III B.Tech - II Semester

Subject. Non- Destructive Evaluation

Unit - 1

Introduction to non-destructive Evaluation & Radiography

Non destructive Test and Evaluation (NDE) is aimed at extracting Information on the Physical, chemical, mechanical, or metallurgical state of materials or structures. This Information is obtained through a process of interaction between the Information - generating device and the object under test.

The Information can be generated using X-rays, gamma rays, neutrons, ultrasonic methods, magnetic and Electromagnetic methods, or any other established physical phenomenon.

The process of interaction does not damage the test object or impair its intended utility value. The process is influenced by the physical, chemical and mechanical properties as well as by the fabrication procedure of the test object.

Objective of any NDE:

1. Design stipulated standards (e.g. dimension, strength and stiffness) do not deviate beyond permissible limits and immediate action is initiated in case of such deviations

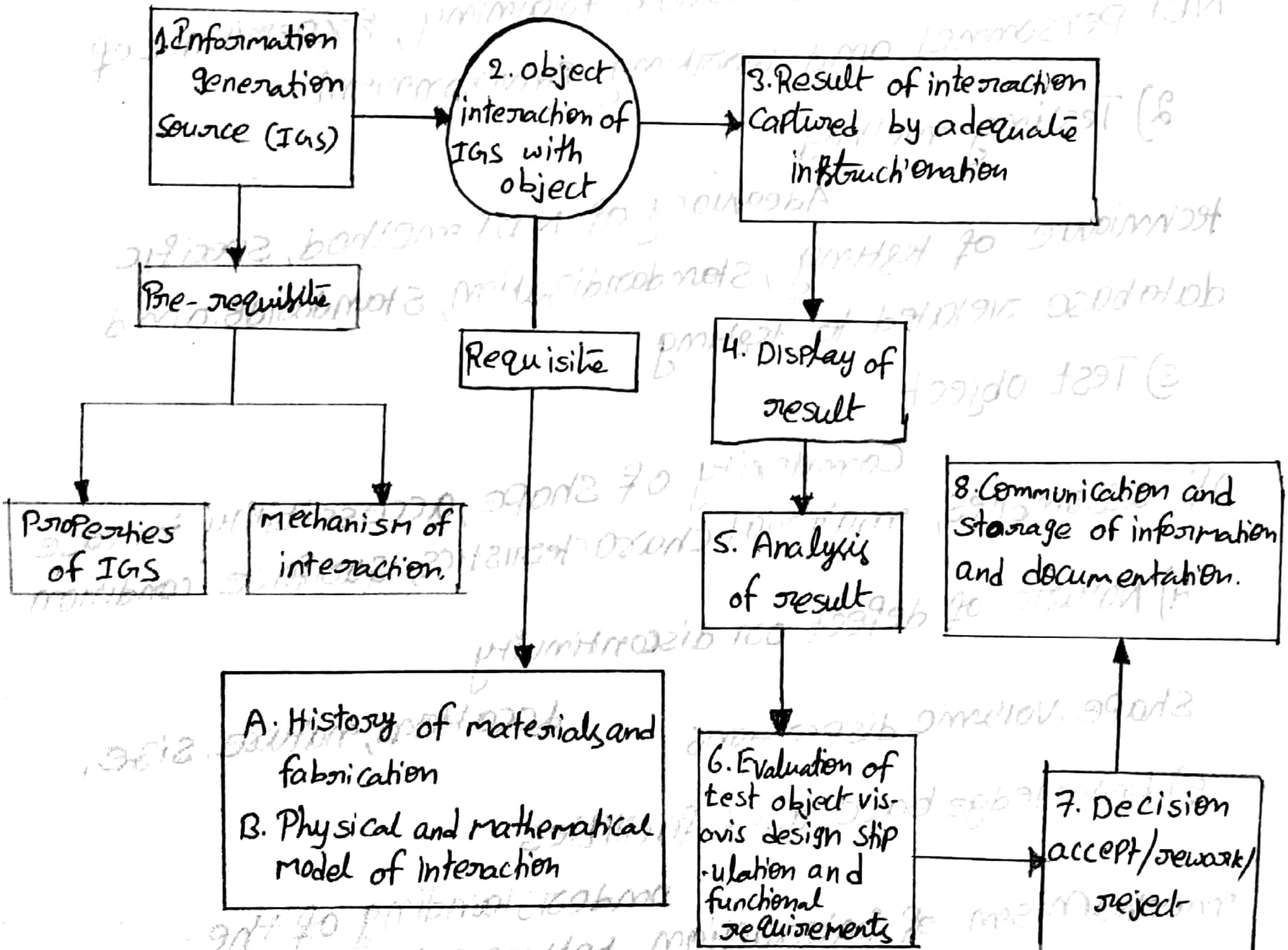
2. To establish reproducibility of the fabrication process for successive batches of production with minimum rejection or repair

3. To establish reliability of NDT methods so that potentially harmful defects, damages, material in-homogeneities or dimensions are noticed while minor defects or deviations do not lead to unnecessary rejection or repair.

The science and technology of NDE involves the following:

* A device that interacts with the test object and generates information.
* Knowledge of material and fabrication process
* Understanding the mechanism of interaction between the information-generating device and the object
* Adequate tools (hard & software) to capture and record the results of the interactions

* Analysis of generated Information and its correlation with test object conditions that caused them.
* Presentation of results
* Evaluation of the test object based on results of interaction with the Information generating source
* Decision on accept/repair/reject, keeping in view the design stipulation and usage environment
* Communication, documentation and archiving for future retrieval of usable information.



Factors Influencing the reliability of NDE

Each NDT method is most effective only in a particular area of testing. Two or more methods of testing may complement each other but are not used for cross-checking the effectiveness or efficiency of each other. The sucess of any NDT method depends on its adequacy and reliability for a particular test situation. The major factors that influence the reliability of NDT methods are.

1) Human factors:

Education, training, Experience of NDT personnel and working environment.

2) Testing method:

Adequacy of NDT method, specific technique of testing, standardization, standards and database related to testing.

3) Test object:

Complexity of shape, accessibility in case of assemblies, material characteristics, surface condition

4) Nature of defect or discontinuity:

Location, nature, size, shape, volume dispersions

5) Knowledge base and facilities:

understanding of the mechanism of interaction between the test object and the information-generating tool, adequacy of hardware and software skills of data presentation

6. Risk factors in relation to functional requirements:

Probability of defect detection, structural significance of single or dispersed defects or the probability of failure. Statistical data for reliable decision making.

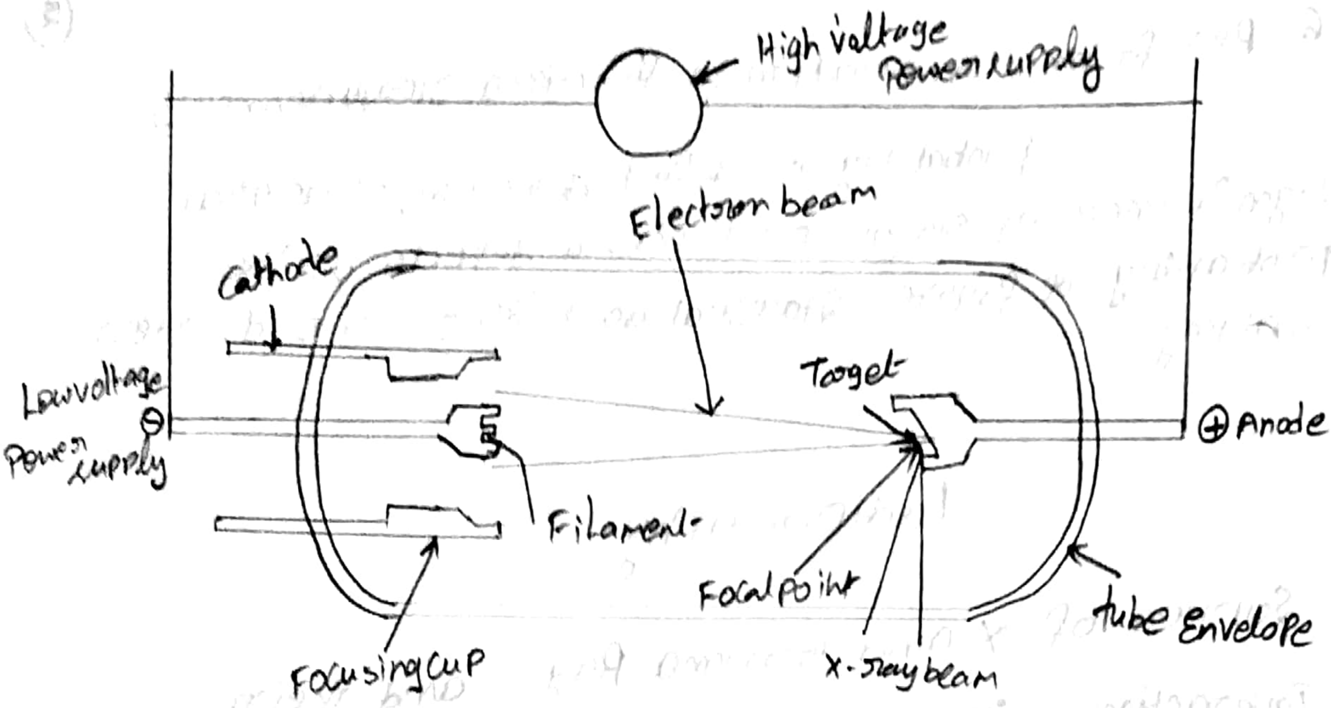
RadioGraphy

Sources of X and Gamma Rays and their Interaction with Matter:

X-rays and Gamma rays are the most commonly used penetrating radiations for industrial radiography.

X-rays:

X-rays are produced when high-speed Electrons strike a metal target in a highly Evacuated glass Enclosure (Vacuum $\simeq 10^{-9}$ to -13 mm/Hg). A metal filament is sealed inside the Enclosure, which is heated by a current of a few amperes to produce Electrons at its surface. At the other End of the glass Enclosure a high atomic number metal target is sealed on which the fast moving Electrons strike. To accelerate the Electrons, high voltage of a few thousand volts is applied between the filament (cathode) and the metal target (anode)



Arragement for Producing X-rays

* If the applied voltage is 'V' and charge of the Electron is 'e', the kinetic Energy imparted to the Electron 'Ve'.

* If the mass of the Electrons is 'm' and acquired velocity is v, then the kinetic Energy of the Electron is Equal to $\frac{1}{2}mv^2 = Ve$

Electrons approaching the target lose their Energy in one or more of the following ways:

* Cathode Electrons interact with free Electrons of the target atom and, in the process, lose part of their Energy, which is converted into heat and X-rays of low frequency.

The corresponding wavelength of the Emitted X-rays is given by

$$\lambda = \frac{hc}{e(V-V')}$$

Where

h = Planck's constant

c = Velocity of light

(V − V')e = part of the electron's energy converted into heat or X-Rays

* Cathode electrons with sufficient energy may reach and be stopped by the heavy nucleus of the target. In the process, the entire energy of the electron is converted into X-rays of wavelength given by

$$\lambda_{min} = \frac{hc}{Ve} = \frac{12395}{V} \text{ Å}$$ (Substituting the value of h, c, e)

* It may also happen that the cathode electron knocks out one of the orbital electrons of the target atom and the atom is subsequently returning to its normal energy state when one of the electrons from an outer orbit falls into the vacancy. In this process, the X-rays of a definite wavelength, characteristic of the target material, are emitted. This is called "characteristic radiation"

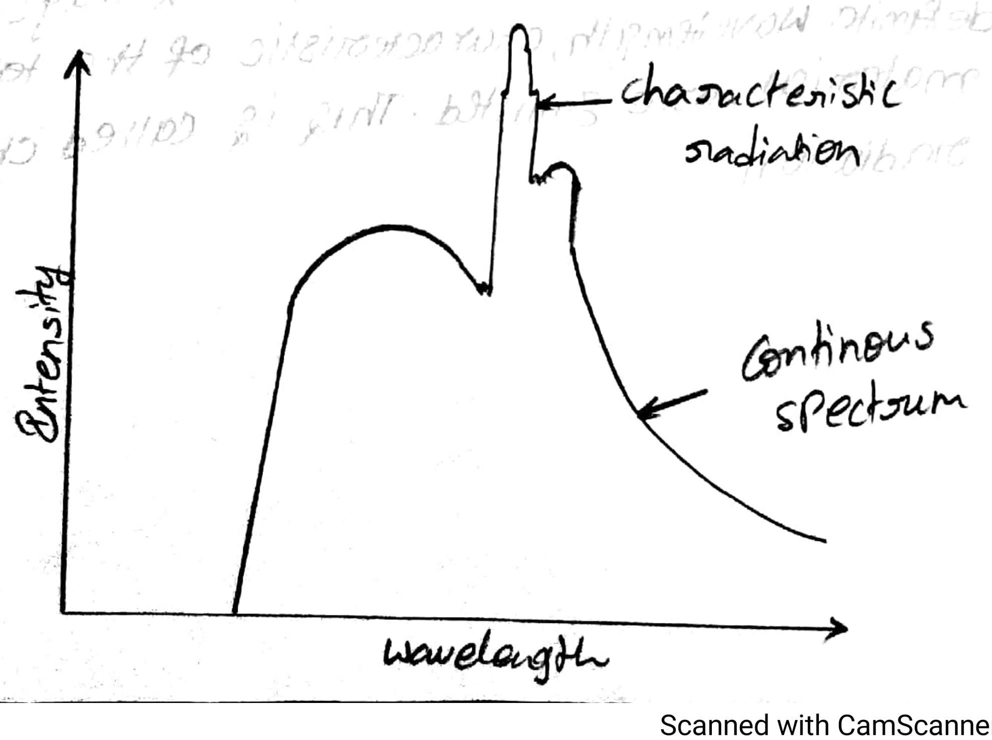
Effect of tube voltage and current on Intensity of X-rays :

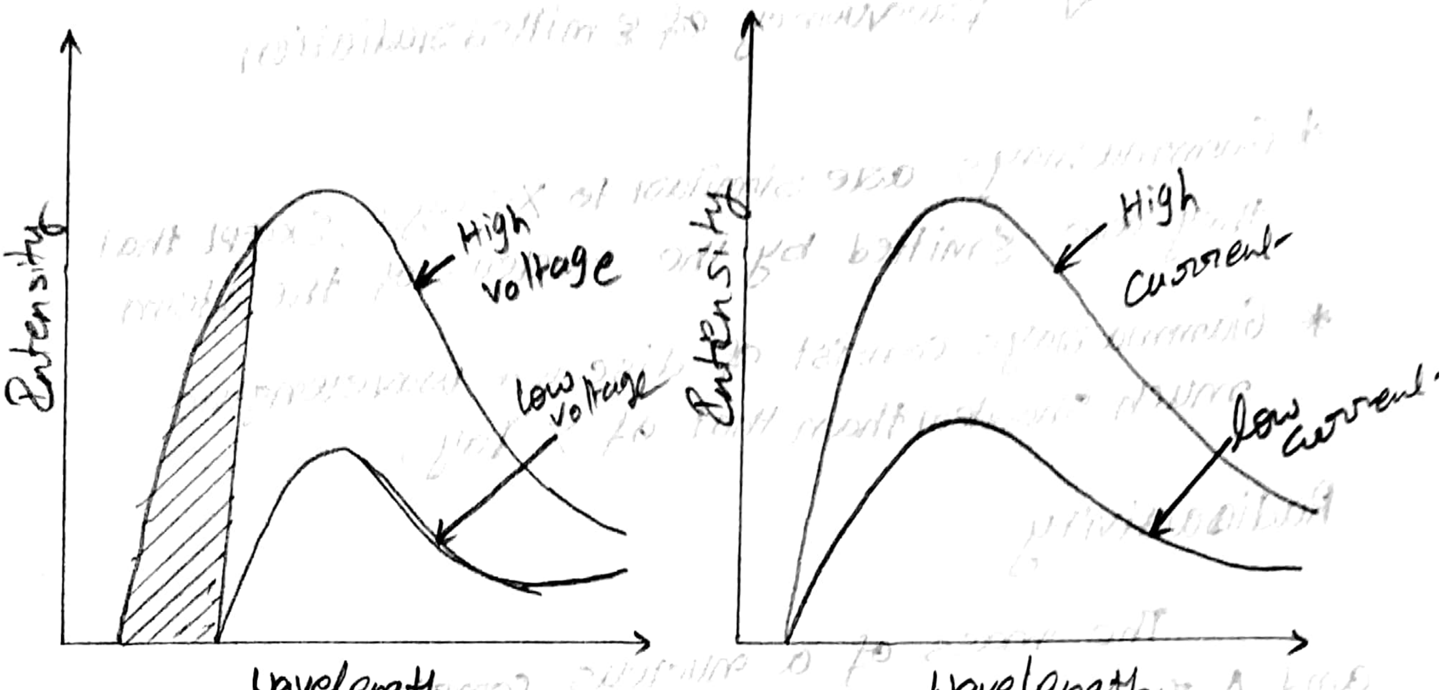
The X-ray spectrum is significantly influenced by change in voltage between Electrodes of the X-ray tube. Increased voltage leads to increase in generation of shorter wavelength compared to those that were present at low voltage. Also, the Intensity of X-ray beam increases significantly and is given by the relation

$$I = KV^2$$

where K is a constant.

The intensity also increases as the tube current increases. (Tube current is the current that flows between the cathode and the anode and should not be confused with filament current, which heats the filament to produce Electrons at its surface).





a) Effect of change in voltage   b) Effect of change in tube current

Effect of change in voltage and Tube current on the X-ray spectrum

Gamma Rays:

The nucleus of an atom mainly consists of protons and neutrons bound to it. These particles exist in discrete energy level similar to energy levels of orbital electrons of atoms. The nuclei exist in different energy states. A transition of nuclear energy level from a higher state E_1 to a lower energy level E_2 is possible. In such a transition of nuclear energy, gamma rays may be emitted according to the relation.

$$E_1 - E_2 = h\nu$$

where h = Planck's constant

ν = frequency of emitted radiation

* Gamma rays are similar to X-rays, Except that they are emitted by the nucleus of the atom
* Gamma rays consist of discrete wavelengths much shorter than that of X-rays

Radioactivity:

The mass of a nucleus, consisting of Z protons and A-Z neutrons, is found to be less than the sum of masses of Z protons and A-Z neutrons.

This difference is called mass defect. If this mass difference is Δm then the Energy Equivalent of this mass

$$E = \Delta M c^2$$

(c = velocity of light), is said to be responsible for keeping the constituents of the nucleus bound together.

* Coulomb forces between them tend to break the nucleus. However, for the nucleus to be stable, it is essential that the nucleon binding forces overcome this repulsive force

* It is found that in Elements of atomic numbers higher than 82, repulsive forces are very high and such Elements are no longer stable.

* These element start disintegrating to form stable Elements of lower atomic number.

* This disintegration of nuclei of high atomic number, owing to repulsive Coulomb force is called "radioactivity".

During the process of disintegration, alpha (α) and beta particles and gamma rays are emitted.

Alpha Particles (α):

* Positively charged particles, with a mass of about four times that of the Hydrogen atom and carrying two units of positive charge. They Produce fluorescence, can ionize gases and are Easily absorbed by a thin sheet of Paper. They are deflected by magnetic fields.

Beta Particles (β)

* Negatively charged Particles, identified with Electrons. It is believed that they are created during the radioactive decay process. They ionize gases and are deflected by magnetic fields in a direction opposite to the direction of alpha particles. They are Easily absorbed by matter

Gamma rays (γ):

* Uncharged and not affected by magnetic fields.
* They are highly penetrating rays, emitted in discrete energy levels.

Properties of X and Gamma Rays:

* Invisible, pass through space without transference of matter
* Not affected by electric and magnetic fields
* Propagate in straight line, also exhibit wave properties and are reflected, refracted, diffracted and polarized.
* Transverse electromagnetic waves, velocity of propagation
* Capable of blackening photographic film
* Produce fluorescence and phosphorescence in some substances
* Damage or kill living cells and produce genetic mutation
* Differentially absorbed by matter
* Produce characteristic spectra of chemical elements.

