the point of retentivity on the graph and indicates the remanence or level of residual magnetism in the material. (Some of the magnetic domains remain aligned but some have lost their alignment.) As the magnetizing force is reversed, the curve moves to point "c", where the flux has been reduced to zero. This is called the point of coercivity on the curve. (The reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero.) The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material.

As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction (point "d"). Reducing **H** to zero brings the curve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction. Increasing **H** back in the positive direction will return **B** to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "f" back to the saturation point where it with complete the loop.

From the hysteresis loop, a number of primary magnetic properties of a material can be determined.

1. **Retentivity** - A measure of the residual flux density corresponding to the saturation induction of a magnetic material. In other words, it is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation. (The value of **B** at point b on the hysteresis curve.)

2. **Residual Magnetism** or **Residual Flux -** the magnetic flux density that remains in a material when the magnetizing force is zero. Note that residual magnetism and retentivity are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentivity value when the magnetizing force did not reach the saturation level.

3. **Coercive Force** - The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero. (The value of **'H'** at point c on the hysteresis curve.)

4. **Permeability, m -** A property of a material that describes the ease with which a magnetic flux is established in the component.

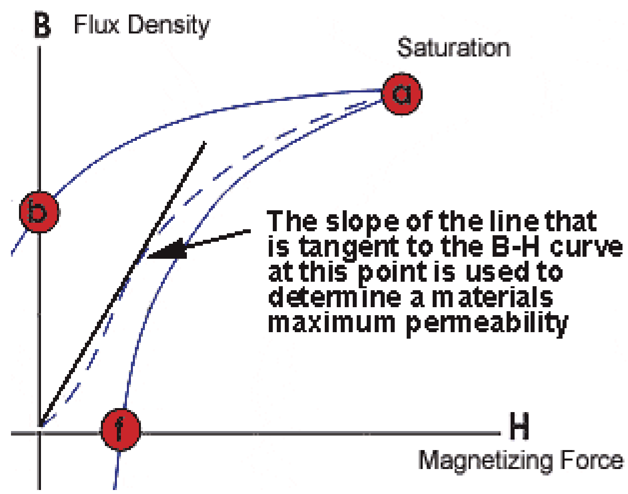
5. **Reluctance** - Is the opposition that a ferromagnetic material shows to the establishment of a magnetic field. Reluctance is analogous to the resistance in an electrical circuit.

Hysteresis loop tests: Permeability

As previously mentioned, permeability (m) is a material property that describes the ease with which a magnetic flux is established in a component. It is the ratio of the flux density (B) created within a material to the magnetizing field (H) and is represented by the following equation:

$$m = B/H$$

It is clear that this equation describes the slope of the curve at any point on the hysteresis loop. The permeability value given in papers and reference materials is usually the maximum permeability or the maximum relative permeability. The maximum permeability is the point where the slope of the B/H curve for the unmagnetized material is the greatest. This point is often taken as the point where a straight line from the origin is tangent to the B/H curve.

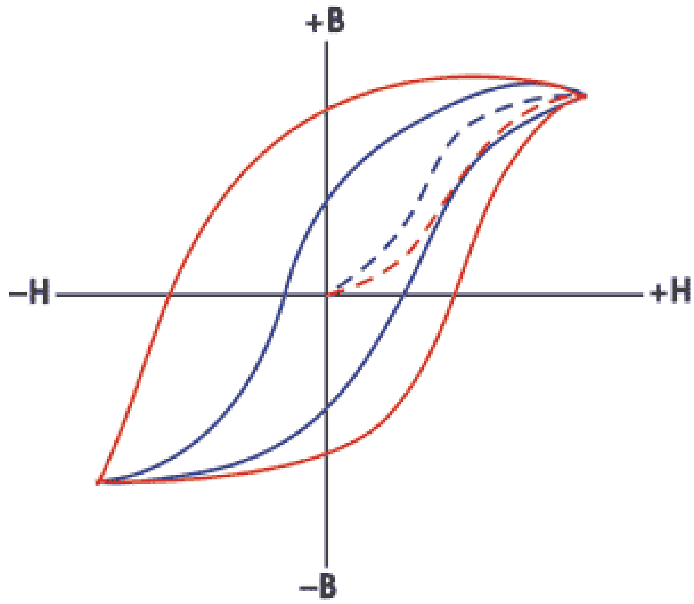


The relative permeability is arrived at by taking the ratio of the material's permeability to the permeability in free space (air).