Interaction of X-rays and Gamma rays with matter :

* Penetrating radiation like X-rays or gamma rays passing through a material medium interact with matter in a complex manner
* The effect of interaction is attenuation of incident radiation
* Attenuation takes place in two ways i.e absorption and scattering

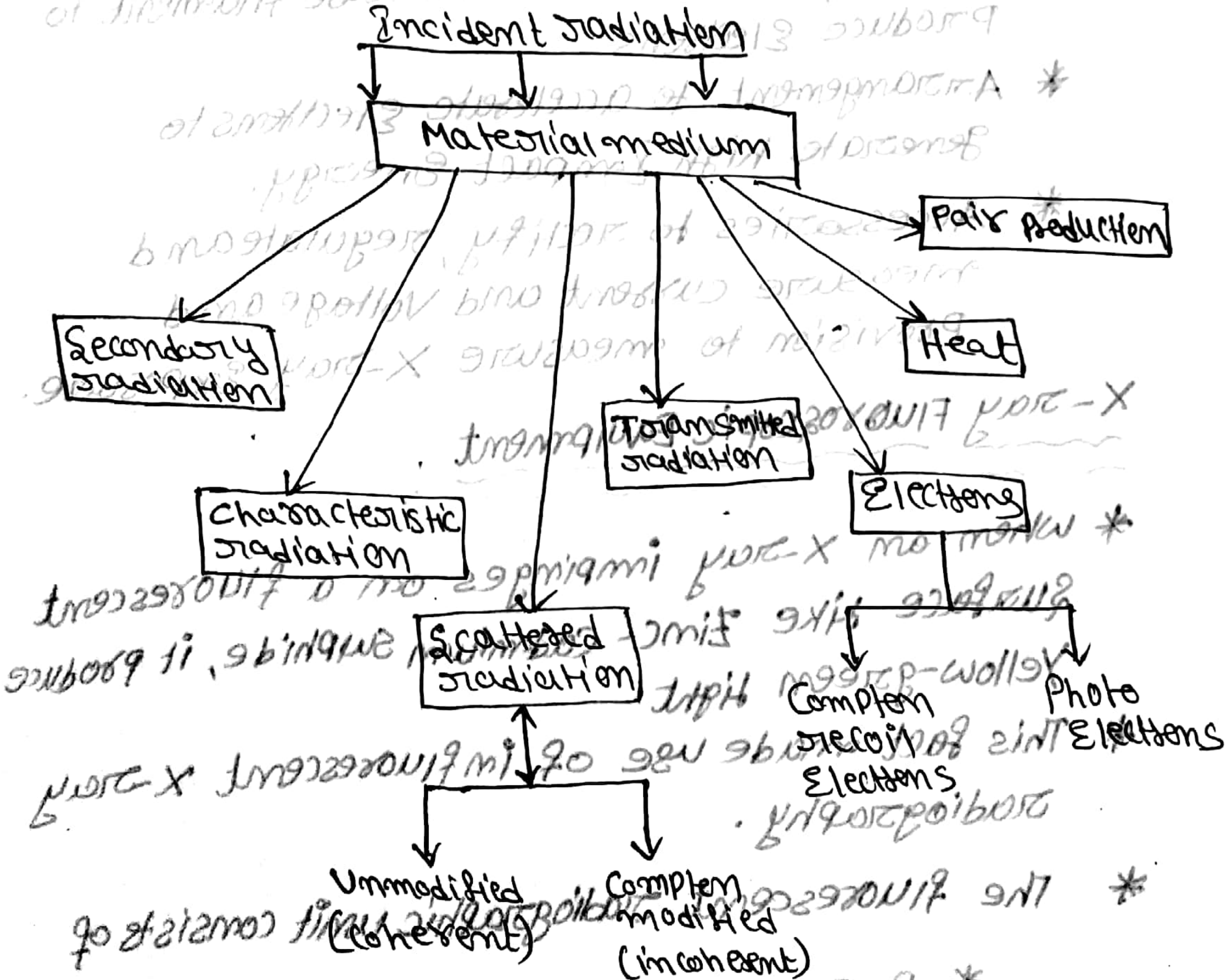


Fig: Interaction of Radiation with matter

* Major factors for attenuation of incident X-rays or gamma rays are
  - → Photo Electric Emission
  - → Compton Scattering
  - → Pair Production

X-ray Equipment

X-ray radiographic Equipment consists of
* X-ray tube
* Arrangement to heat the tube filament to produce Electrons
* Arrangement to accelerate Electrons to generate high Impact Energy.
* Accessories to rectify, regulate and measure current and voltage and Provision to measure X-ray Exposure.

X-ray Fluoroscopic Equipment

* When an X-ray impinges on a fluorescent surface like Zinc - Cadmium sulphide, it produce Yellow-green light.
* This fact made use of in fluorescent X-ray radiography.
* The fluorescent radiographic unit consists of
  * A 50-300 KV range X-ray unit
  * A radiation leak proof Enclosure
  * A suitable window fitted with a fluorescent screen for viewing the -

- radiographic Image

* A mechanism for manoeuvering the object position with respect to the X-ray beam.

* X-rays are differentially absorbed while traversing the object and the Emergent beam forms an image of varying brightness on the fluorescent screen.

* The Image is observed in a semi-dark Enclosure.

* The quality of a fluorescent radiographic Image is improved by use of image intensifiers

* An Image intensifier system has a photo cathode layer next to fluorescent screen mounted on a aluminium support and the assembly is sealed in an Evacuated glass chamber.

* The X-rays, Emerging from the object fall on the fluorescent screen and form a visible Image of the object.

* The light from the fluorescent screen falls on the Photo cathode layer and causes the Emission of Electrons.

* The number of Emitted Electrons is proportional to the intensity distribution of the X-ray Image.

* Electrons are then accelerated under a potential difference to the intensity distribution of the x-ray Image.

* Electrons are then accelerated under a potential difference of about 30kV and focused Electrostatically on a fluorescent screen.

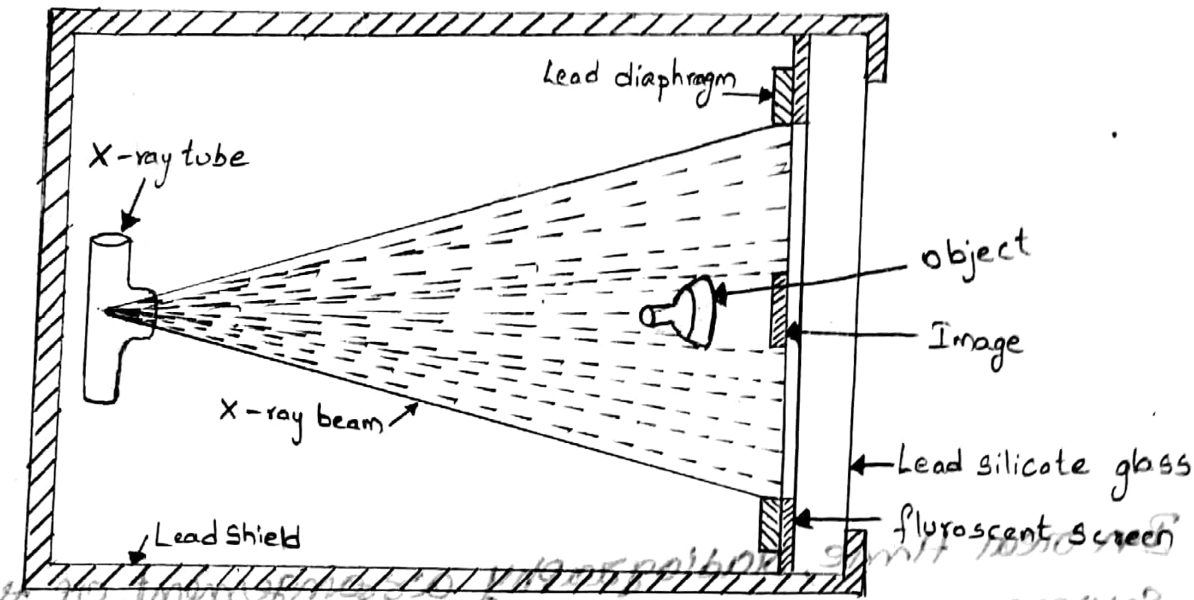
* The brightness of the this Image on this screen is increased to about 1000 times compared to a conventional fluoroscopic Image.

* The intensified Image is observed through through a lens system.

* The improved sensitivity of the radiographic image is almost comparable to film radiographic sensitivity.

* X-rays after undergoing differential absorption in the object are converted into visible light by the fluoroscopic screen, where a radiographic Image of the object is formed.

* This Image is collected by an optical lens system and focused on a TV camera tube. The information contained in the fluoroscopic Image of the object is converted into Electrical signals.



X-Ray Fluoroscopic Unit.

* The Electrical signals are suitably amplified and converted from analogue to digital Image, which is stored, enhanced and viewed on TV monitor

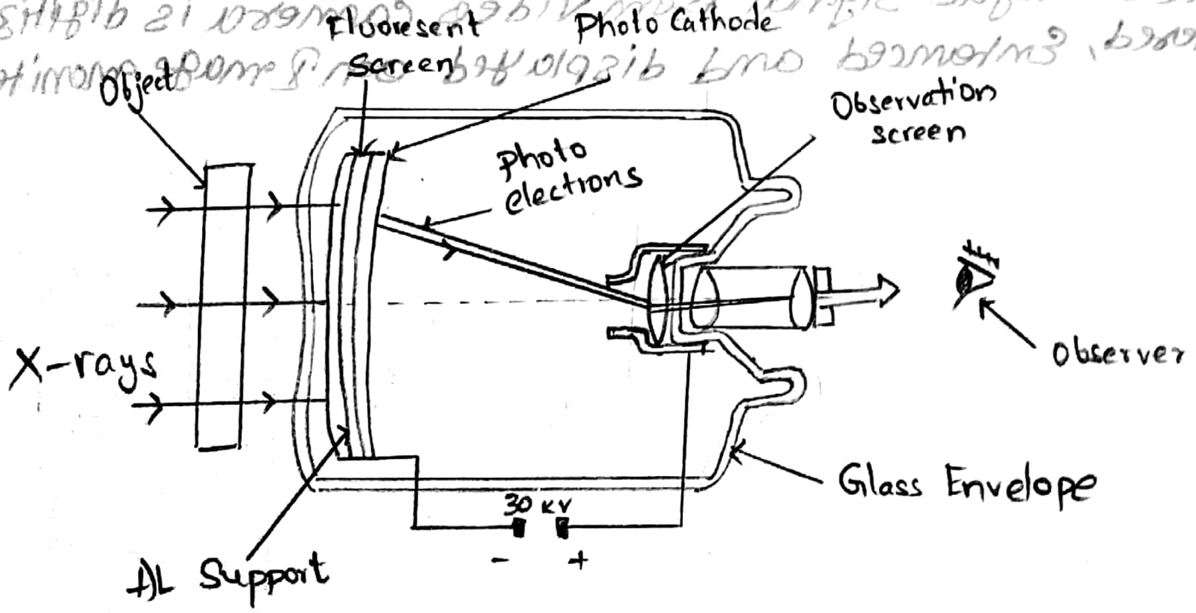
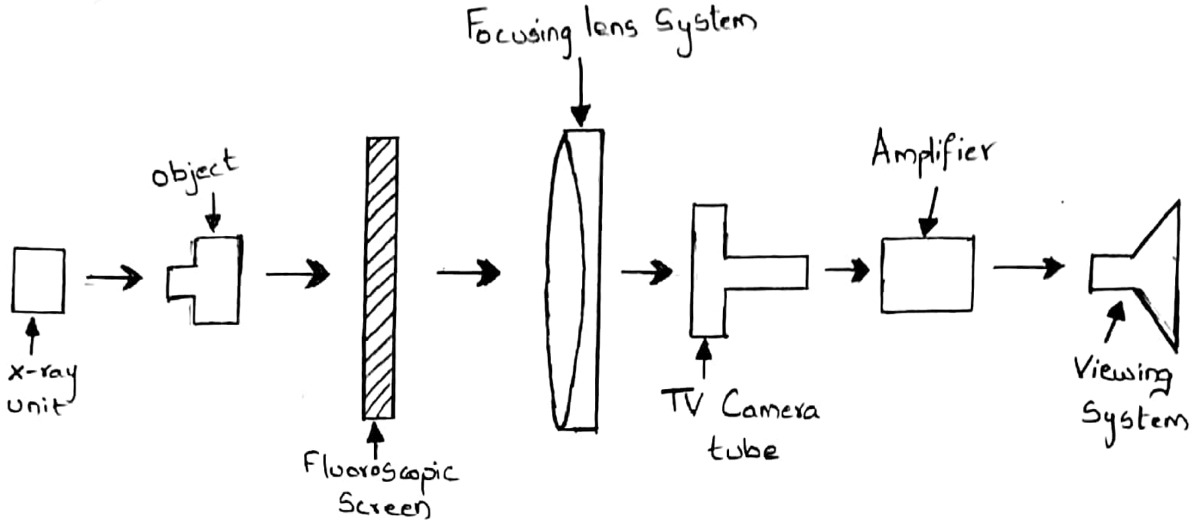


Fig. ~~2.10~~ Image Intensifier

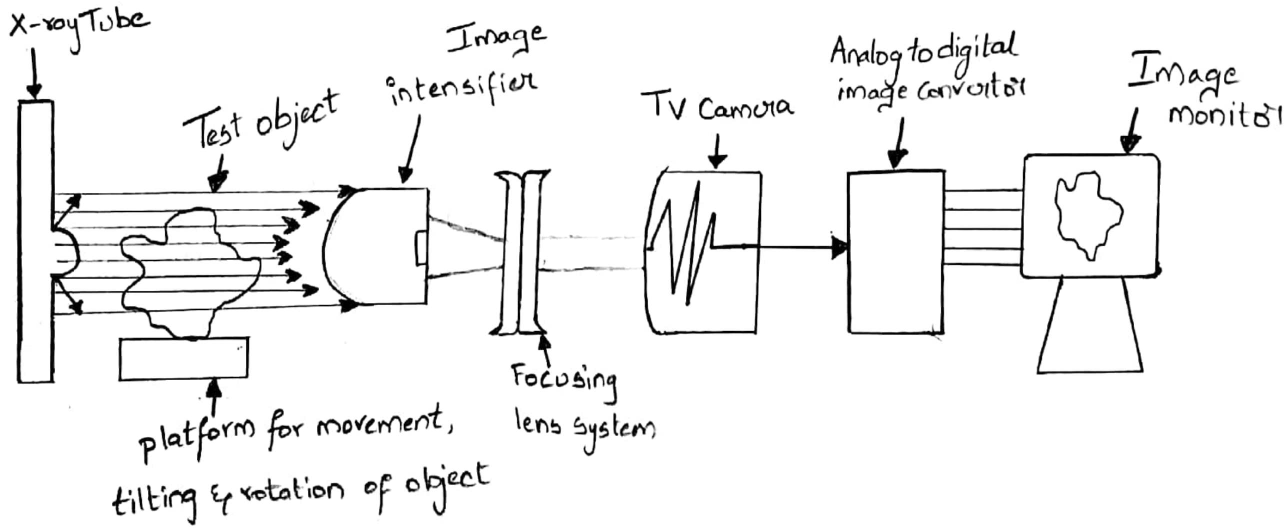


Principle of closed Circuit X-ray TV System

* In real time, radiography arrangement of the source, object and Image plane is similar to film radiography.

* Radiographic Image is converted into a digital Image through Image intensifier, optical lens system between intensifier and video camera.

* The analogue signal from video camera is digitized stored, Enhanced and displayed on Image monitor



Schematic Arrangement of Real Time Radiography

* Real time radiographic systems are widely used in Aerospace, pressure vessel, Automotive, Electronic Industries etc.

* General Radiographic procedure :

Radiography is essentially a technique of projecting a three-dimensional object on a plane, utilizing a few of the properities of x-rays, gamma rays or any other penetration radiation. The properities used are :

1. Rectilinear propagation
2. Differential propagation
3. photographic or fluroescence effects

The projected image of the object is called a "radiography" and the process of obtaining the radiographic image and evaluating its contents is called "radiography".

The essential requirements for producing a radiograph are :

1. A source of radiation
2. object to be examined
3. Recording medium and
4. processing chemicals

In this section, the radiographic process using x-rays and gamma rays as the source of radiation and films as the recording medium is discussed

Irrespective of the type of component/assembly to be radiographed, the following steps are followed during radiography:

1. surface preparation
2. selection of radiation source depending on density and thickness of the object
3. optimizing exposure parameters and usage of exposure chart
4. selection and processing of film
5. ensuring appropriate radiographic sensitivity by using Image quality indicators (IQI)
6. keeping image unsharpness to as low a value as possible.

* <u>Radiographic Techniques And Acceptance Standard</u>:-

In industries, one encounters a wide range of conditions in regard to component size, shape and composition. The objective of radiography is to examine and evaluate these components as clearly as possible. This requires the standardizing the most efficient way of projecting the object, depending on its shape, size, thickness and compositions. The major stages involved in establishing a standardized radiographic techniques are:

1. study of drawing, alloy composition, part geometry and inspection requirements
2. conducting radiographic experiments to optimize exposure parameters
3. selective destructive tests to validate radiographic

observation

4. Documentation

Initially necessary information such as areas of high stress, alloy composition, manufacturing process and inspection requirements must be collected and the geometry of the component studied.

Radiographic experiments are conducted to optimize the following parameters.

1. Energy of penetration (kV)
2. Exposure factor (mA x time)
3. Radiographic coverage, which implies projecting every portion of the component on the film. This may involve one or more normal and angular exposures of the component
4. exposure parameters needs to be adjusted in a such a way as to achieve 2-2T sensitivity better than 2%
5. selection of the type and size of film must match the requirements of the defect details and the component area coverage
6. Density range of 1.5 to 3.0 over area of interest
7. optimization of film focus distance, geometric un-sharpness, filters and screens and chemical processing of films

The limit of acceptance of defects is decided based on the functional and stress classification of the components in co-ordination with the designer

Generally, components are classified into following three catagories:-

1. class I :- These components are often subjected to high temperature, pressure, fatigue and impact stresses. The failure of such components can cause significant danger to operating pa personnel or would result in serious operational penalities or loss of the entire system. one should be extremely careful in the examination and assessment of such components.

2. class II :- These are stressed components whose failure may not have as drastic an effect as in class I case. Failure of the components may lead to the damage of subassemblies that can be replaced without causing serious damage to the system. One should be extremely careful in the examination and assessment of such components.

3. class III :- These are low stressed or unstressed components, whose failures does not cause any significant damage to the system. often, radiographic examination is not required for such components.

Safety Aspects of Industrial Radiography

* In industrial radiography, high-energy X-ray and gamma radiation is used. Since radiation can damage the body, it is essential that persons working with radiation would give rise to exposure to the human body resulting in undesirable somatic and genetic effects.

* Government of India has promulgated "Radiation protection Rules 1971" under the atomic Energy Act, 1962.

* Under these rules it is necessary that

1. All radiation workers, be monitored regularly
2. The dose received by the person be well within prescribed limits
3. Causes of excessive exposure be detected with minimum delay and suitable corrective measures taken to avoid future excessive exposure
4. The cumulative records of the individual radiation workers be maintained for the entire period during which they work with the radiation source.

* Radiation protection is the prevention of illness or injury from over-exposure to X-rays and nuclear radiation.

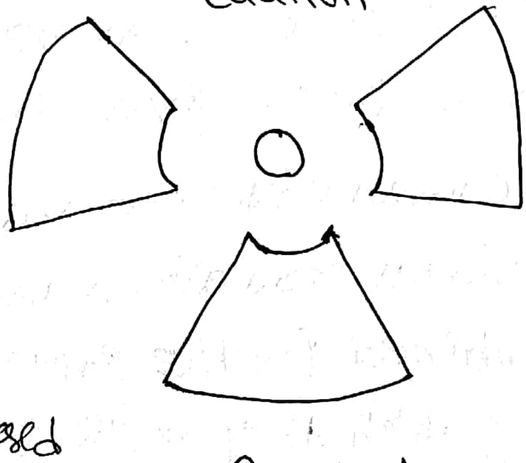
* Radiation is considered hazardous when a person is exposed to it beyond a certain limit.

* The human body is exposed to background radiation from naturally occurring radio-isotopes and from cosmic rays.

* Based on experience and studies on the effects of radiation, a maximum permissible level has been specified for occupational personnel and the general public.

* Radiation protection activity consists of
  i) Measurement and Evaluation of Exposure level
  ii) Introducing measures to minimize Exposure and Eliminate needless Exposure.

Caution



This sign is used as warning to protect people from being exposed to radiation.

Radiation area

Unit-2

Ultrasonic Test

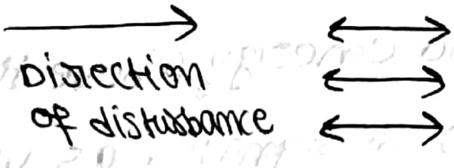
Principle of wave propagation :

Sound energy above the audible frequency of 16,000 Hz is designated as ultrasonics. It is a form of mechanical Energy and propagates through the material medium as a stress wave by direct and intimate mass contacts. The propagation of these waves through the material medium is sustained and controlled by the Elastic properties of the medium. Also, in-homogeneities and discontinuities in the medium significantly modify and modulate the propagation of these waves.

Thus ultrasonics is a study of a form of mechanical Energy, its propagation and its interaction with the medium through which it propagates. It is a common Experience that whenever a medium is disturbed by a force, the particles of the medium are set into oscillation. The oscillation of the particles is Either longitudinal or transverse or a combination of both.

on the basis of particle displacement of the medium, ultrasonic waves are classified as

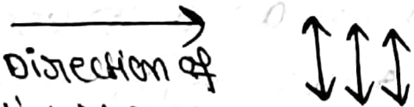
* Longitudinal waves particle



Direction of disturbance

Direction of particle motion

* Transverse waves particle



Direction of disturbance

Direction of particle motion

* Compressional and flexural waves (Rayleigh waves and lamb waves)

Direction of disturbance

Direction of particle motion

* Rayleigh waves (also called surface waves):

→ During propagation of these waves, particle oscillation follows elliptical orbits as shown in fig.

→ The major axis of the ellipse is perpendicular to the surface along which the waves moves

→ The minor axis is parallel to the direction of wave motion

→ These waves travel along flat or curved surfaces of thick solids

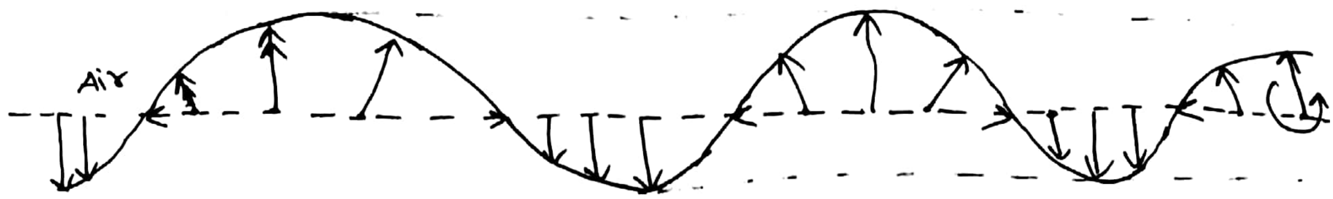


Fig: Rayleigh waves (Surface waves)

* These waves are used to detect flaws or cracks on or near the surface of the test objects.

Lamb waves (flexural waves or plate waves):

* These waves are complex in nature; Elastic properties, structure, dimensions of the medium and cyclic frequency determine their propagation through medium.
* These waves are produced in thin metals whose thickness is comparable to the wavelength.
* These waves travel both symmetrically and asymmetrically with respect to the neutral axis of the material medium
* symmetrical Lamb waves have compressional particle displacement along the neutral axis and Elliptical particle displacement along the surface.

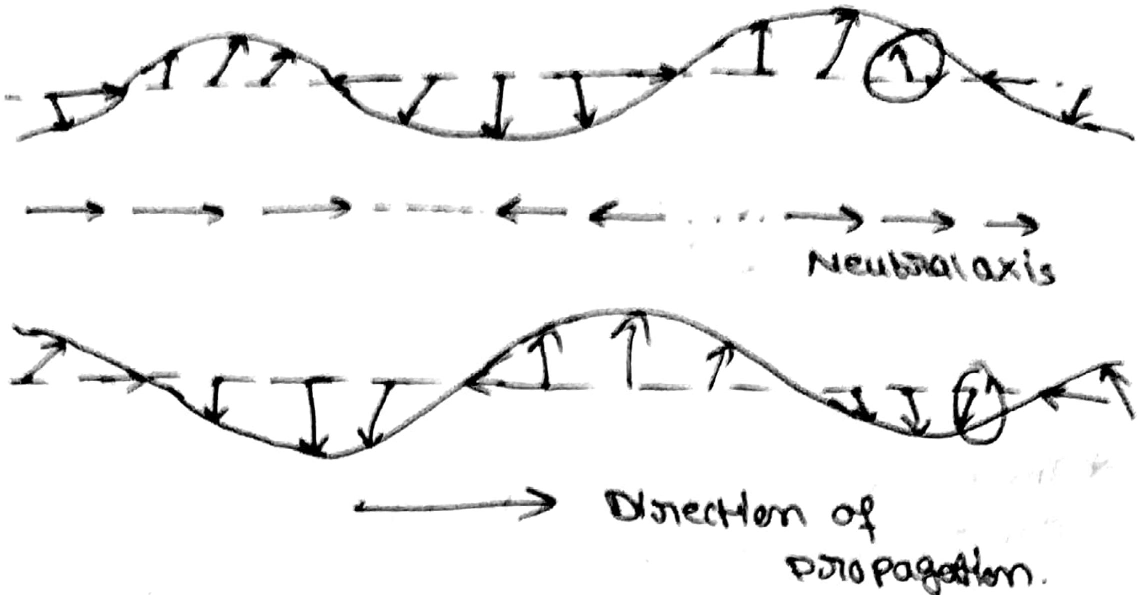


Fig: symmetric Lamb waves

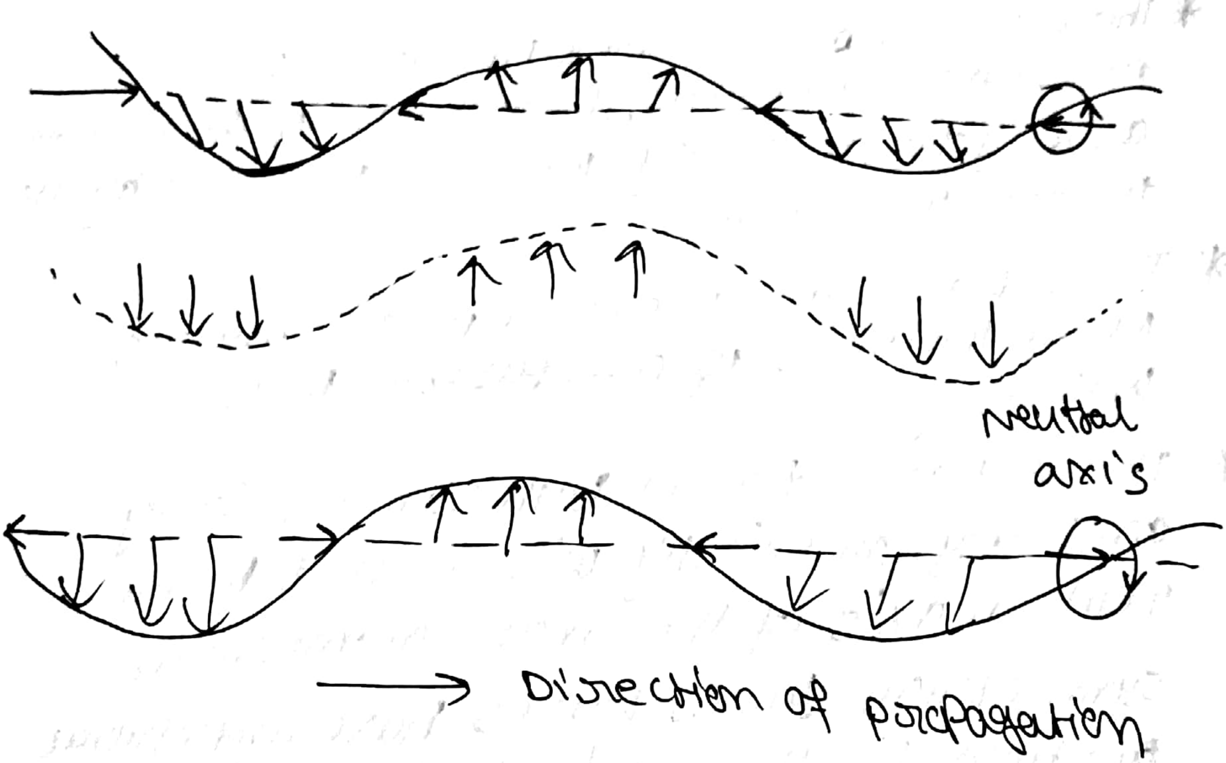


Fig: Asymmetric waves

Reflection

* The snail's law of reflection, as applicable to light rays, is applicable to acoustics, provided that the dimensions of the reflecting medium are large compared with the wavelength
* The law may be stated as
  a) The incident ray, the reflected ray and the normal, at the point of incidence lie in one plane
  b) The angle of incidence is equal to the angle of reflection

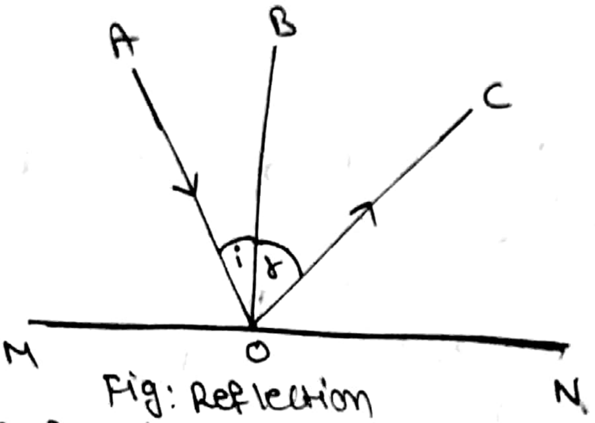


Fig: Reflection

MN = Reflecting surface
AO = Incident beam
OC = Reflected beam
OB = Normal at the point of incidence

$\angle AOB = i$ = Angle of incidence
$\angle BOC = r$ = Angle of reflection

Refraction :

* Sound waves incident obliquely on the boundary separating two media, where the velocities of propagation are different, undergo an abrupt change in direction
* This phenomenon is known as refraction
* The laws governing the phenomenon of sound refraction are similar to those applicable to light waves.
* The laws may be stated as:

a) The incident ray, the normal to the refracting surface at the point of incidence and the refracted ray lie in one plane.

b) The sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction which is equivalent to the ratio of the sound velocities in the media concerned.

MN = Refraction ~~beam~~ surface

AO = Incident beam

OC = Refracted beam

$\sin i / \sin r$ = constant

$= C_1/C_2$

BOB' = Normal at the point of incidence

∠AOB = Angle of incidence i

∠B'OC = Angle of refraction r

c_1 = velocity of sound in medium I

c_2 = velocity of sound in medium II

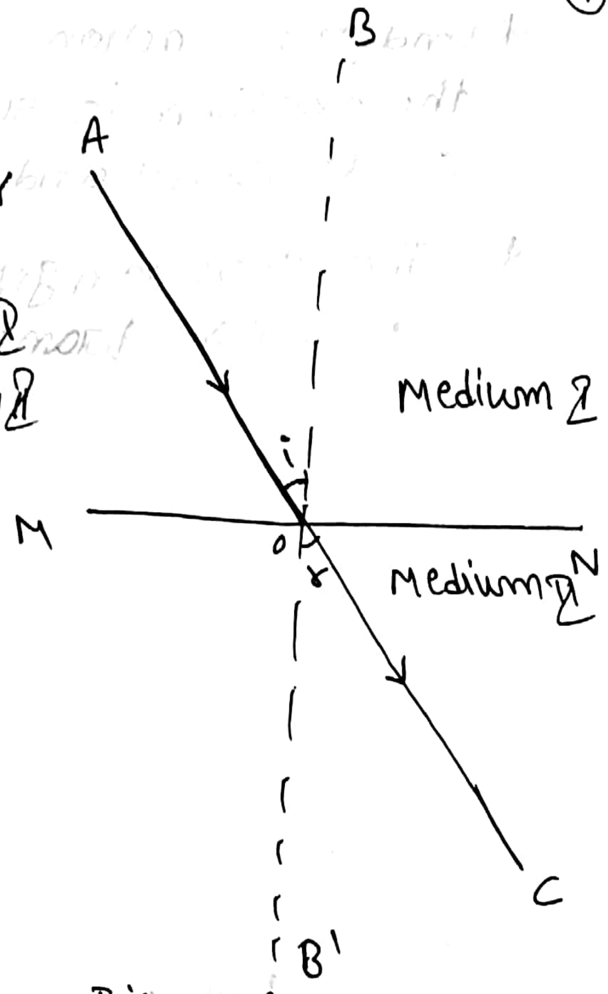


Fig: Refraction

Mode Conversion :

* When a sound waves strike an interface at angle between two materials having different acoustic impedances, some of its energy converted into modes of vibration other than incident mode.

* If we consider a force 'F' acting on the interface at an angle, the force may be resloved into mutually perpendicular directions F sin α along the boundary and F cos α at right angles to it.

* Under the action of these two components, the medium is subjected to both compressional and shear forces.

* The situation gives rise to longitudinal as well as transverse modes of vibration

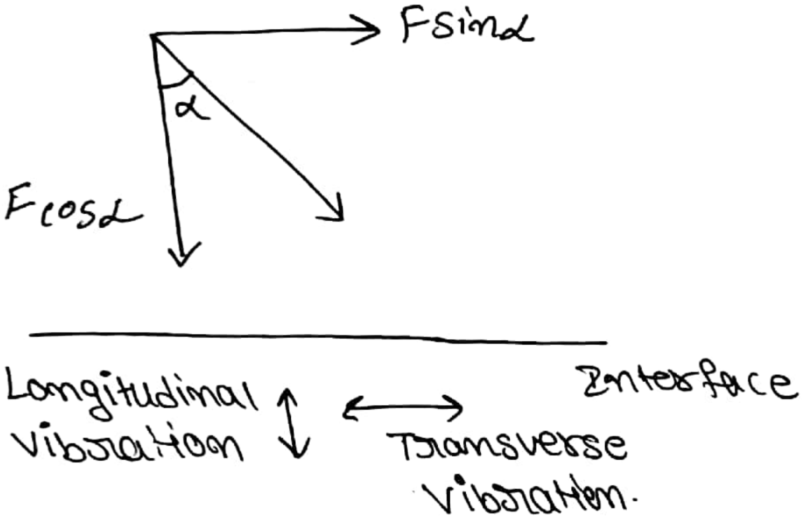


Fig: Mode conversion at oblique Incidence

* At normal incidence, F will have no component along the boundary hence a shear mode of vibration is not produced.

* Thus for any angle of incidence other than normal, Every longitudinal wave has a reflected and refracted component.

* Both reflected and refracted components contain longitudinal and transverse waves.

i = Angle of incidence

γ_1 = Angle of reflection for longitudinal wave

γ_2 = Angle of reflection for transverse wave

γ_3 = Angle of refraction for transverse wave

γ_4 = Angle of refraction for longitudinal wave.

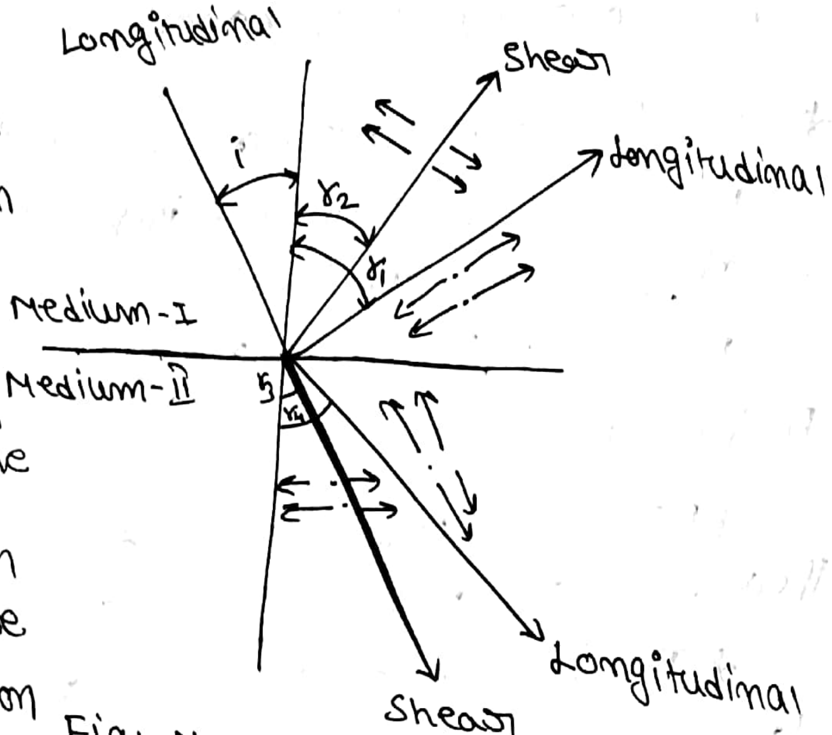


Fig: Mode conversion at oblique Incidence

* As the angle of incidence increases, the angle of refraction for a longitudinal wave reaches 90°.
* The angle of incidence corresponding to a 90° angle of refraction is called first critical angle
* For Further Increase in the angle of incidence the longitudinal wave is totally reflected in medium I and no longitudinal wave exists in medium II only the refracted shear wave exists
* If the angle of incidence is increased further the angle of incidence for which the angle of refraction for transverse waves is 90° is called the second critical angle for a transverse wave (or shear wave)

* Further increase in the angle of incidence results in total reflection for both longitudinal and transverse wave modes

* The transformation and distribution of incident sound energy into various modes of vibration at the interface, for oblique incidence, is called mode conversion.

Diffraction.

* Whenever sound waves encounter an obstacle, their direction of propagation changes.

* This change of direction or departure from the original direction of propagation is called diffraction.

* It takes place when the wavelength of sound is comparable to the dimensions of the obstacle.

Attenuation:

* As the ultrasonic beam impinges on a surface and propagates through the medium, the energy of the beam gets divided into reflected, refracted, mode converted, diffracted and scattered beams.

* Part of this energy gets absorbed.

* The loss of ultrasonic energy due to scattering and absorption is referred to as "Attenuation".

* Scattering includes losses due to such factors as reflection, refraction and diffraction.

* While absorption includes loss due to conversion of sound energy into kinetic energy of particles of the medium, attenuation increases with the increasing frequency of the ultrasonic wave.

Sound Field:

* The space around a source of sound over which its effect is felt is called sound field
* The effect is assessed by the parameters that characterize sound.
* The characteristic parameters associated with sound at any point in its field are the variation of density of the material through which it travels, the velocity or displacement of the particle of the medium or the pressure variation that accompanies the propagation of sound.

Piezo-Electric EFFECT:

* The word 'piezo' means pressure and piezo-electric effect implies pressure electricity.

* Certain naturally occurring crystals like quartz and tourmaline show piezo-electric property. The crystals, when subjected to mechanical vibration produce electrical pulses

in perpendicular direction.

* Also when the crystals are subjected to high frequency electrical pulses, dimensional distortion is observed in a perpendicular direction.

* Continuous impingement of electrical pulses results in mechanical vibration of the crystal.

* This shows that piezo-electric effect is a reversible phenomenon.

* If a sound wave with its alternating expansion and compression, impinges on the piezo-electric plate, the latter produces an alternating voltage with the frequency of the wave.

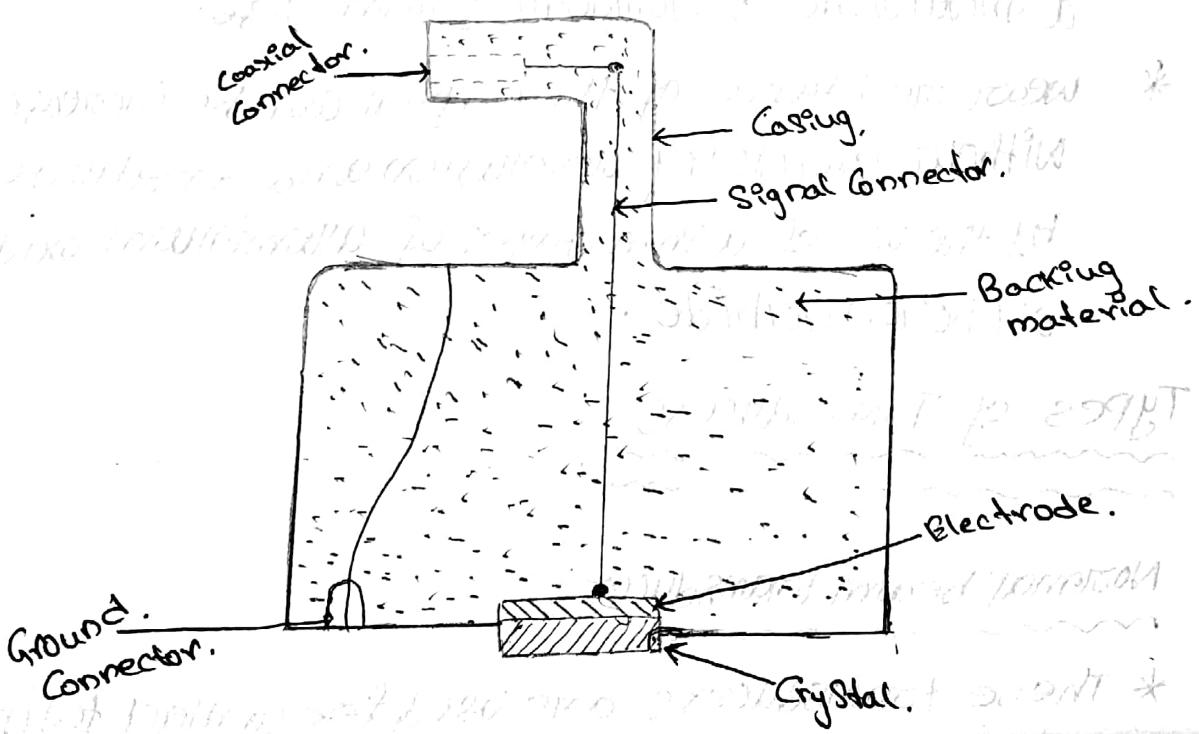
* The generated voltage is proportional to the amplitude of sound pressure. Thus, a direct piezo-electric effect is used to receive ultrasound, while the reciprocal effect is used for generating ultrasound.