$$m_{(relative)} = m_{(material)}/m_{(air)}$$

where, $m_{(air)} = 1.256 \times 10^{-6}$ H/m

The shape of the hysteresis loop tells a great deal about the material being magnetized. The hysteresis curves of two different materials are shown in the graph.



Relative to other materials, a material with a wider hysteresis loop has:

- Lower Permeability
- Higher Retentivity
- Higher Coercivity
- Higher Reluctance
- Higher Residual Magnetism

Relative to other materials, a material with the narrower hysteresis loop has:

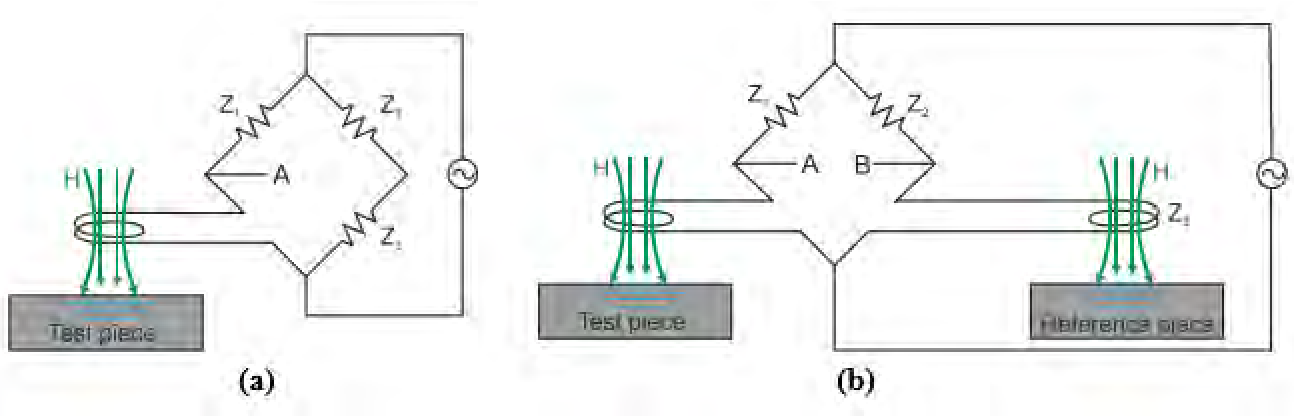
- Higher Permeability
- Lower Retentivity
- Lower Coercivity
- Lower Reluctance
- Lower Residual Magnetism

In magnetic particle testing, the level of residual magnetism is important. Residual magnetic fields are affected by the permeability, which can be related to the carbon content and alloying of the material. A component with high carbon content will have low permeability and will retain more magnetic flux than a material with low carbon content.

Comparator-Bridge Test: The most widely used circuitry for eddy current coil sensors is the bridge mode, which can be balanced or unbalanced depending on the probe type. Non-compensated absolute coil probes can be polarized in serial connection with a resistor in one leg, as Figure 26(a) shows, and a balancing impedance network formed by Test piece in one leg and Reference piece in the other leg. The voltage differences are measured between the two legs. The balancing network permits the use of the entire range of the instrument with respect the single RL circuit. The disadvantage of this configuration is that it is also not compensated with regard to temperature, as the coil probe, impedances and resistances have different temperature coefficients.

(a) Unbalanced bridge connection.

(b) Balanced bridge connection.



Compensated absolute coil probes can be polarized in both legs of the bridge in order to balance it as Figure 26(b) illustrates. The system has the advantage of being temperature compensated. The circuitry for separate-function differential probes is commonly done by connecting the primary circuit using an RL circuit. The secondary pick-up coils may be connected directly to the input of a differential amplifier.