* Some piezo-electric materials like quartz tourmaline and rochell salt occur in nature

* But most of the commercially used piezo-electric materials are synthetic compounds such as ammonium dihydrogen phosphate, lithium sulfate, lead niobate etc

Ultrasonic Transducers and their characteristics

* Ultrasonic transducers (or probes or searchunits) are devices to generate and recieve ultrasound.
* For non-destructive test purposes, piezo-electric elements of suitable dimensions are used to generate the complete range of ultrasonic frequencies at all levels of intensities.
* The transducers convert electrical signal into mechanical energy (vibration) and vice-versa
* A transducer essentially consists of a case, a piezo-electric, backing material, electrodes, connectors and protection for the piezo-electric element from the mechanical damage.



ELEMENTS OF A TRANSDUCER ASSEMBLY

* A casing is the housing within which various Elements are contained. It is metallic or molded plastic.

* When the piezo-electric element is subjected to electrical impulses, it vibrates (or) rings for a long time.

* For non-destructive testing, a long period of vibration is undesirable as it adversely affects defect resolution capability.

* To prevent excessive ringing, highly attenuating materials (called backing materials) are bonded to the back face of the piezo electric element.

* Backing materials consist of a mixture of graphite, powdered metals (e.g. tungsten) and a metal oxide of random grain size.

* Wear resistance of the crystal can be increased without sacrificing resolution and sensitivity by the use of a thin layer of aluminium oxide or boron carbide.

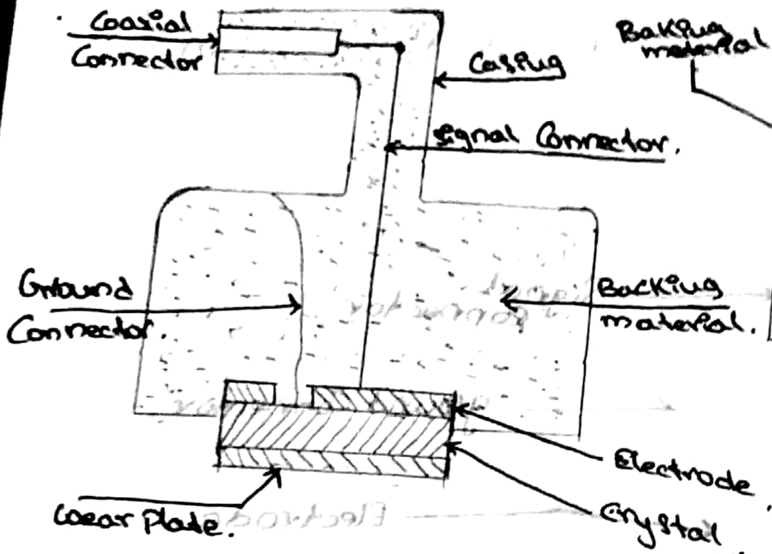
Types of Transducers :

Normal beam transducers :

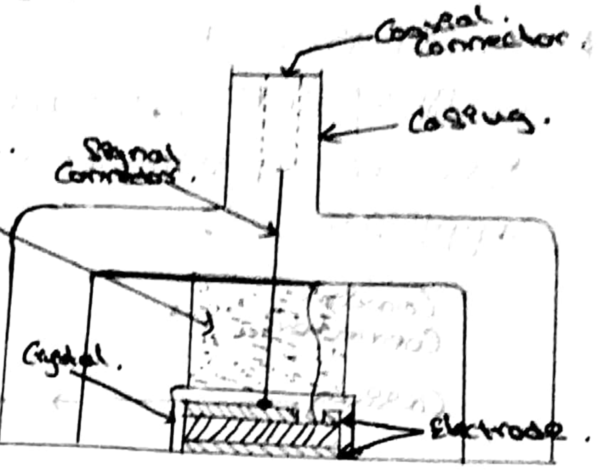
* These transducers are used for contact testing and immersion testing.

* Transducers generate, transmit and receive longitudinal waves, normal to the test surface.

* In the Immersion type of testing, the piezo electric element is made completely waterproof and a grounding electrode is provided in the front face.



NORMAL BEAM WITH WEAR PLATE.



IMMERSION SEARCH UNIT.

Angle Beam Transducers :

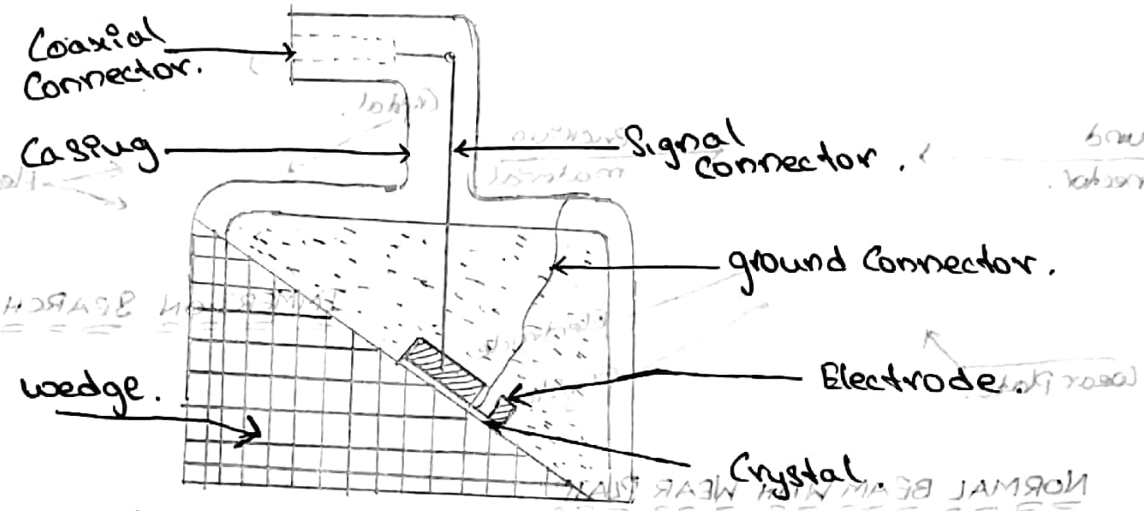
* These are contact type transducers that transmit and receive longitudinal waves at an angle to the test material surface.

* During the transmission of the wave, the longitudinal wave is mode converted to a shear or surface wave on ~~th~~ entering the material.

* During reception, the shear or surface wave is mode converted back to the longitudinal wave

* The transducer is similar to normal beam probe, except that a wedge cut an appropriate angle is attached to the normal beam transducer.

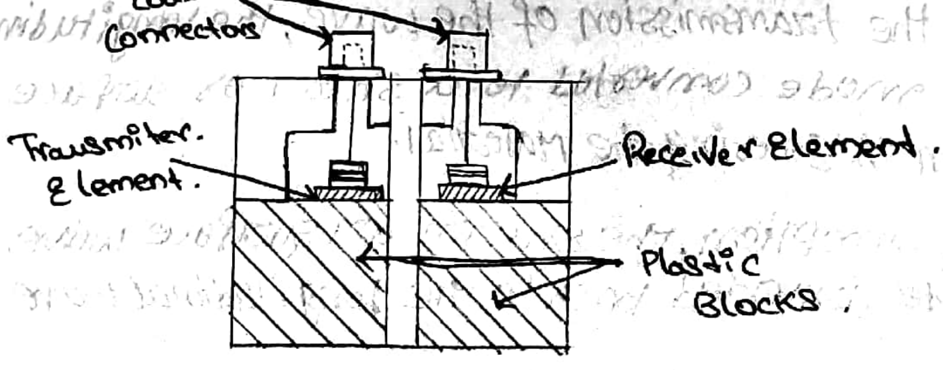
* Apart from those mentioned various types of transducers, in different size and frequencies have been developed for specific inspection applications.



ANGLE . BEAM CONTACT SEARCH UNIT.

Dual Element Transducers

* In this type, the transmitter and receiver elements are separated with a cork-divider



DUAL ELEMENT TRANSDUCER.

Characteristics of Transducers

A transducer is characterized by its

* Electro-mechanical coefficient, which is the ratio of electrical energy appearing as mechanical energy to the applied electrical energy
* To achieve maximum conversion of energy the crystal is operated at its resonance frequency
* Sensitivity which refers to the relationship between the amplitude of electrical voltage impinging on the crystal and the magnitude of the ultrasonic signal produced
* Therefore it determines the smallest defect size that can be detected.
* Resolution, which refers to the ability to separate signals from two discontinuities located at only slightly different depths
* A long pulse has poor resolving power
* Short pulses are desirable for high resolutions
* Quality factor.

Ultrasonic equipment and variables Affecting Ultrasonic Test

* The essential features of an ultrasonic pulse-Echo flaw detector are

Pulse generator :

* This component of the pulse-Echo system acts in two ways - it energizes the piezo-electric-crystal in short pulses at regular intervals and causes i to vibrate; it triggers the time base circuit and causes a bright spot to move across the CRT screen.

* The short pulses are of micro-second duration and usually range from 50-1000 pulses per second.

* This is also called pulse rate frequency (PRF).

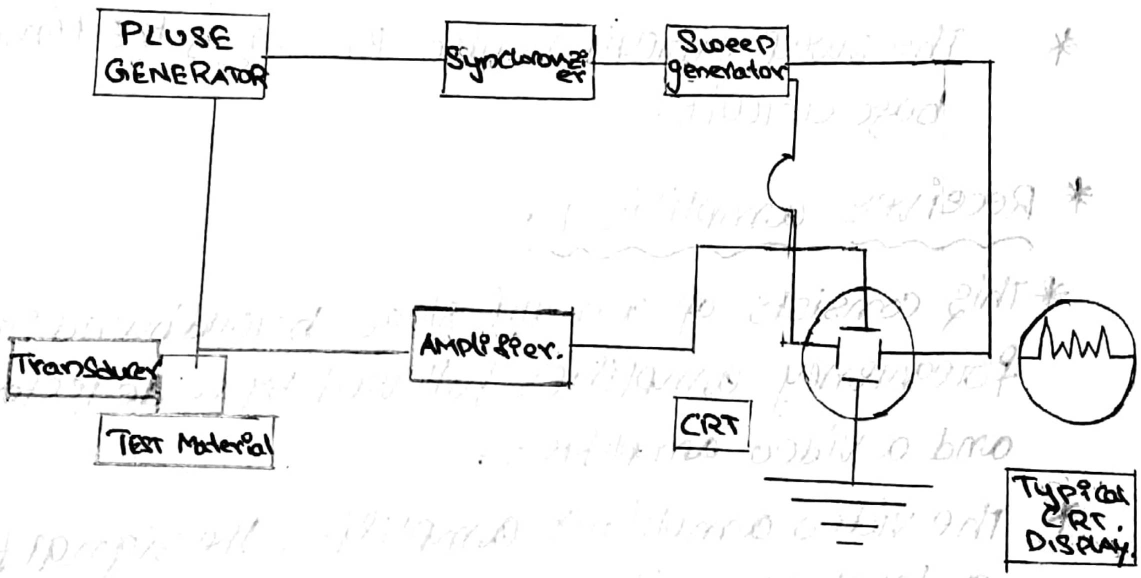
* The impingement of short pulses ensures the vibration of the crystal during the period.

Transmitter-receiver unit :

* The transmitter unit generates a voltage pulse, which is applied to the crystal transducer.

* The crystal under the Excitation of voltage pulses, Executes damped vibrations.

* which contain natural vibration frequencies of the crystal transducer (of the order KHz and MHz). This frequency is different from PRF which is the frequency at which voltage pulses impinge on the crystal to cause damped vibration of the crystal.



BLOCK DIAGRAM OF A PULSE - ECHO System

Synchronizer :

* In a basic ~~principle~~ Pulse-Echo system, the time taken by sonic waves to travel a specified material thickness is compared to the time taken by the pulse to travel a known distance between the x-plates of the CRT.

* This is possible only when the pulse leaving probe and the pulse that excites the x-plates are synchronized. This function is achieved by the synchronizer, a clocking mechanism.

* **Sweep Generator**:

* The output of the synchronizer is applied to the rectifier circuit so that only positive half cycle is conducted and the negative half is supressed
* The output voltage is applied to the x-deflection plates of the CRT so that the bright spot moves left to right
* The sweep circuit is also known as the time base circuit.

* **Receiver amplifier**:

* This consists of a multi-stage broadband radio frequency amplifier followed by a detector and a video amplifier.
* The video amplifier amplifies the signal to a level where it can be fed to the Y-plates and displayed on the CRT screen.

Variables Affecting Ultrasonic Test:

* A range of factors influence the ultrasonic testing of materials. Broadly speaking, these are classified into two categories:

1. Operator-Controlled parameters: Such as the Equipment and probe selection, the test technique adopted, the couplant used, the speed and the method of scanning and Equipment characteristics like linearity of time base pulse length and frequency used.

2. parameters beyond the control of operator: such as material properties, surface roughness and curvature, geometry, velocity and attenuation of sound in the material, acoustic impedance defect characteristics like the size, shape, orientation, depth and acoustic properties of the defect.

Ultrasonic Testing

Basic Methods and General Considerations

* Ultrasonic testing depends on the nature of product, its manufacturing process, the surface condition geometry and accessibility of the scanning area.

There are three basic test methods commonly used in industries

Pulse-Echo test method:

* here short pulses of ultrasonic waves are transmitted in the material under test.

* These pulses are reflected from discontinuities in their path or from any boundary of the material.

* The reflected waves (or) echoes are recieved by the transducer and are displayed on the CRT which provides the following

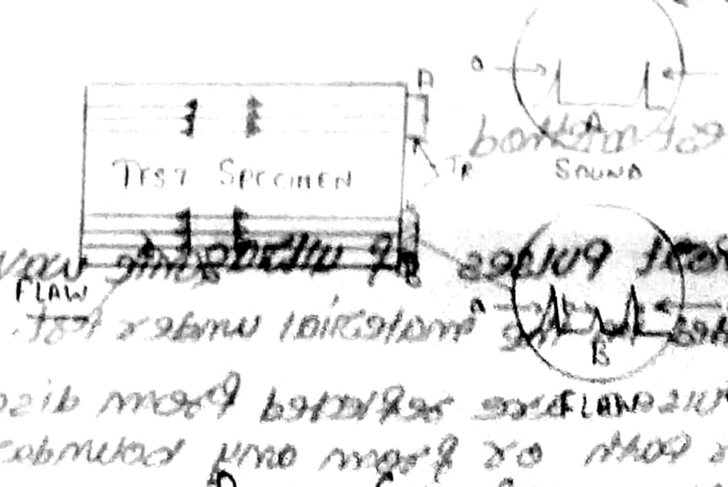
→ The relative size of the discontinuity in terms of the amplitude of the signal displayed on the CRT

→ The depth of the discontinuity on the CRT time base scale, which is appropriately calibrated in terms of known material thickness

* In this method a single transducer is used both as transmitter and receiver of the waves

* Sometimes two transducers are used, one as transmitter and the other as receiver.

* The main advantage of this method is that only one surface of the object is required for testing and the method is capable of providing size as well as depth location of the discontinuity.



PULSE ECHO SYSTEM

Through transmission method:

* Two transducers are used here, one as transmitter, the other as receiver
* Short pulses of waves are transmitted into the material.
* The test method requires access to two nearly parallel surfaces of the object
* The receiver transducer is aligned properly with the transmitter transducer on the opposite side of the test object to pick up the ultrasonic waves passing through the material.
* The soundness or quality of the test material is evaluated in terms of energy lost as the ultrasound travels through the material
* The presence of a discontinuity is indicated by variations in the energy amplitude
* A significant reduction in energy amplitude indicates a discontinuity.
* The main disadvantage of this method is its inability to locate the defect.

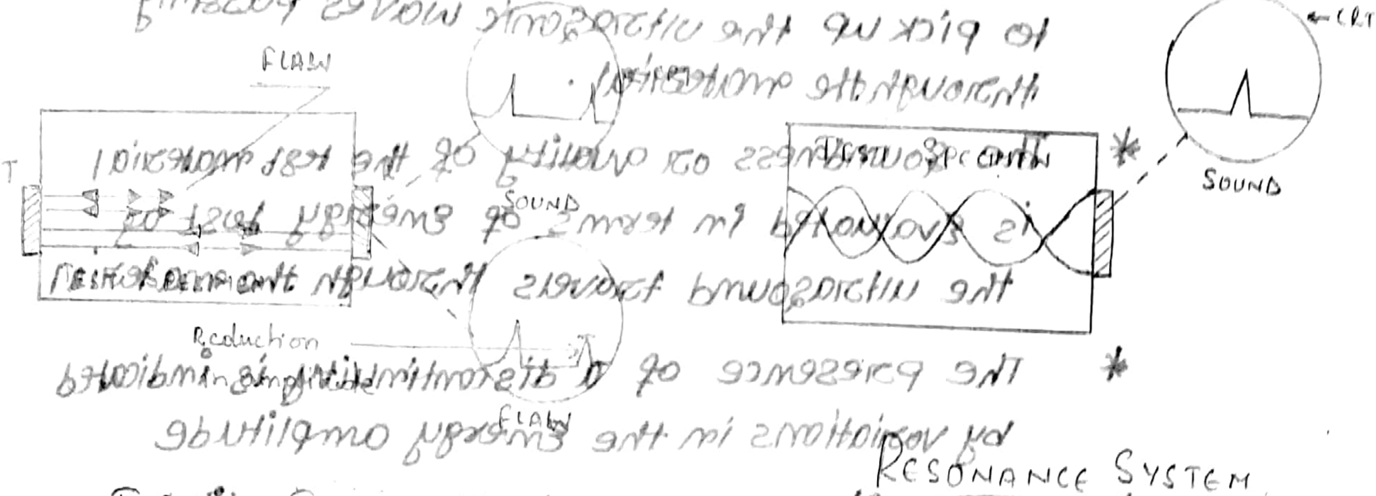
3. Resonance system:

* This system makes the use of the resonance phenomenon to measure material thickness and to determine the bond quality of a test object.
* Continuous longitudinal waves are transmitted into the material and the wave frequency is varied until standing waves are setup within the specimen, causing the specimen

to vibrate at greater amplitude

* At resonance, the specimen thickness is equal to one half or multiples of a wavelength.

* A disadvantage of this system is that the accuracy of the test reduces as the material thickness increases.



Guidelines for Acceptance/Rejection

* After assessing the size of a defect, a final verdict as to acceptance or rejection is required.

* Guidelines for the acceptance of critical stressed engineering components are

a) For forgings and other primarily members that are finished or semi-finished a single echo-amplitude more than or equal to the one obtained from a 2 mm (5/64") diameter flat bottom hole is not acceptable.

b) For any defect giving an amplitude indication greater than a 1.2mm (3/64") diameter flat bottom hole is accepted and the estimated defect is recorded.

c) A stringer type of discontinuity giving a continuous indication with an amplitude greater than that given by a 1.2mm diameter flat bottom hole over a length exceeding 12.5mm is unacceptable.

d) Multiple discontinuities giving indications greater than that given by a 1.2mm diameter flat bottom hole are considered acceptable provided the minimum separation between them is 25mm.

c) Over and above clauses (a) - (d), if a defect indication is found to break into a surface of hole on the finished part, the defect is unacceptable.

Effectiveness and Limitations of Ultrasonic Testing:

* The success of an ultrasonic test is influenced by the test location, the assembly condition, the working Environment, the technicians skills and their understanding of the geometry of wave propagation, the equipment used and the technique of test employed.

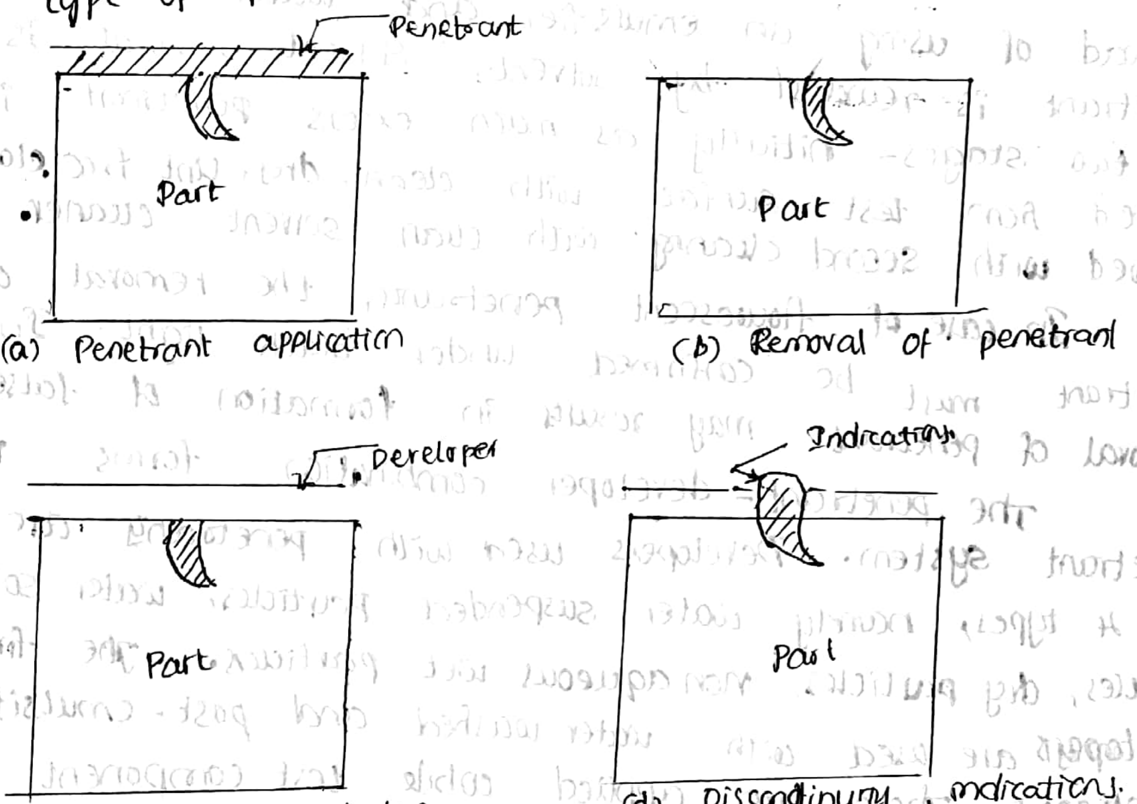
Product / Process	Effective Detection	Limit of Detection (Approximate Linear Size)	
		Condition	limit of detection (mm)
Billets forgings, extrusions, plates, sheets bars, rods.	cracks, bursts, lamination, inclusion, voids, debond, Porosity.	Laboratory	1.0
		Production	2.0
Fibre-re-inforced Polymer Composites,	Porosity, cracks, delamination fibre damage, resin rich, resin starved, impact damage, insufficient curing thickness Variation	Production	2-3.
Assembly	Stress Corrosion, cracks, Corrosion, pits, fatigue cracks, delamination, impact damage, lightning strike damage.	Service	2-3.

APPLICATIONS OF ULTROSONIC TESTING

LIQUID PENETRANT TESTING & EDDY CURRENT TESTING

Liquid Penetrant Testing Principle:-

The liquid penetrant method is used to detect discontinuities open to surface in solids and essentially non porous materials. This method employs a penetrating liquid, applied over cleaned surface of component, which enters discontinuities under capillary action. After adequate time (also called dwell time), excess penetrant removed from surface either by solvent or by water, depending upon type of penetrant used.



(a) Penetrant application (b) Removal of penetrant

(c) Developer application (d) Discontinuity indications.

The washed surface is dried and thin layer of developer (either fluffy talc powder or talc powder suspended in voltatile liquid) is applied uniformly over the surface. The developer acts as blotter and draws out any excessive in discontinuity.

An indication is produced over the background of developer layer, when discontinuities is open to surface.

The indications are examined either in daylight, adequate artificial illumination or under black light (λ=3650A°) depending upon application of coloured (or) fluoroscent penetrant.

Liquid Penetrant system:

Liquid Penetrant systems are of two types, visible liquid penetrant and flourescent penetrant. Each of these systems is further classified as water soluable, post emulsified and solvent removable.

Water washed penetrants are self emulsifying, removed simply by washing with water. Post emulsifiable penetrants requires two-step removal. First, the excessive penetrant is treated with an emulsifier for stipulated period of time and then water washed.

Solvent removable penetrants are of post-emulsifiable type. Instead of using an emulsifier and water wash, excess penetrant is removed by solvent. Solvent removal is done in two stages- initially as much excess penetrant is possible wiped from test surface with clean, dry, lint-free cloth is followed with second cleaning with clean solvent cleaner.

In case of flourescent penetrants, the removal of excess penetrant must be confirmed under black light. Incomplete removal of penetrant may results in formation of false indication.

The penetrant - developer combination forms the liquid penetrant system. Developers used with penetrants are classified into 4 types, namely water suspended particles, water soluable particles, dry particles, non aqueous wet particles. The first 2 developers are used with water washed and post-emulsified penetrants. These are applied while test component is still wet from water wash. Dry and non-aqueous developers are used when component is thoroughly dried after water rinsing. Dry developer is applied on rough surfaces and also on sharp fillets, holes and threaded components, where wet developers tend to accumulate powder lumps.

Non aqueous wet developer is most sensitive of all developers. It is applied to dry test surface. Here, the powder particles are held in suspension in rapid dry solvent like methylated spirit. This type of developer is used for spot checks or 'insitu' test in field.

Test procedure

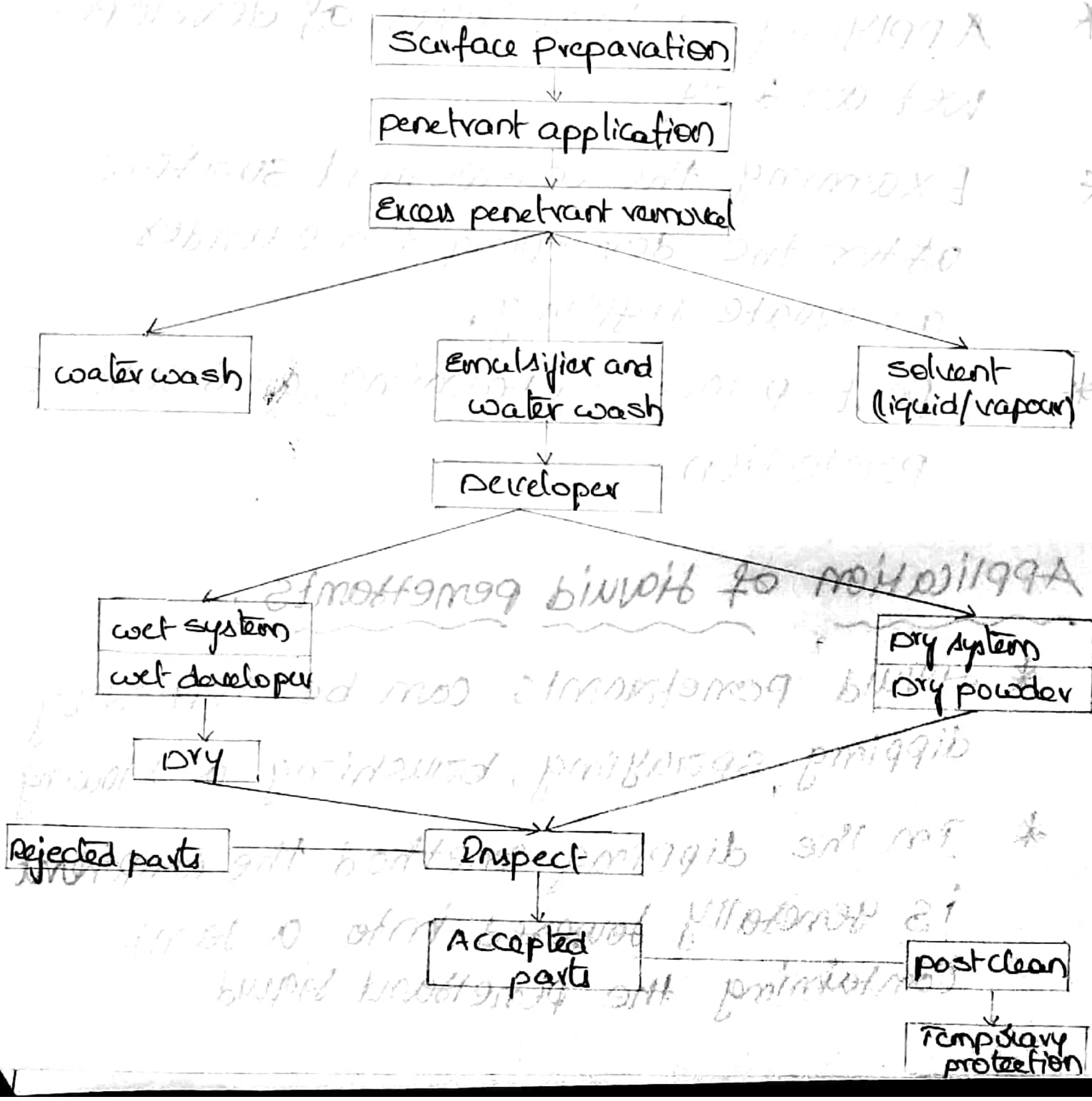
The liquid penetrant test process essentially consists of the following steps.

* Pre-cleaning the component surface
* Applying penetrant liquid by dipping spraying or brushing to form a film over the part surface and allowing it sufficient time to enter the open defect
* Removing excess pentrant with a water wash, solvent or emulsifier and drying.
* Applying a thin layer of developer wet or dry
* Examing the component surface after the developing time under adequate lighting.
* Post-process cleaning and surface protection.

Application of liquid penetrants

* Liquid penetrants can be applied by dipping, spraying, brushing or flowing
* In the dipping method the component is generally lowered into a tank containing the penetrant liquid

* It is then raised and allowed to drain
* The spraying method involves the use of conventional spray guns or pressurized spray cans.
* Brushing is done with brushes or swabs. Flowing requires pouring the penetrant over the test specimen and allowing it to drain.
* Regardless of which method is used the area to be tested must be adequately covered by the penetrant liquid.

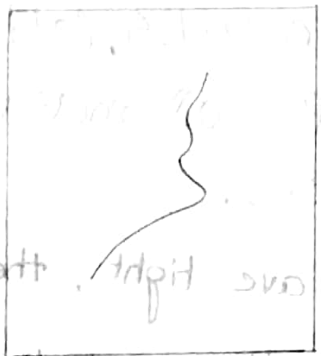


Examination, Interpretation and Evaluation :

* Penetrant Indications are Examined under natural daylight or under artifical illumination of at least 500Lux, where visible colored penetrants are used.
* In case of fluorescent penetrants, Examination is carried out in a dark Enclosure under black light (ultraviolet light) of minimum 10 Lux intensity.
* A minimum of 5 minutes is allowed for the black light to warm up and for the Examiner's eye to eye to get adapted to the dark.
* The identification of indications requires practice. For Example, cracks, cold shunt seams and forging laps, all show up as continuous line Indications.
* If these discontinuities are tight, they appear as an intermittent or broken line. Small dots and rounded indications generally indicate porosity or blowholes
* The size of the indications and the intensity and degree of bleeding can sometimes give a rough estimate of the depth of the discontinuity; fine cracks shows a faint indication.

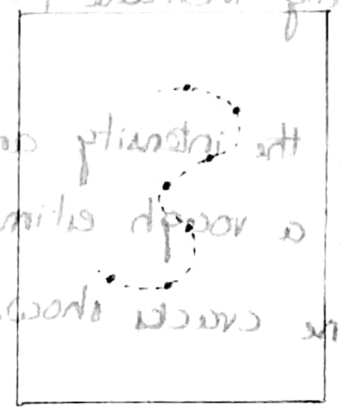
* some of the penetrant indications are shown and indications of some defects

Name of defect	Visible penetrant	Fluorescent penetrant
cracks	Thin red lines - depth indicated by the degree of spread	Thin, greenish - yellow lines
very tight crack	series of very small red dots in continuous formation	series of very small, greenish - yellow dots
porosity	series of red spots spread over the surface	series of greenish - yellow spot
shrinkage/ micro- shrinkage	pale red blotches	pale greenish - yellow blotches



a). coarse crack

b). porosity



c). tight crack

d). shrinkage

Safety precautions :-

The following safety precautions are essential while performing a liquid penetrate test :

* Adequate ventilation must be made available while handling cleaners, penetrants, emulsifiers & developers
* Gloves must be worn during the test. Remains of fluorescent penetrants on skin, clothes and gloves must be checked in black light after the test and washed properly
* The manufacturer instruction's must be followed while using a black light source. sodium glass spectacles are worn while examining the components
* pressurized spray can should be stored in a cool, dry area. protected from direct sunlight. Open flames should be avoided. Any temperature above 50°C may cause the pressurized to burst
* The draining of chemicals in the ~~drainage~~ drainage system, surface water & dumps should be approved by health authorities.

Effectiveness and limitation of liquid penetrante testing :-

The liquid penetrant test is used extensively for locating and evaluating discontinuities open to the surface in all non-porous materials during the production, processing and maintenance of engineering components and assemblies.
A variety of industries like nuclear, aerospace, shipping, railway, chemical, petroleum, food, paper Etc use the liquid penetrant test for economy, safety and easy of interpretation.

However, the success of the test methods depends on the careful operations of the procedures. Area of effective application of this test method during routine testing are given below.

Product / process	effective detection	limit of detection (mm)	
All non-porous, ferrous and non-ferrous materials like casting, weldments, forgings, assemblies and structures, machined, anodized, corroded, finished products, etc	open surface defect like cracks, porosity, folds, laps, seams, corrosion and grinding cracks.	Laboratory level	0.25
		Production level	1.0
		service level	Fatigue cracks 1.0

EDDY CURRENT TEST

principle of eddy current test:-

when magnetic flux through a conductor changes, induced currents are setup in closed paths. on the surface of the conductor. these currents are in a direction perpendicular to the magnetic flux and are called eddy currents.

the basic arrangement for producing eddy currents in a conducting material is shown in fig.2.

when an alternating current is passed through a coil, a magnetic field is set up around it. the direction of magnetic field changes with each cycle of alternating current. If a conductor is brought near this

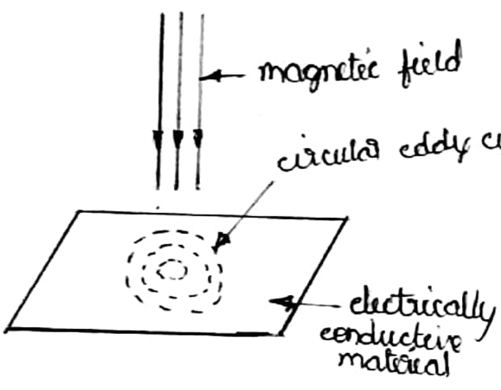


Fig.1. eddy current

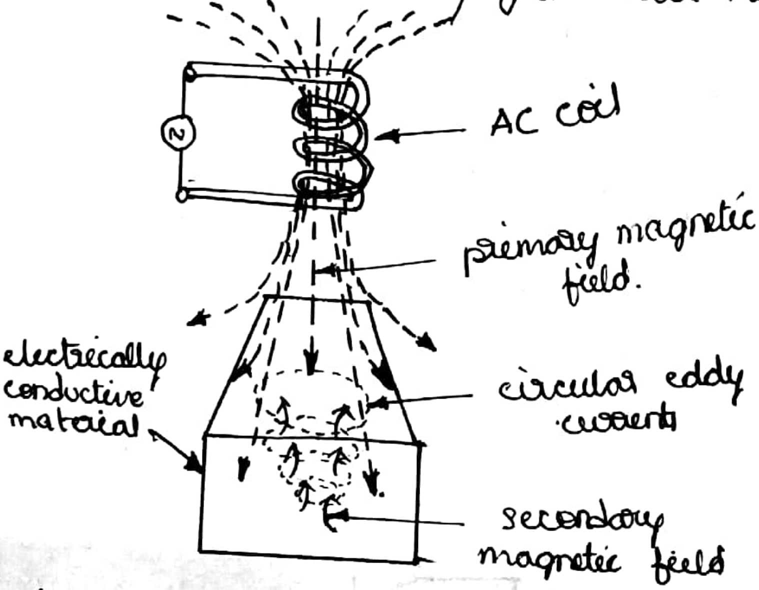


Fig. 2. generation of eddy current

field, eddy currents are induced in it. the direction of eddy current changes in the ~~with~~ direction of the magnetic field during the cycles of alternating current.

the induced eddy current produces its own magnetic field in a direction opposite to the primary magnetic field. the secondary magnetic field due to the eddy current interacts with the primary magnetic field and changes the overall magnetic field and magnitude of the current flowing through the coil. This means that the impedance of the coil is altered due to the influence of the eddy current.

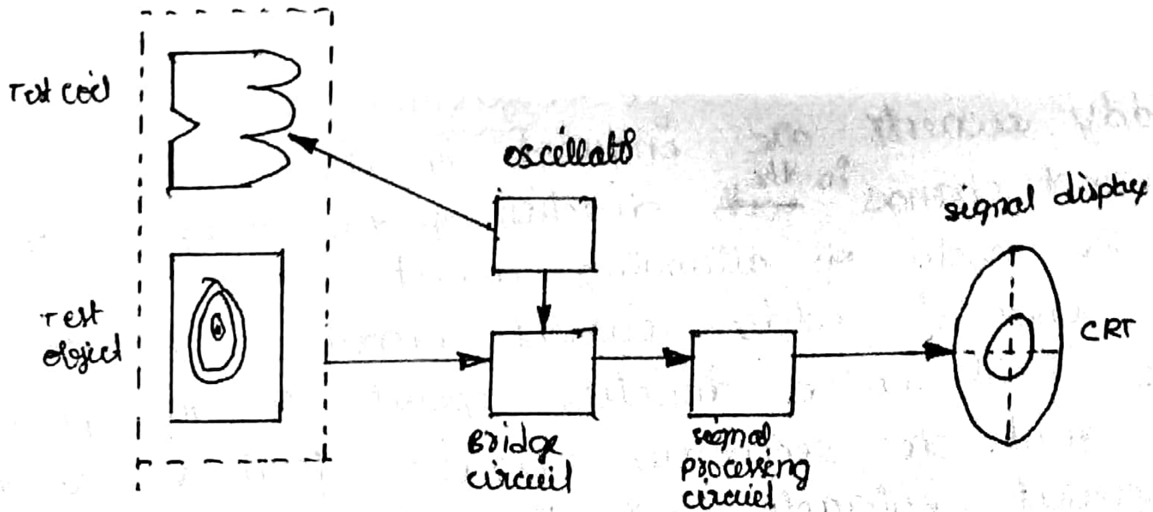
During non-destructive testing, changes in impedance are displayed either on a meter or on a CRT screen.

EDDY CURRENT TEST SYSTEM:-

Any eddy current test system consists of

* An oscillator to provide the alternating current for exciting the test coil.
* A combination of test coil and a test object to generate information in the form of an electrical signal. Varying the property of the test object modulates the impedance magnitude of the coil.
* signal processing and display.

The oscillator provides an alternating current of the required frequency to the test coil, which generates an eddy current in the test object. Test object variables like conductivity, permeability & discontinuities modulate the test coil impedance. The modulated impedance signal is processed and displayed over a readout mechanism like meters, CRT, relays, recorders etc.



Block diagram of eddy current test system

There are four basic types of eddy current instruments that carry out the following measurements.

* measurement of the change in magnitude of the total impedance of the test coil, regardless of phase.
* phase-sensitive measurement, which separates the resistive and reactive components of the test coil impedance.
* measurement of the resistive component of the test coil impedance
* measurement of the inductive component of the test coil impedance.
* measurement of the total impedance of the test coil, regardless of phase

Sensing element and test arrangements:

The sensing element (also called the test coil) serves as the main link between the test instrument and the test object. It establishes a varying electromagnetic field, which induces the eddy current in the test object and increases the magnetic effect in magnetic materials. It also senses the current flow and magnetic effect within the test object and feeds the information to the signal analysis system. The test coils are essentially of three types.

1) ENCIRCLING COIL

The test coil is in the form of a solenoid into which the test part is placed as shown in fig a.

Test object in the form of rods and tubes are examined conveniently. The entire external circumferential surface of the test object covered by the coil is scanned. This arrangement also helps high speed testing. However, it is not possible to exactly locate the defect on the circumference.

fig.a encircling coil

2) coil inside the test object:

Here the test coil is in the form of a winding over a bobbin. The coil, thus wound, passes through test objects like tubes, bolt holes, etc. and scans the inner circumferential surface of the test object as illustrated in fig. b.

This arrangement evaluates the entire internal circumferential surface at a time, which is not accessible to any other optical method of inspection. However, it is not possible to exactly locate the defect over the circumferential examined.