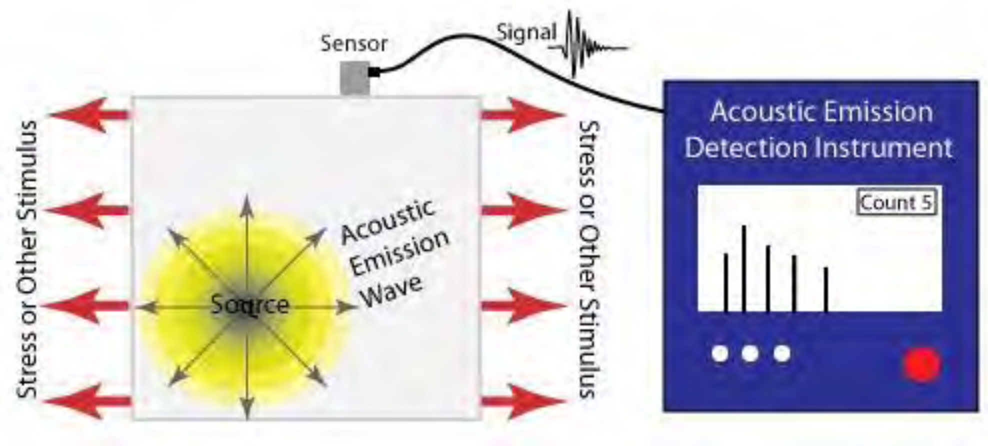
Absolute Single coil systems: Absolute probes generally have a single test coil that is used to generate the eddy currents and sense changes in the eddy current field. As discussed in the physics section, AC is passed through the coil and this sets up an expanding and collapsing magnetic field in and around the coil. When the probe is positioned next to a conductive material, the changing magnetic field generates eddy currents within the material. The generation of the eddy currents take energy from the coil and this appears as an increase in the electrical resistance of the coil. The eddy currents generate their own magnetic field that opposes the magnetic field of the coil and this changes the inductive reactance of the coil. By measuring the absolute change in impedance of the test coil, much information can be gained about the test material.

Absolute coils can be used for flaw detection, conductivity measurements, liftoff measurements and thickness measurements. They are widely used due to their versatility. Since absolute probes are sensitive to things such as conductivity, permeability liftoff and temperature, steps must be taken to minimize these variables when they are not important to the inspection being performed. It is very common for commercially available absolute probes to have a fixed "air loaded" reference coil that compensates for ambient temperature variations.

UNIT 5

OTHER NDT METHODS

Introduction to Acoustic Emission Testing:



Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material. When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors. With the right equipment and setup, motions on the order of pico-meters (10^{-12} m) can be identified. Sources of AE vary from natural events like earthquakes and rock bursts to the initiation and growth of cracks, slip and dislocation movements, melting, twinning, and phase transformations in metals. In composites, matrix cracking and fiber breakage and de-bonding contribute to acoustic emissions. AE's have also been measured and recorded in polymers, wood, and concrete, among other materials.

Detection and analysis of AE signals can supply valuable information regarding the origin and importance of a discontinuity in a material. Because of the versatility of Acoustic Emission Testing (AET), it has many industrial applications (e.g. assessing structural integrity, detecting flaws, testing for leaks, or monitoring weld quality) and is used extensively as a research tool.

Acoustic Emission is unlike most other nondestructive testing (NDT) techniques in two regards. The first difference pertains to the origin of the signal. Instead of supplying energy to the object under examination, AET simply listens for the energy released by the object. AE tests are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions.

The second difference is that AET deals with dynamic processes, or changes, in a material. This is particularly meaningful because only active features (e.g. crack growth) are highlighted. The ability to discern between developing and stagnant defects is significant. However, it is possible for flaws to go undetected altogether if the loading is not high enough to cause an acoustic event. Furthermore, AE testing usually provides an immediate indication relating to the strength or risk of failure of a component. Other advantages of AET include fast and complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen.