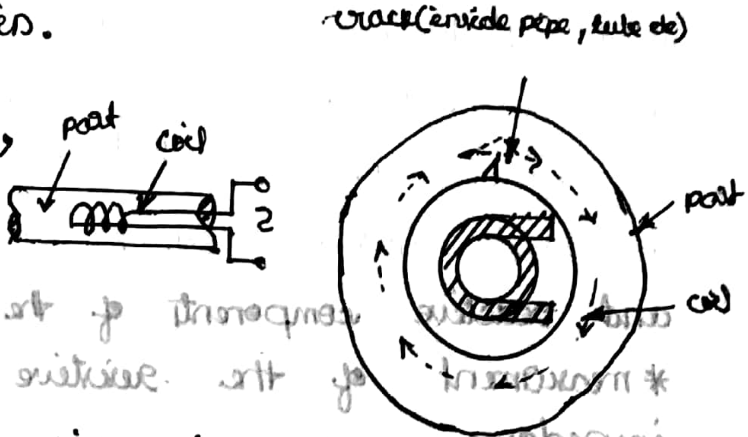


Fig b. coil inside the test object

3) surface coil:

Here, the test coil is in the form of a spring-mounted flat pole, which scans the surface of the selected location of the test object. The arrangement is shown in fig. c

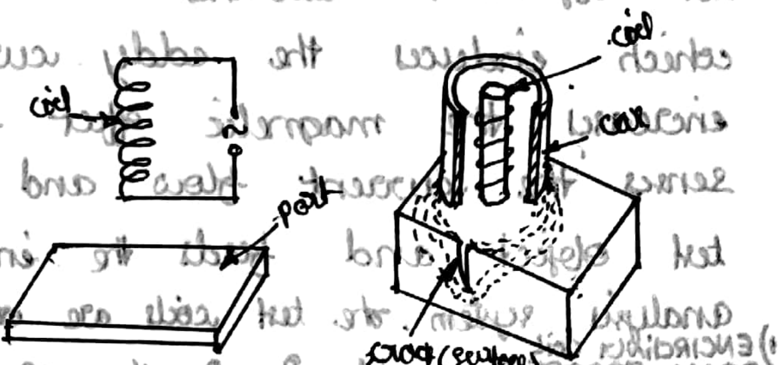
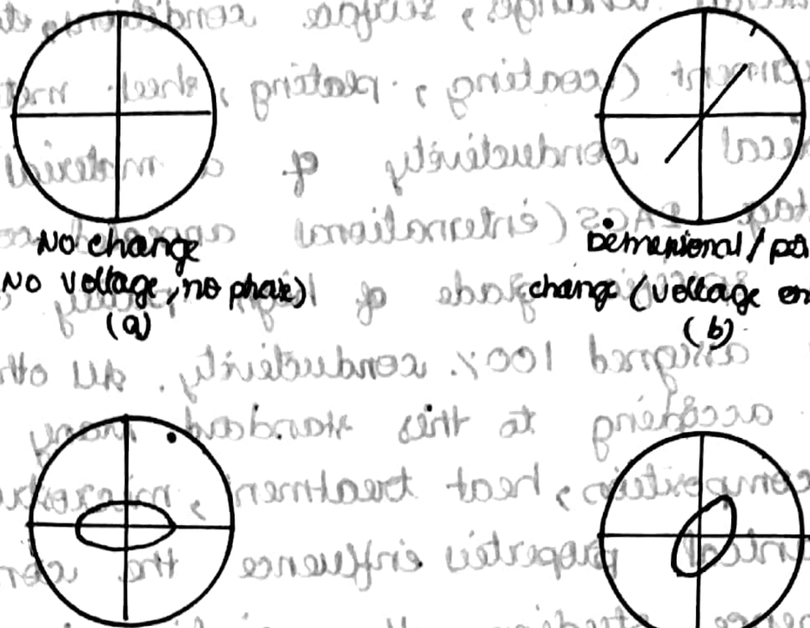


Fig c. surface coil

STANDARDIZATION AND CALIBRATION:

eddy current test methods are applied on GO/NO GO's basis by calibrating the test system against a prefabricated standard with known magnitudes of variation of the parameters desired to be measured. The standard test specimen is identical to the test component except in the parameter being measured. Artificially fabricated standard may contain notches, slots, holes, etc.

Reference standards are used to standardize the test system under operating conditions to ensure sensitivity, reproducibility of results and for periodic evaluation of the system.



No change (No voltage, no phase) (a)

Dimensional / permeability change (voltage only, no phase) (b)

conductivity change (phase only) (c)

conductivity & permeability & dimensional change (Both voltage and phase) (d)

Typical ellipse pattern

Acceptance standards

Acceptance standards are used to establish an acceptable level in a test component under standardized conditions. For practical applications, reference standards are employed to establish quality control checks for uniformity of response, which can be related to the minimum size of the crack defect to be detected.

APPLICATIONS OF EDDY CURRENT TESTING:

eddy current test methods are put to a variety of applications. Broadly, eddy current applications can be grouped into - conductivity measurement (sorting, hardness, heat treatment, alloy segregation, case depth assessment, etc.), discontinuity testing (cracks, dimensional changes, surface conditions, etc) and thickness measurement (coating, plating, sheet metal gauging).

The electrical conductivity of a material is expressed as a percentage IACS (international annealed copper standard), in which a specific grade of high purity annealed copper is arbitrarily assigned 100% conductivity. All other metals can be identified according to this standard. Many factors like temperature, composition, heat treatment, microstructure, grain size & mechanical properties influence the conductivity of a material. Hence, studying the variation in conductivity helps in indirectly assessing these properties and controlling variables such as composition, heat treatment, metal working, etc. To measure the conductivity of a magnetic material, it is subjected to a strong magnetic field, to its saturation value so that the magnetic ~~no~~ characteristics of permeability, hysteresis, etc. do not interfere with conductivity measurement.

In homogeneities like cracks, inclusions, voids, seams, laps, etc. appreciably change the normal circular eddy current flow pattern & can be detected by the eddy current test coil.

Further, phase changes are unique for several eddy current inspection parameters. By determining the phase change of an eddy current response, it is possible to isolate the response of specific variables such as conductivity, lift-off, thickness, permeability and cracks.

In so far as coating thickness measurement is concerned, the eddy current system measures the variation in impedance it can. The basic requirement for the thickness measurement is that the electrically conductivity of the coating should differ significantly from that of the substrate. The accuracy and range of metal thickness that can be measured with the eddy current system depends on the electromagnetic properties of the material and the capability of the test system. Increasing the conductivity & permeability increases the accuracy of measuring a thin specimen but decreases the effective range of measurement & accuracy at greater depths. The main purpose of using an eddy current to measure the total thickness of a metal part is to detect corrosion, erosion, wear out, etc. (15)

EFFECTIVENESS OF EDDY CURRENT TESTING

Eddy current testing is normally used for the study of surface & subsurface anomalies in conducting materials. The method is complementary of ultrasonic testing for detecting defects close to the surface. It is also complementary to liquid penetrant test inspection, which cannot reveal sub-surface defects. The method, however, cannot be used on non-conducting materials. Also, local variation in conductivity & permeability of an acceptable nature may interfere with accurate detection of discontinuities. The measurement of metal coating thickness is also difficult unless a substantial difference in conductivity exists between the coating and substrate under normal operating conditions. It is possible to detect defects of sizes as indicated in Table 1. The detectability of defects is, however, influenced considerably by the surface condition, material properties, test equipment capability, the frequency used and the test environment.

Table: approximate sizes of detectable defects

Defects	Detectable size of defects (mm)	
surface & sub-surface anomalies	laboratory condition	0.25
	production/processing	1.0
	service condition	1.0 (fatigue cracks)

At high frequencies (2 MHz or more) and in good conductors, surface cracks of length 15-20 microns can be detected. It is possible to improve limits of detection significantly with improved facilities and techniques.

4. Magnetic Particle Test

* Magnetic Materials :-

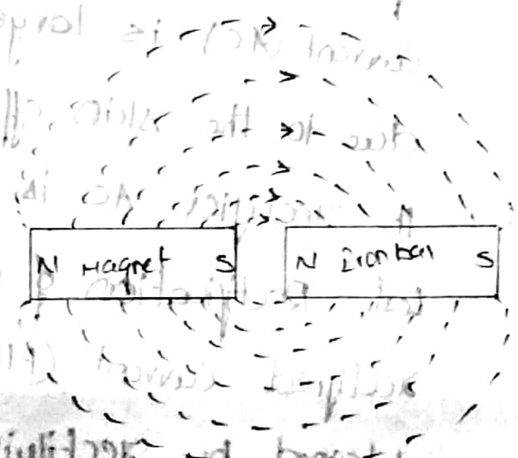
Materials are classified as ferromagnetic, Paramagnetic & diamagnetic depending on their behaviour in a magnetic field. Ferromagnetic materials are easily magnetized and show a high value of magnetic susceptibility. Also, it is observed that the magnetization of such materials is not proportional to the magnetizing field.

Paramagnetic materials have magnetic permeability greater than one and of a small positive value magnetic susceptibility.

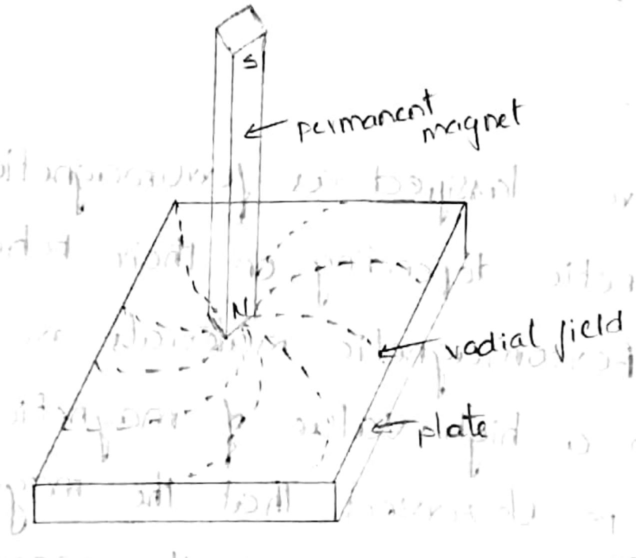
Diamagnetic materials have magnetic permeability less than one and constant susceptability.

* Magnetization of Materials :-

Materials are magnetized by a permanent magnet & by the magnetic field produced by an electric current. The earth's magnetic field also magnetizes materials. Here, we are concerned with magnetization by a permanent magnet & by a magnetic field produced by an electric current. fig 5.1 illustrated magnetization by permanent magnets.



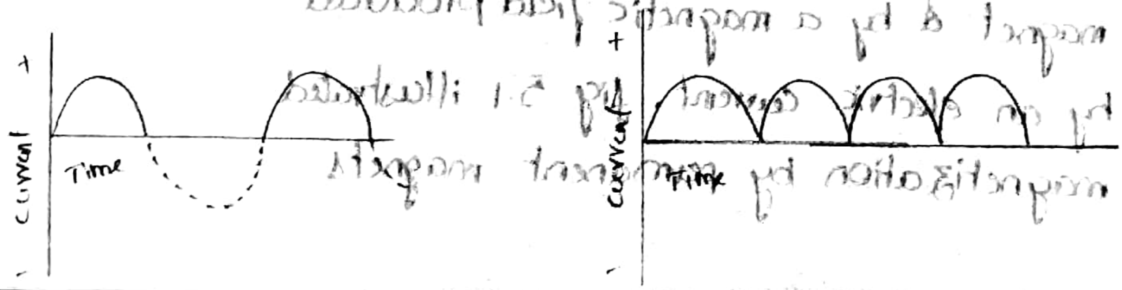
a). Magnetization of an iron bar by a permanent bar magnet



magnetization by permanent magnet

* Magnetic field using an electric current :

Direct as well as alternating currents are used to magnetized components for the magnetic particle test. The choice of current depends on the strength, direction and distribution of the desired magnetic field. A magnetic field produced by direct current (DC) penetrates the cross-section of a component, where as the field produced by an alternating current (AC) is largely confined to the surface of the component due to the skin effect. The direct current obtained from the rectifier AC is invariably used for the magnetic particle test. Rectification of a single phase AC gives a Half wave rectified current (HWDC). A full wave rectified DC is obtained by rectifying the alternating current.



* Demagnetization of Materials :-

After completion of a magnetic particle test, it is essential to demagnetization the component, as a certain amount of magnetism is retained, depending on the

1. Magnetic charcteristics of the materials
2. Geometry of the components
3. Direction of magnetization
4. strength of the magnetic field

The reasons for demagnetization are :-

1. Residual magnetism may interfere with subsequent machining, causing machined chips of the materials to adhere to the surface of the component or the tool
2. During welding with an electric arc, residual magnetism may cause deflection of the arc and obstruct proper welding
3. The functioning of navigational instruments, which are sensitive to magnetic field, is affected by the proximity of ferromagnetic components having residual magnetism

However, demagnetism may not be necessary under these condition

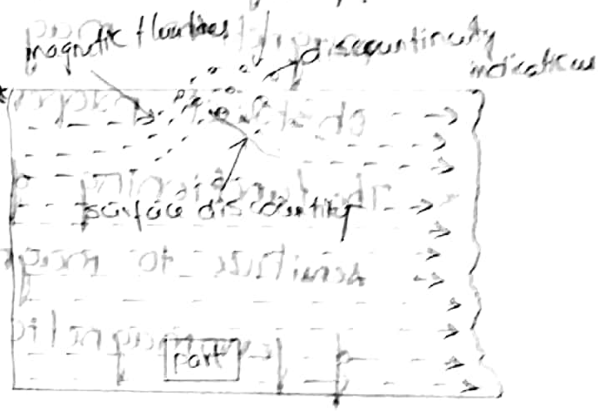
1. If the materials of the components has low retentivity
2. welded structural components large casting, boiler Etc.. made of high-strength alloys, residual magnetism does not effect the service performance of such components
3. components that undergo heat-treatment above Curie temperature.

* Methods of demagtization

components	methods of demagnetization
large components of high hardness	AC coil method
small components of medium hardness	(i) AC through current (decreasing in amplitude in stages) (ii) DC through current (decreasing in stages as well as alternating in dir/.)
Localized demagnetization (big & small parts)	(i) AC yoke (ii) Reversing DC yoke

* Principle of magnetic particle test :-

When a homogeneous feromagnetic materials is placed in a magnetic field, it gets magnetized and the magnetic field forms a continuous circuit form pole to pole through the materials. If any surface & subsurface discontinuity is present, the magnetic field gets deflected and forms a leakage field.



The methods involves in the magnetic particle test are :-

1. Cleaning/degreasing of the surface and demagnetisation
2. magnetization of the component
3. Application of fine magnetic particles on the surface of the components

* Magnetic particle test equipment :-

The magnetic particle test equipment essentially consists of

1. A means to magnetize the component
2. A device for the application of magnetic particles
3. A means of demagnetizing the components after the test.

Depending on the requirements, the equipment could be portable in stationary. portable equipment like permanent magnetic yokes, prodes and cables are useful for field work, there is electrical power source it is not available or in areas of explosive hazards.

In a stationary system, the components of the equipment are mounted on a table. It consists of a transformer working at a low voltage between 6-27 volts and giving a current in a range of 5000 - 20,000 amps.

* Magnetic particle test procedure :-

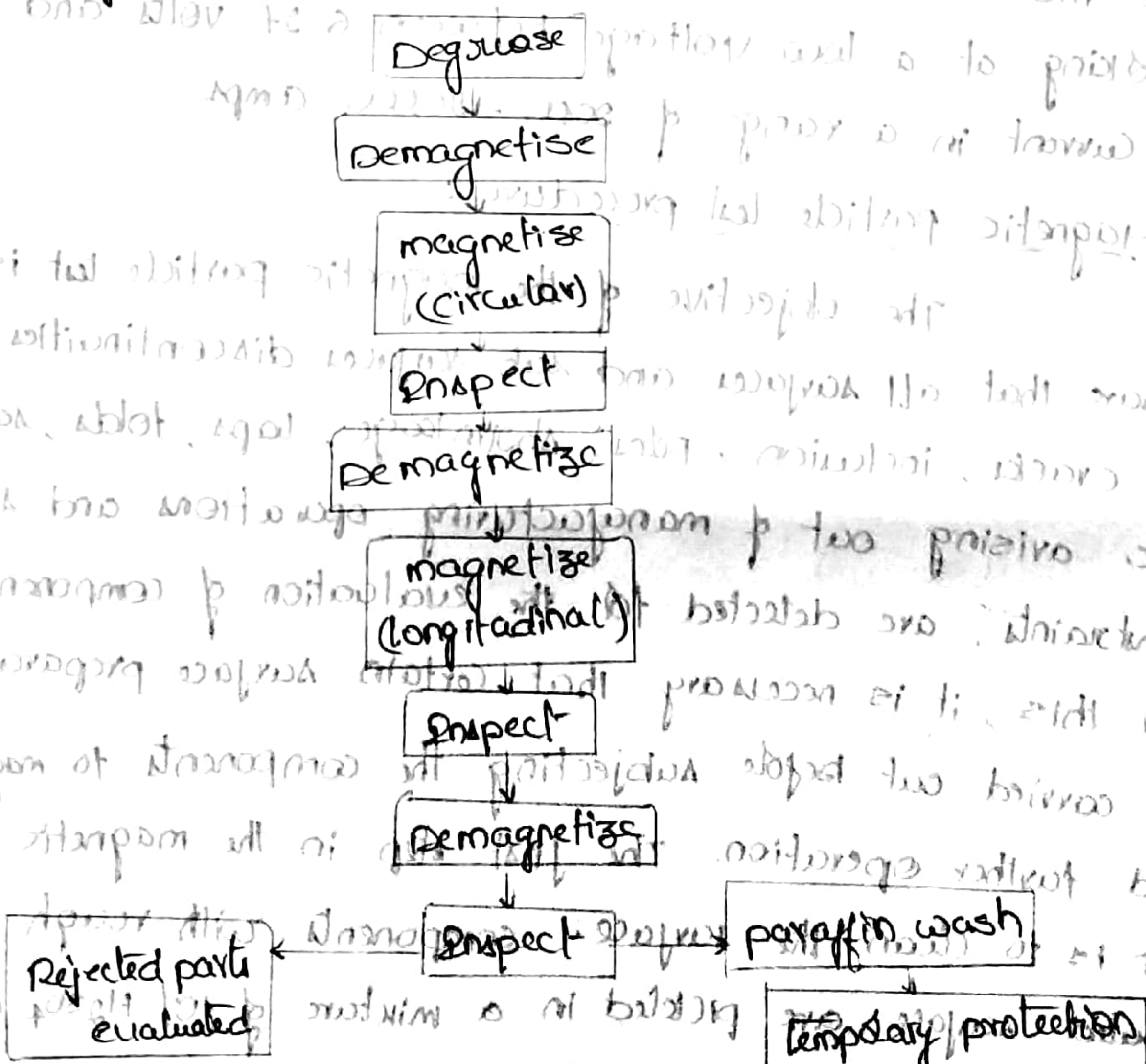
The objective of the magnetic particle test is to ensure that all surfaces and sub-surfaces discontinuities such as cracks, inclusion, poles, shrinkage, laps, folds, seams etc arising out of manufacturing operations and service constraints, are detected for the evaluation of components. For this, it is necessary that certain surface preparations be carried out before subjecting the components to magnetizing and further operation. The first step in the magnetic particle test is to clean the surface. components with rough and scaled surface are pickled in a mixture of 10% H_2SO_4 and

4 examination of the component surface for defects

5 demagnetization and temporary protection

The following factors influences the indications of discontinuity:

1. The intial stage of magnetization of the component
2. The direction and strength of the magnetizing field with respect to size, shape and orientation of the discontinuity
3. The magnetic nature and chemical composition of the component materials
4. The size, shape, geometry and surface finish of the component
5. The physical charcteristics of the magnetic particle (eg: size, shape)

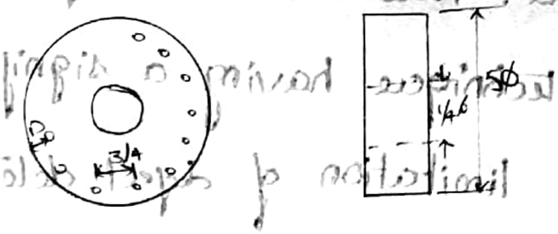


magnetic particle test flow chart

bump 5% HF and 10% HCl and 2-gm/lit-stanic solution to loosen & remove adherent surface scales and throughly washed in cold water. components are subjected to shot blasting until all scales are removed. This is followed by degreasing to remove any oil, grease, dirt, corrosion residual & making dyes.

* Standardization and Calibration :

The purpose of the standardization of the magnetic particle test system is to ensure that the equipment and accessories are working under conditions of acceptable and reproducible sensitivity. To ensure this, the system is calibrated for detecting the smallest discontinuity with a high degree of confidence. In pratice, artifical discontinuity are made in a test piece and variable of the test system are optimized to indicate these discontinuities clearly under praticle conditions of observation. Magnetic particle test system employ standard test blocks containing artifical discontinuities



Hetz	1	2	3	4	5	6	7	8	9	10	11	12
Dia (inch)	← 0.070" common in all →											
D (inch)	0.070	0.140	0.210	0.280	0.350	0.420	0.490	0.560	0.630	0.700	0.770	0.840

Before starting each shift of work, the test block is degraused demagnetized and magnetic checks are carried out. The maximum magnetizing current that gives a satisfactory indication at each hole is established and recorded for the specific magnetic unit. This values are utilized to establish the satisfactory functioning of the test system at perodic intervals.

the satisfactory functioning of the test system at perodic intervals. the satisfactory functioning of the test system below the optimal

1. There is a concentration of magnetic particle below the optimal level

2 The ammeter reading is inaccurate

3 Some other malfunctioning of the equipment.

* **Effective Application and limitation of the magnetic particle test :-**

The magnetic particle test is extensively used for locating and evaluating surface and sub-surfaces defects in ferromagnetic material during production, processing and maintenance. A wide variety of industries, eg. nuclear, aerospace, shipping, railways, chemical, petroleum, food, paper, etc., utilize these method. However the surface finish and appropriateness of the technique having a significant effect on the sensitivity and limitation of defect detection

Table 5.4 gives the range of applications and limitations in flow detection during routine examination

product/process	Detection of	Limitation of detection (mm)	
All ferromagnetic materials, castings, weldments, forgings, assemblies, ground & machined components	surface and sub-surface cracks, grinding cracks, heat treatment, stringer type non-metallic inclusions, porosity, laps & folds, fatigue cracks.	laboratory condition	0.5
		production conditions	1-2
		service condition	1-2

The limits of detection can be significantly improved with improved facilities and techniques.

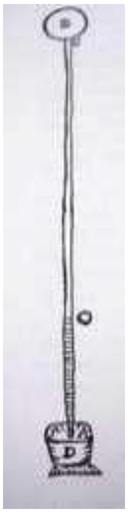
Thermal NDT methods involve the measurement or mapping of surface temperatures as heat flows to, from and/or through an object. The simplest thermal measurements involve making point measurements with a thermocouple. This type of measurement might be useful in locating hot spots, such as a bearing that 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 allow 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

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 Thermometer

Ancient Greeks knew that air was expanded by heat. This knowledge was eventually used to develop the thermoscope, which traps air in a bulb so that the size of the bulb changes as the air expands or contracts in response to a temperature increase or decrease. The image on the right shows the first published sketch of a thermoscope,. The next step in making a thermometer was to apply a scale to measure the expansion and relate this to heat.

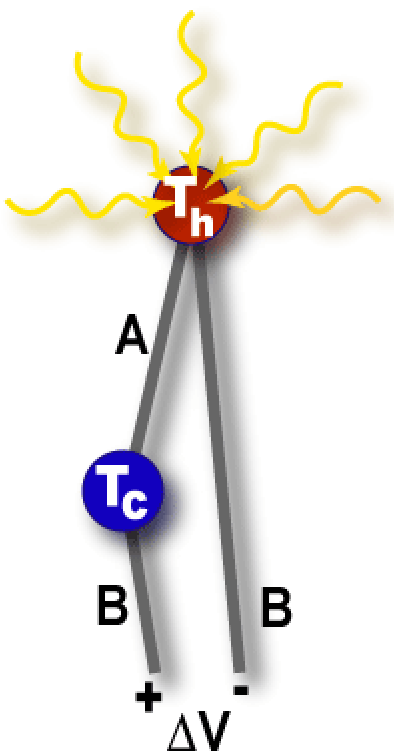


Infrared Energy

Sir William Herschel, an astronomer, is credited with the discovery of infrared energy in 1800. Knowing that sunlight was made up of all the colors of the spectrum, Herschel wanted to explore the colors and their relationship to heat. He devised an experiment using a prism to spread the light into the color spectrum and thermometers with blackened bulbs to measure the temperatures of the different colors. Herschel observed an increase in temperature from violet to red and observed that the hottest temperature was actually beyond red light. Herschel termed the radiation causing the heating beyond the visible red range "calorific rays." Today, it is called "infrared" energy.

The Seebeck Effect (Thermocouples)

In 1821, Thomas Johann Seebeck found that a circuit made from two dissimilar metals, with junctions at different temperatures, would deflect a compass needle. He initially believed this was due to magnetism induced by a temperature difference, but soon realized that it was an electrical current that was induced. More specifically, the temperature difference produces an electric potential (voltage) which can drive electric current in a closed circuit. Today, this is known as the Seebeck effect.



The voltage difference, DV, produced across the terminals of an open circuit made from a pair of dissimilar metals, A and B, whose two junctions are held at different temperatures, is directly proportional to the difference between the hot and cold junction temperatures, Th - Tc. The Seebeck voltage does not depend on the distribution of temperature along the metals between the junctions. This is the physical basis for a thermocouple,

Noncontact Thermal Detectors

Melloni soon used the thermocouple technology to produce a device called the thermopile. A thermopile is made of thermocouple junction pairs connected electrically in series. The absorption of thermal radiation by one of the thermocouple junctions, called the active junction, increases its temperature. The differential temperature between the active junction and a reference junction kept at a fixed temperature produces an electromotive force directly proportional to the differential temperature created. This effect is called a thermoelectric effect. Melloni was able to show that a person 30 feet away could be detected by focusing his or her thermal energy on the thermopile. Thermopile detectors are used today for spectrometers, process temperature monitoring, fire and flame detection, presence monitor, and a number of other non-contact temperature measurement devices. A device similar to the thermopile measured a change in electrical resistance rather than a voltage change. This device was named the bolometer, and in 1880 it was shown that it could detect a cow over 1000 feet away.

During World War I, Case became the first to experiment with photoconducting detectors. These thallium sulfide detectors produced signals due to the direct interaction of infrared photons and were faster and much more sensitive than other thermal detectors that functioned from being heated. During World War II, photoconductive or quantum detectors were further refined and this resulted in a number of military applications, such as target locating, tracking, weapons guiding and intelligence gathering.

Imaging Systems

Application areas expanded to surveillance and intrusion during the Vietnam era. Shortly thereafter space-based applications for natural resource and pollution monitoring and astronomy were developed. IR imaging technology developed for the military spilled over into commercial markets in the 1960s. Initial applications were in laboratory level R&D, preventative maintenance applications, and surveillance. The first portable systems suitable for NDT applications were produced in the 1970s. These systems utilized a cooled scanned detector and the image quality was poor by today's standards. However, infrared imaging systems were soon being widely used for a variety of industrial and medical applications.

Current State

In 1992, the American Society for Nondestructive Testing officially adopted infrared testing as a standard test method. Today, a wide variety of thermal measurement equipment is commercially available and the technology is heavily used by industry. Researchers continue to improve systems and explore new applications.

Scientific Principles of Thermal Testing

Thermal Energy

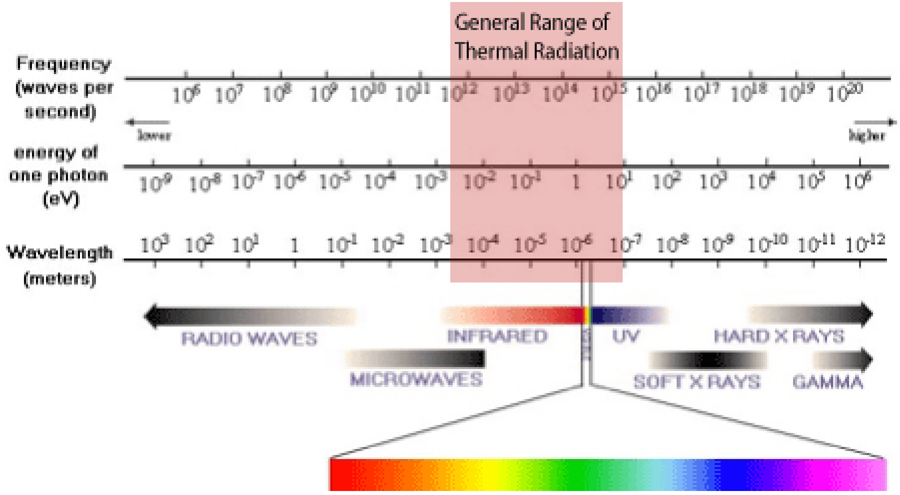
Energy can come in many forms, and it can change from one form to another but can never be lost. This is the First Law of Thermodynamics. A byproduct of nearly all energy conversion is heat, which is also known as thermal energy. When there is a temperature difference between two objects or two areas within the same object, heat transfer occurs. Heat energy transfers from the warmer areas to the cooler areas until thermal equilibrium is reached. This is the Second Law of Thermodynamics. When the temperature of an object is the same as the surrounding environment, it is said to be at ambient temperature.

Heat Transfer Mechanisms

Thermal energy transfer occurs through three mechanisms: conduction, convection, and/or radiation. Conduction occurs primarily in solids and to a lesser degree in fluids as warmer, more energetic molecules transfer their energy to cooler adjacent molecules. Convection occurs in liquids and gases, and involves the mass movement of molecules such as when stirring or mixing is involved.

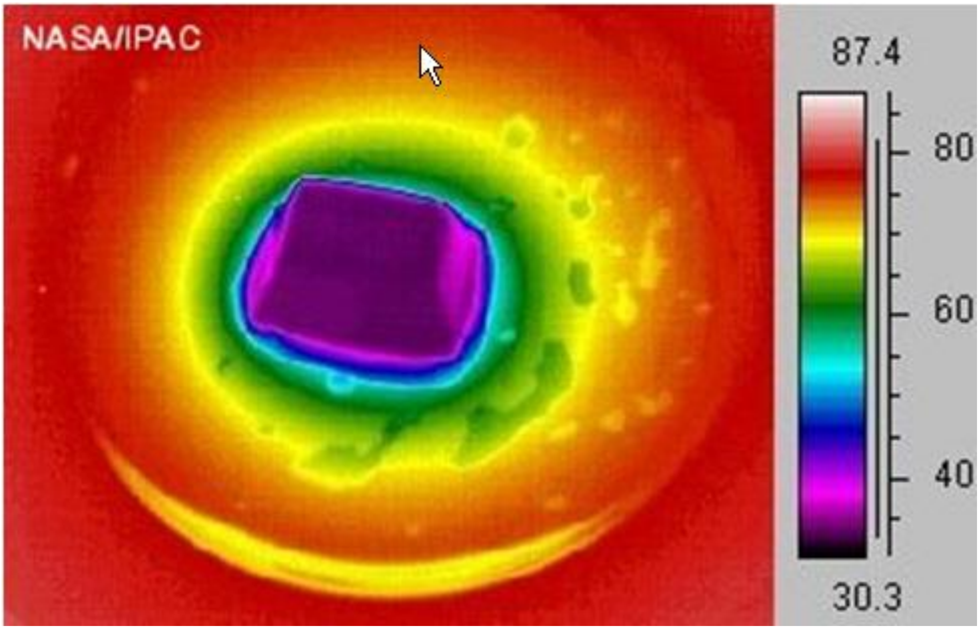
The third way that heat is transferred is through electromagnetic radiation of energy. Radiation needs no medium to flow through and, therefore, can occur even in a vacuum. Electromagnetic radiation is produced when electrons lose energy and fall to a lower energy state. Both the wavelength and intensity of the radiation is directly related to the temperature of the surface molecules or atoms.

Wavelength of Thermal Energy



The wavelength of thermal radiation extends from 0.1 microns to several hundred microns. As highlighted in the image, this means that not all of the heat radiated from an object will be visible to the human eye…but the heat is detectable. Consider the gradual heating of a piece of steel. With the application of a heat source, heat radiating from the part is felt long before a change in color is noticed. If the heat intensity is great enough and applied for long enough, the part will gradually change to a red color. The heat that is felt prior to the part changing color is the radiation that lies in the infrared frequency spectrum of electromagnetic radiation. Infrared (IR) radiation has a wavelength that is longer than visible light or, in other words, greater than 700 nanometers. As the wavelength of the radiation shortens, it reaches the point where it is short enough to enter the visible spectrum and can be detected with the human eye.

An infrared camera has the ability to detect and display infrared energy. Below is an infrared image of an ice cube melting. Note the temperature scale on side, which shows warm areas in red and cool areas in purple. It can be seen that the ice cube is colder than the surrounding air and it is absorbing heat at its surface. The basis for infrared imaging technology is that any object whose temperature is above 0°K radiates infrared energy. Even very cold objects radiate some infrared energy. Even though the object might be absorbing thermal energy to warm itself, it will still emit some infrared energy that is detectable by sensors. The amount of radiated energy is a function of the object's temperature and its relative efficiency of thermal radiation, known as emissivity.



(Photo courtesy of NASA/JPL-Caltech/IPAC)

Emissivity
A very important consideration in radiation heat transfer is the emissivity of the object being evaluated. Emissivity is a measure of a surface's efficiency in transferring infrared energy. It is the ratio of thermal energy emitted by a surface to the energy emitted by a perfect blackbody at the same temperature. A perfect blackbody only exists in theory and is an object that absorbs and reemits all of its energy. Human skin is nearly a perfect blackbody as it has an emissivity of 0.98, regardless of actual skin color.

If an object has low emissivity, IR instruments will indicate a lower temperature than the true surface temperature. For this reason, most systems and instruments provide the ability for the operator to adjust the emissivity of the object being measured. Sometimes, spray paints, powders, tape or "emissivity dots" are used to improve the emissivity of an object.

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 pryoelectric 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, mirobolometers 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.

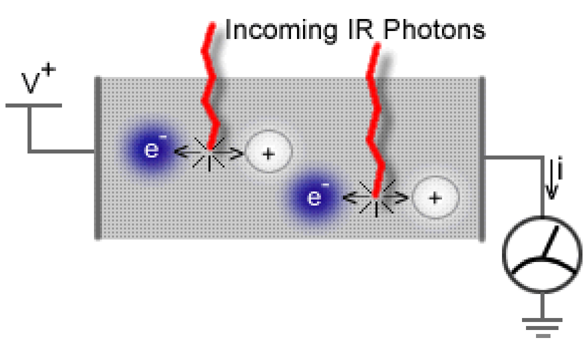
Image Courtesy of GE Thermometrics

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 are 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.

Equipment - Imaging Technology

Imaging Systems

Thermal imaging instruments measure radiated infrared energy and convert the data to corresponding maps of temperatures. A true thermal image is a gray scale image with hot items shown in white and cold items in black. Temperatures between the two extremes are shown as gradients of gray. Some thermal imagers have the ability to add color, which is artificially generated by the camera's video enhancement electronics, based upon the thermal attributes seen by the camera. Some instruments provide temperature data at each image pixel. Cursors can be positioned on each point, and the corresponding temperature is read out on the screen or display. Images may be digitized, stored, manipulated, processed and printed out. Industry-standard image formats, such as the tagged image file format (TIFF), permit files to work with a wide array of commercially available software packages.

Images are produced either by scanning a detector (or group of detectors) or by using with focal plane array. A scanning system in its simplest form could involve a single element detector scanning along each line in the frame (serial scanning). In practice, this would require very high scan speeds, so a series of elements are commonly scanned as a block, along each line. The use of multiple elements eases the scan speed requirement, but the scan speed and channel bandwidth requirements are still high. Multiple element scans do, however, result in a high degree of uniformity. The frame movement can be provided by frame scanning optics (using mirrors) or in the case of line scan type imagers, by the movement of the imager itself. Another method is to use a number of elements scanning in parallel (parallel scanning). These scanners have one element per line and scan several lines simultaneously. Scan speeds are lower but this method can give rise to poor image uniformity.

Equipment for Establishing Heat Flow

In some inspection applications, such as corrosion or flaw detection, the components being inspected may be at ambient temperature and heat flow must be created. This can be accomplished by a variety of means. Heating can be accomplished by placing the part in a warm environment, such as a furnace, or directing heat on the surface with a heat gun or with flash lamps. Alternately, cooling can be accomplished by placing the component in a cold environment or cooling the surface with a spray of cold liquid or gas.

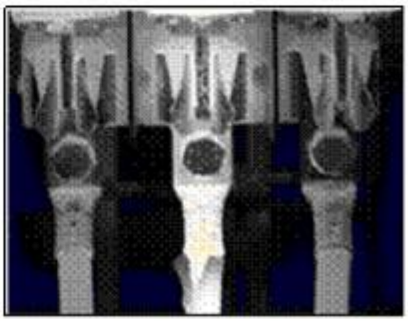
Image Capturing and Analysis

IR cameras alone or used with an external heat source can often detect large, near-surface flaws. However, repeatable, quantifiable detection of deeper, subtler features requires the additional sensitivity of a sophisticated computerized system. In these systems, a computer is used to capture a number of time sequence images which can be stepped through or viewed as a movie to evaluate the thermal changes in an object as a function of time. This technique is often referred to as thermal wave imaging.

The image to the right shows a pulsed thermography system. This system uses a closely controlled burst of thermal energy from a xenon flash lamp to heat the surface. The dissipation of heat is then tracked using a high speed thermal imaging camera. The camera sits on top of the gray box in the foreground. The gray box houses the xenon flash lamp and it is held against the surface being inspected. The equipment was designed to inspect the fuselage skins of aircraft for corrosion damage and can make quantitative measurements of material loss. It has also been shown to detect areas of water incursion in composites and areas where bonded structure have separated.

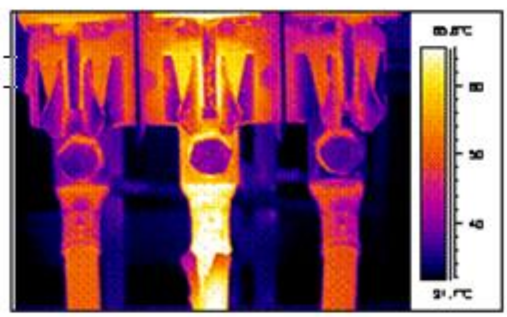
Image Interpretation

Most thermal imagers produce a video output in which white indicates areas of maximum radiated energy and black indicates areas of lower radiation. The gray scale image contains the maximum amount of information. However, in order to ease general interpretation and facilitate subsequent presentation, the thermal image can be artificially colorized. This is achieved by allocating desired colors to blocks of grey levels to produce the familiar colorized images. This enables easier image interpretation to the untrained observer. Additionally, by choosing the correct colorization palette the image may be enhanced to show particular energy levels in detail.



Imager

Radiometric Imager



Many thermal imaging applications are qualitative in nature. The inspection simply involves comparing the temperatures at various locations within the field of view. The effects of the sun, shadows, moisture and subsurface detail must all be taken into account when interpreting the image, but this type of inspection is straightforward. However, great care must be exercised when using an infrared imager to make quantitative temperature measurements. As mentioned previously, the amount of infrared radiation emitted from a surface depends partly upon the emissivity of that surface. Accurate assessment of surface emissivity is required to acquire meaningful quantitative results.

Techniques and Select Industrial Applications of Thermal Imaging

Some thermal imaging techniques simply involve pointing a camera at a component and looking at areas of uneven heating or localized hot spots. The first two example applications discussed below fall into this category. For other applications, it may be necessary to generate heat flow within the component and/or evaluate heat flow as a function of time. A variety of thermal imaging techniques have been developed to provide the desired information. A few of these techniques are highlighted below.

Electrical and Mechanical System Inspection

Electrical and mechanical systems are the backbone of many manufacturing operations. An unexpected shutdown of even a minor piece of equipment could have a major impact on production. Since nearly everything gets hot before it fails, thermal inspection is a valuable and cost-effective diagnostic tool with many industrial applications.

With the infrared camera, an inspector can see the change in temperature from the surrounding area, identify whether or not it is abnormal and predict the possible failure. Applications for infrared testing include locating loose electrical connections, failing transformers, improper bushing and bearing lubrication, overloaded motors or pumps, coupling misalignment, and other applications where a change in temperature will indicate an undesirable condition. Since typical electrical failures occur when there is a temperature rise of over 50°C, problems can be detected well in advance of a failure.

The image on the right above shows three electrical connections. The middle connection is hotter than the others. Connections can become hot if they are loose or if corrosion causes an increase in the electrical resistance.

Electronic Component Inspection

In electronics design and manufacturing, a key reliability factor is semiconductor junction temperature. During operation, a semiconductor generates heat and this heat will flow from the component. The heat will flow from the component in all directions, but will flow particularly well along thermally conductive connectors. This leads to an increase in temperature at the junctions where the semiconductor attaches to the board. Components with high junction temperatures typically have shorter life spans. Thermal imaging can be used to evaluate the dissipation of heat and measure the temperature at the junctions.

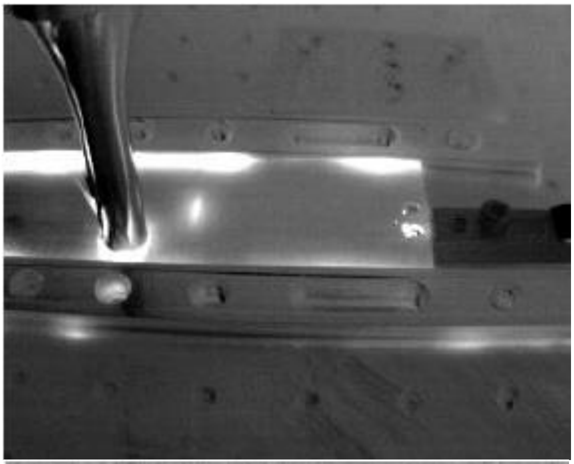
Corrosion Damage (Metal Thinning)

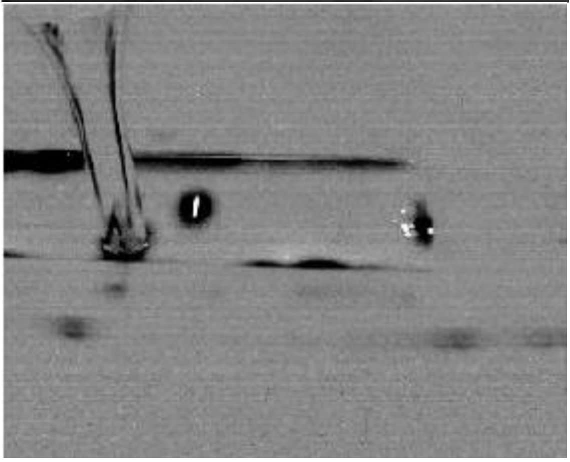
IR techniques can be used to detect material thinning of relatively thin structures since areas with different thermal masses with absorb and radiate heat at different rates. In relatively thin, thermally conductive materials, heat will be conducted away from the surface faster by thicker regions. By heating the surface and monitoring its cooling characteristics, a thickness map can be produced. Thin areas may be the result of corrosion damage on the backside of a structure which is normally not visible. The image to the right shows corrosion damage and disbonding of a tear strap/stringer on the inside surface of an aircraft skin. This type of damage is costly to detect visually because a great deal of the interior of the aircraft must be disassembled. With IR techniques, the damage can be detected from the outside of the aircraft.