Unfortunately, AE systems can only qualitatively gauge how much damage is contained in a structure. In order to obtain quantitative results about size, depth, and overall acceptability of a part, other NDT methods (often ultrasonic testing) are necessary. Another drawback of AE stems from loud service environments which contribute extraneous noise to the signals. For successful applications, signal discrimination and noise reduction are crucial.

Acoustic Emission Sources: As mentioned in the Introduction, acoustic emissions can result from the initiation and growth of cracks, slip and dislocation movements, twinning, or phase transformations in metals. In any case, AE's originate with stress. When a stress is exerted on a material, a strain is induced in the material as well. Depending on the magnitude of the stress and the properties of the material, an object may return to its original dimensions or be permanently deformed after the stress is removed. These two conditions are known as elastic and plastic deformation, respectively.

The most detectible acoustic emissions take place when a loaded material undergoes plastic deformation or when a material is loaded at or near its yield stress. On the microscopic level, as plastic deformation occurs, atomic planes slip past each other through the movement of dislocations. These atomic-scale deformations release energy in the form of elastic waves which "can be thought of as naturally generated ultrasound" traveling through the object. When cracks exist in a metal, the stress levels present in front of the crack tip can be several times higher than the surrounding area. Therefore, AE activity will also be observed when the material ahead of the crack tip undergoes plastic deformation (micro-yielding).

Two sources of fatigue cracks also cause AE's. The first source is emissive particles (e.g. nonmetallic inclusions) at the origin of the crack tip. Since these particles are less ductile than the surrounding material, they tend to break more easily when the metal is strained, resulting in an AE signal. The second source is the propagation of the crack tip that occurs through the movement of dislocations and small-scale cleavage produced by triaxial stresses.

The amount of energy released by an acoustic emission and the amplitude of the waveform are related to the magnitude and velocity of the source event. The amplitude of the emission is proportional to the velocity of crack propagation and the amount of surface area created. Large, discrete crack jumps will produce larger AE signals than cracks that propagate slowly over the same distance.

Detection and conversion of these elastic waves to electrical signals is the basis of AE testing. Analysis of these signals yield valuable information regarding the origin and importance of a discontinuity in a material. As discussed in the following section, specialized equipment is necessary to detect the wave energy and decipher which signals are meaningful.

Acoustic method for pipeline Leak detection: The acoustic pressure wave method analyses the rarefaction waves produced when a leak occurs. When a pipeline wall breakdown occurs, fluid or gas escapes in the form of a high velocity jet. This produces negative pressure waves which propagate in both directions within the pipeline and can be detected and analyzed. The operating principles of the method are based on the very important characteristic of pressure waves to travel over long distances at the speed of sound guided by the pipeline walls. The amplitude of a pressure wave increases with the leak size. A complex mathematical algorithm analyzes data from pressure sensors and is able in a matter of seconds to point to the location of the leakage with accuracy less than 50 m (164 ft). Experimental data has shown the method's ability to detect leaks less than 3mm (0.1 inch) in diameter and operate with the lowest false alarm rate in the industry – less than 1 false alarm per year.

However, the method is unable to detect an ongoing leak after the initial event: after the pipeline wall breakdown (or rupture), the initial pressure waves subside and no subsequent pressure waves are generated. Therefore, if the system fails to detect the leak (for instance, because the pressure waves were masked by transient pressure waves caused by an operational event such as a change in pumping pressure or valve switching), the system will not detect the ongoing leak.

Introduction to Thermal Testing:(Thermal Inspection, Thermography, Thermal Imaging, Thermal Wave Imaging and Infrared Testing): Thermal NDT methods involve the measurement or mapping of surface temperatures as heat flows to, from and/or through an object. The simplest thermal measurements involve making point measurements with a thermocouple. This type of measurement might be useful in locating hot spots, such as a bearing that is wearing out and starting to heat up due to an increase in friction.

In its more advanced form, the use of thermal imaging systems allows thermal information to be very rapidly collected over a wide area and in a non-contact mode. Thermal imaging systems are instruments that create pictures of heat flow rather than of light. Thermal imaging is a fast, cost effective way to perform detailed thermal analysis. The image above is a heat map of the space shuttle as it lands.

Thermal measurement methods have a wide range of uses. They are used by the police and military for night vision, surveillance, and navigation aid; by firemen and emergency rescue personnel for fire assessment, and for search and rescue; by the medical profession as a diagnostic tool; and by industry for energy audits, preventative maintenance, processes control and nondestructive testing. The basic premise of thermographic NDT is that the flow of heat from the surface of a solid is affected by internal flaws such as disbonds, voids or inclusions. The use of thermal imaging systems for industrial NDT applications will be the focus of this material.

Equipment – Detectors: Thermal energy detection and measurement equipment comes in a large variety of forms and levels of sophistication. One way to categorize the equipment and materials is to separate thermal detectors from quantum (photon) detectors. The basic distinction between the two is that thermal detectors depend on a two-step process. The absorption of thermal energy in these detectors raises the temperature of the device, which in turn changes some temperature-dependent parameter, such as electrical conductivity. Quantum devices detect photons from infrared radiation. Quantum detectors are much more sensitive but require cooling to operate properly.

Thermal Detectors: Thermal detectors include heat sensitive coatings, thermoelectric devices and pyroelectric devices. Heat sensitive coatings range from simple wax-based substances that are blended to melt at certain temperatures to specially formulated paint and greases that change color as temperature changes. Heat sensitive coatings are relatively inexpensive but do not provide good quantitative data.

Thermoelectric devices include thermocouples, thermopiles (shown right), thermistors and bolometers. These devices produce an electrical response based on a change in temperature of the sensor. They are often used for point or localized measurement in a contact or near contact mode. However, thermal sensors can be miniaturized. For example, microbolometers are the active elements in some high-tech portable imaging systems, such as those used by fire departments. Benefits of thermal detectors are that the element does not need to be cooled and they are comparatively low in price. Thermal detectors are used to measure the temperature in everything from home appliances to fire and intruder detection systems to industrial furnaces to rockets.

Quantum (Photon) Detectors: Unlike thermal detectors, quantum detectors do not rely on the conversion of incoming radiation to heat, but convert incoming photons directly into an electrical signal. When photons in a particular range of wavelengths are absorbed by the detector, they create free electron-hole pairs, which can be detected as electrical current. The signal output of a quantum detector is very small and is overshadowed by noise generated internally to the device at room temperatures. Since this noise within a semiconductor is partly proportional to temperature, quantum detectors are operated at cryogenic temperatures [i. e. down to 77 K (liquid nitrogen) or 4 K (liquid helium)] to minimize noise. This cooling requirement is a significant disadvantage in the use of quantum detectors. However, their superior electronic performance still makes them the detector of choice for the bulk of thermal imaging applications. Some systems can detect temperature differences as small as 0.07°C.

Quantum detectors can be further subdivided into photoconductive and photovoltaic devices. The function of photoconductive detectors is based on the photogeneration of charge carriers (electrons, holes or electron-hole pairs). These charge carriers increase the conductivity of the device material. Possible materials used for photoconductive detectors include indium antimonide (InSb), quantum well infrared photodetector (QWIP), mercury cadmium telluride (mercad, MCT), lead sulfide (PbS), and lead selenide (PbSe).

Photovoltaic devices require an internal potential barrier with a built-in electric field in order to separate photo-generated electron-hole pairs. Such potential barriers can be created by the use of p-n junctions or Schottky barriers. Examples of photovoltaic infrared detector types are indium antimonide (InSb), mercury cadmium telluride (MCT), platinum silicide (PtSi), and silicon Schottky barriers.

Detector Cooling: There are several different ways of cooling the detector to the required temperature. In the early days of thermal imaging, liquid nitrogen was poured into imagers to cool the detector. Although satisfactory, the logistical and safety implications led to the development of other cooling methods. High pressure gas can be used to cool a detector to the required temperatures. The gas is allowed to rapidly expand in the cooling systems and this expansion results in the significant reduction in the temperature of a gas. Mechanical cooling systems are the standard for portable imaging systems. These have the logistical advantage of freeing the detection system from the requirements of carrying high pressure gases or liquid nitrogen.

END