Flaw Detection

Infrared techniques can be used to detect flaws in materials or structures. The inspection technique monitors the flow of heat from the surface of a solid and this flow is affected by internal flaws such as disbonds, voids or inclusions. Sound material, a good weld, or a solid bond will see heat dissipate rapidly through the material, whereas a defect will retain the heat for longer. A new technique call vibro thermograph or thermosonic testing was recently introduced by researchers at Wayne State University for the detection of cracks. A solid sample is excited with bursts of high-energy, low-frequency acoustic energy. This causes frictional heating at the faces of any cracks present and hotspots are detected by an infrared camera. Despite the apparent simplicity of the scheme, there are a number of experimental considerations that can complicate the implementation of the technique. Factors including acoustic horn location, horn-crack proximity, horn-sample coupling, and effective detection range all significantly affect the degree of excitation that occurs at a crack site for a given energy input.

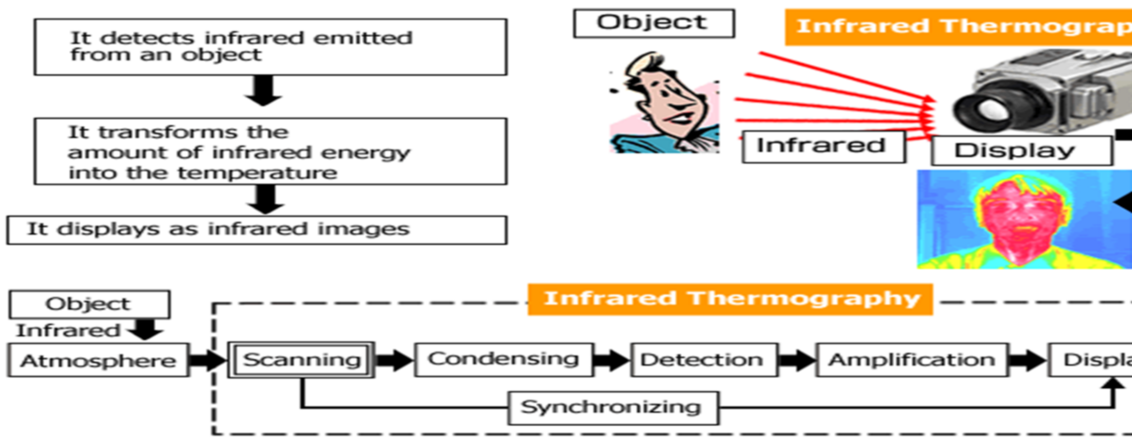
Below are two images from an IR camera showing a 0.050" thick 7075 aluminum plate sample with a prefabricated crack being inspected using a commercial vibro thermography system. The image on the left is the IR image with a pre-excitation image subtracted. A crack can be seen in the middle of the sample and just to the right of the ultrasonic horn. Also seen is heating due to the horn tip, friction at various clamping sites, and reflection from the hole at the right edge of the sample. The image on the right is the same data with image processing performed to make the crack indication easier to distinguish.



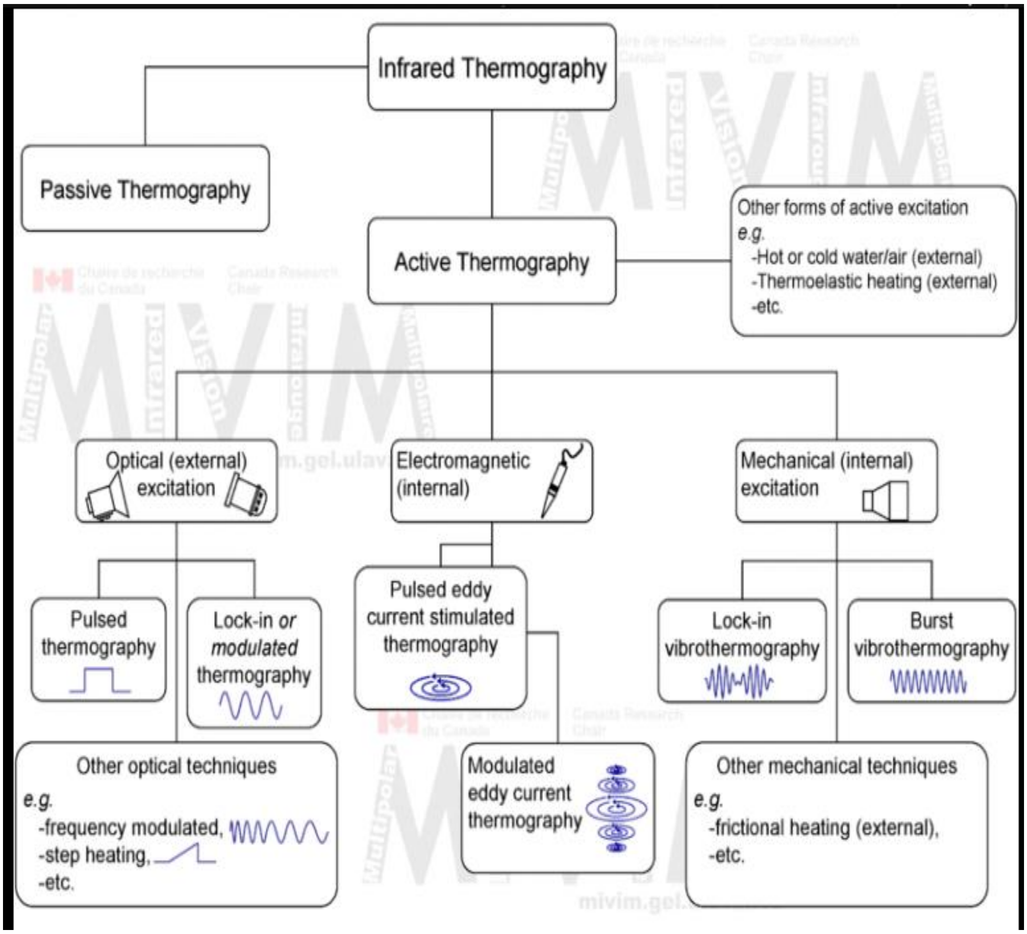


- A special lens focuses the infrared light emitted by all of the objects in view.
- The focused light is scanned by a phased array of infrared-detector elements. The detector elements create a very detailed temperature pattern called a **thermogram**

- The thermogram created by the detector elements is translated into electric impulses.
- The impulses are sent to a signal-processing unit that translates the information from the elements into data for the display.
- Appears as various colours depending on the intensity of the infrared emission. The combination of all the impulses from all of the elements creates the image.



Infraredthermgographytechniques



Passive techniques

Typically, passive techniques display information from an infrared sensor on a monitor; these images can be visualized in black and white or in false color. Passive techniques are capable of detecting temperature differences as small as 0.01 °C above or below ambient temperatures.

Active techniques

Active techniques may be further subdivided depending on the type of energy imparted (typically, optical or acoustic), whether energy is applied externally or internally, and mode of excitation.A wide variety of energy sources can be used to induce a thermal contrast between defective and non-defective zones that can be divided in external, if the energy is delivered to the surface and then propagated through the material until it encounters a flaw; or internal, if the energy is injected into the specimen in order to stimulate exclusively the defects.

Typically, external excitation is performed with optical devices such as photographic flashes (for heat pulsed stimulation) or halogen lamps (for periodic heating), whereas internal excitation can be achieved by means of mechanical oscillations, with a sonic or ultrasonic transducer for both burst and amplitude modulated stimulation.

As depicted in the figure, there are three classical active thermographic techniques based on these two excitation modes: lock-in (or modulated) thermography and pulsed thermography, which are optical techniques applied externally; and vibrothermography, which uses ultrasonic waves (amplitude modulated or pulses) to excite internal features. In vibrothermography, an external mechanical energy source induces a temperature difference between the defective and non-defective areas of the object. In this case, the temperature difference is the main factor that causes the emission of a broad electromagnetic spectrum of infrared radiation, which is not visible to the human eye. The locations of the defects can then be detected by infrared cameras through the process of mapping temperature distribution on the surface of the object.

Active thermography

Active thermography uses an external source for measured object excitation, that means introducing an energy into the object. The excitation sources can be classified by the principles:

- optical radiation or microwaves absorption,
- electromagnetic induction,
- elastic waves transformation (e.g. ultrasound),
- convection (e.g. hot air),
- plastic deformation transformation (thermoplastic effect during mechanical loading).

Various excitation sources can be used for the active thermography and nondestructive testing, for example laser heating, flash lamps, halogen lamps, electrical heating, ultrasonic horn, eddy currents, microwaves, and others. The measured object can be heated by an external source directly, e.g. by halogen lamps or hot air. The material inhomogeneities or defects cause then a distortion of temperature field. This distortion is detected as temperature differences on the material surface. Another possibility is to use thermophysical processes in the material, when mechanical or electrical energy is transformed into thermal energy due to defects and inhomogeneities. It creates local temperature sources, which cause temperature differences detected on the object surface by infrared techniques. It is the case of ultrasound excitation for example.

IRNDT methods

A lot of methods were developed for active thermography for the nondestructive testing measurement evaluation. The evaluation methods selection depends on application, used excitation source and excitation type (pulse, periodic, continuous). In the simplest case, the response is evident from a thermogram directly. However, it is necessary to use advanced analysis techniques in most cases. The most common methods include Lock-In, Pulse or Transient (Step thermography) evaluation techniques. Continuous excitation can also be used in some cases.

- Lock-In thermography (periodic excitation method). A modulated periodic source is used for the excitation. The phase and amplitude shift of the measured signal are evaluated and the analysis can be done by various techniques. Halogen lamps, LED lamps, ultrasound excitation or an electric current are suitable excitation sources. It has the advantage that it can be used on large surfaces and it puts a low thermal energy on the part being inspected. The disadvantage is a longer measurement time and dependence of detection capabilities on a geometrical orientation of defects (except of an indirect excitation such as ultrasound). The Lock-In method is suitable for testing components with a low thermal diffusivity and it has many modifications for various specific applications (such as Lock-In Ref, Lock-In Online, etc.).
- Pulse thermography (pulse method). A very short pulse – usually in the units of milliseconds – is used to excite the object. The cooling process is then analyzed. A flash lamp is typically used as an excitation source. The advantage of this method is the speed of the analysis and a possibility to estimate the defects depth. The disadvantage is a limited depth of the analysis, a limited area that can be inspected (with regard to a usable power of excitation sources) and a dependence of detection capabilities on geometrical orientation of defects.
- Transient thermography (step thermography, thermal wave method). In principle, the excitation and evaluation are similar to the pulse thermography, however, the pulse length is much bigger. Less powerful excitation sources are required compared to the pulse thermography. It is therefore possible to analyze larger areas and the measurement time is shorter than in the case of Lock-In thermography. As in the pulse thermography, the sensitivity of the

method is limited by the geometrical orientation of defects. Halogen lamps are the suitable excitation source for this type of evaluation.

- Continual excitation. The simplest method usable only in special applications.

A high-speed cooled infrared camera with a high sensitivity is commonly used for IRNDT applications. However, an uncooled bolometric infrared camera can be used for specific applications. It can significantly reduce acquisition costs of the measurement system.

The IR nondestructive testing system are usually modular. It means that various excitation sources can be combined with various infrared cameras and various evaluation methods depending on application, tested material, measuring time demands, size of a tested area, etc. The modularity allows universal usage of the system for various industrial, scientific and research applications.

Application examples

IRNDT (infra-red nondestructive testing) method is suitable for detection and inspection of cracks, defects, cavities, voids and inhomogeneities in material, it is also possible to use the method for inspection of welded joints of metal and plastic parts, inspection of solar cells and solar panels, determination of internal structure of material etc. The main advantage of IRNDT method is availability for inspection of various materials in wide range of industrial and research applications. IRNDT measurement is fast, nondestructive and noncontact. Restrictive condition for IRNDT method is inspection depth combined with dimension and orientation of defect/crack/inhomogeneity in material.

Thermographic Inspection Of Metallic Honeycomb Sandwich Structures

Honeycomb sandwich structures are widely used in aerospace for their structural efficiency but one drawback has always been the cost of inspection. Inspection is required in these structures as they are normally highly loaded and relatively sensitive to the presence of defects. The manufacturing processes used (typically brazing, diffusion bonding or adhesive bonding) cannot be relied upon to produce defect free parts and thus a fairly lengthy and expensive inspection is performed.

BFGoodrich Aerospace/Aerostructures Group (BFGoodrich) is the Thermal Protection System (TPS) integrator for the X-33/Venturestar single stage to orbit program that is intended to replace the existing Space Shuttle system. Among the many differences between the X-33 and the Shuttle are those aimed at reducing maintenance costs and schedules and one of these is in the area of TPS maintenance. The metallic TPS developed by BFGoodrich has much lower maintenance requirements that other forms of TPS used for the temperature ranges in question. Previous work has demonstrated the capability of pulsed infrared thermography (PIRT) to replace conventional ultrasonic inspection for the metallic TPS systems and this work was intended to indicate where this technology could be extended to other honeycomb sandwich structures. This initial work consisted of modeling the thermographic process to determine its performance on a variety of metallic honeycomb sandwich structures.

INSPECTION OF THERMAL PROTECTION SYSTEMS

The conventional method used at BFGoodrich for inspecting brazed honeycomb sandwich structures is ultrasonics, pulse echo and through transmission. The performance of this method was compared with that of PIRT and optical inspection methods (shearography and holography) through a Probability of Detection (POD) program.This was carried out on a set of 12 brazed tnconel 617 honeycomb sandwich samples withprogrammed (and natural) defects. Examples of data are shown in Figure 1 for the four selected inspection methods (shearography was found not suitable for complex parts and only holography was used for the bulk of this work). Defects can be easily seen in the ultrasonic and thermographic images but are harder to discern in the holographic image.

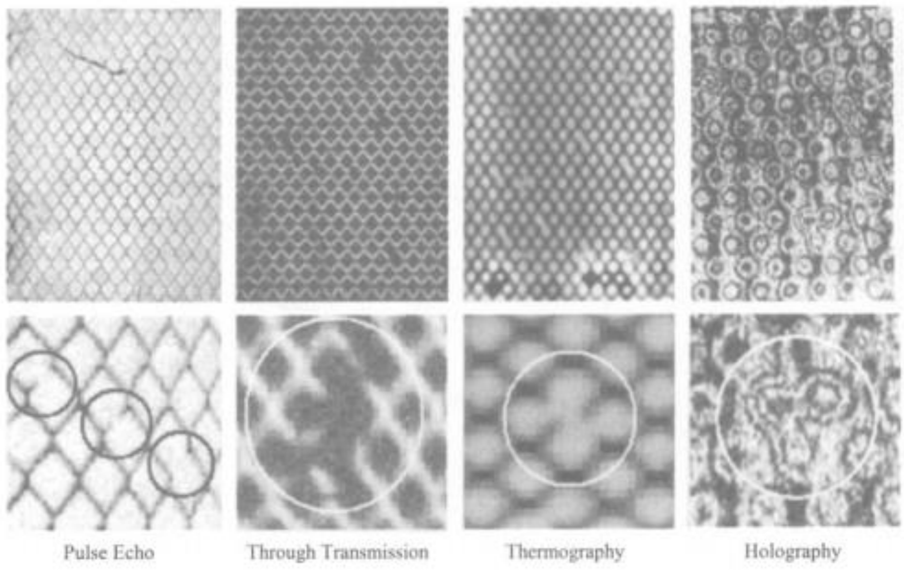


Figure 1 Inspection methods used for brazed honeycomb panels.

Probability of Detection Calculations

In the past, characterization of inspection methods was difficult to quantify. Typically, parts would be manufactured with programmed defects and, when those programmed defects could be seen during the inspection, the method would be deemed capable. The problem with this method is that it is not quantitative and only takes account of the ultimate capability of a method. The human factors, which often dominate, are ignored.

The method of quantifying inspection capability and including human factors is Probability of Detection (POD) and it has gained widespread acceptance over the last few years. This assesses the probability of detecting defects of differing sizes and is ofien expressed in terms of a POD curve. The Probability of Detection calculations used at BFGoodrich are based on the maximum likelihood estimator approach as developed by UDRI for the USAF as a draft MIL-STD . The maximum likelihood estimator is a particularly useful tool for the analysis of binary (hit-miss) data such as those generated by ultrasonic, thermographic or shearographic/holographic systems. In addition to calculating the POD data themselves, an additional parameter representing the lower 95% confidence bound of the 90% POD is defined, referred to as A90/95.

INSPECTION RESULTS

A total of 12 samples were manufactured, each containing 18 programmed defects, and were inspected using each of the three methods, by two separate operators in the case of ultrasonics and thermography. The positions and sizes of the programmed defects were known but the positions and sizes of the natural defects were determined by pulse echo ultrasonic testing, as this is known to detect all defect types [1]. An equipment problem lead to the generation of poor quality ultrasonic data on one of the samples. This would normally have been immediately repeated but other priorities prevented this. Data from the affected area of that one sample were excluded from the pulse echo analysis. In the thermographic inspection, masking from the painting operation obscured some areas. As already mentioned, leaks masked some areas from holography inspection.

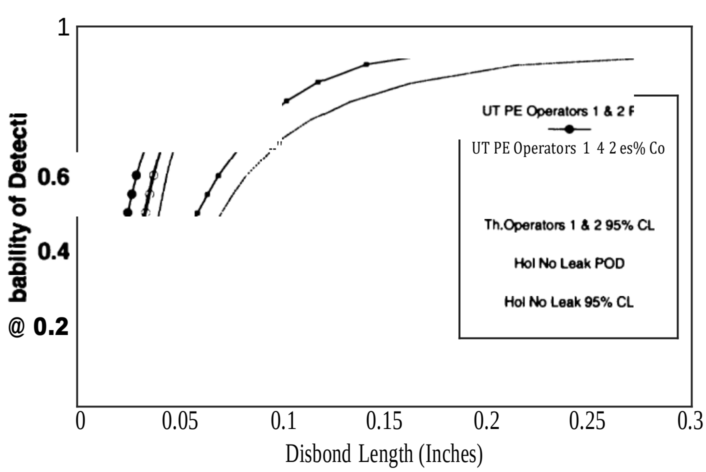


Figure 2 Probability of detection curves for all three inspection methods.

POD curves for all three methods (using pulse echo in the case of ultrasonics) are shown in Figure 2. It can be seen that pulse echo ultrasonic testing is the best method for very small defects (<l.5 mm

long) but thermography is marginally better for larger defects. As the crossover occurs very close to the 90% POD level, their detectable limits would be expected to be very similar. The results obtained for holography were markedly inferior for all defects sizes. The comparison between pulse echo ultrasonic testing and thermography is particularly interesting. The higher slope for the thermography POD curve is a result of the good signal to noise ratio obtained with this method while the cutoff at small defect sizes is a function of the number of pixels contributing to the image of a cell wall. Superior performance could be obtained from thermography by increasing the optical magnification but the area inspected would be less and the time to inspect a given area would increase.

A summary of the POD data is shown in Table 1. For each method, it lists the percentage of defects found, the 90% POD (A90) and the lower 95% confidence bound for the 90% POD (A90/95). If the A90/95 values for all operators are examined, it can be seen that pulse echo ultrasonic testing and thermography produced almost identical results. The poorer performance of holography, after excluding the areas that leaked, is also evident.

Table 1 **Summary of** probability of detection results for all inspection methods.

Method	% Found	A90 (inches)	A90/95 (inches)
Pulse Echo UT	98.2	0.057	0.070
Through Trans. UT	96.8	**0.073**	0.087
Thermography	99.3	0.059	**0.069**
Holography	77.5	0.140	0.214

As a result of this work, BFGoodrich commissioned a pulsed infrared thermography system comprising a 640 x 512 pixel InSb (3-5 pm) camera with a 10 mK NETD, a maximum frame rate of 90 s ' and a 12.8 kJ, 5 ms flash system. All control, data collection and analysis are carried out on Pentium II based computers running Windows NT and Thermal Wave Imaging EchoTherm software. All parts are coated with a water washable black paint prior to inspection and areas of 315 x 250 mm are inspected in one image. The system has now been in use for six months and has been extremely successful.

MODELING

PIRT is extremely sensitive to the depth of a defect below the surface (in this case the skin thickness) and has significant practical limitations as to its range of applications. To make a preliminary determination as to the range of application in metallic honeycomb structures, modeling was performed. P4560F finite difference software was used to evaluate models containing in excess of 200 nodes and 450 thermal pathways. The model included the complete geometry of the inspection system, the temporal profile of the flash system and the properties of all materials used. Radiation, conduction and convection were all modeled and time steps varying from 10 to 10" seconds were used to ensure a maximum temperature difference between steps of 6 mK.

The model was tested against data acquired from one of the brazed honeycomb sandwich parts used in the POD study described above . The braze fillets in this sample were nominal and the test data, along with the model predictions for three different fillet geometries, are shown in Figure 3. The predicted temperature profiles across a cell wall and a node at two different times (0.102 and 0.136 seconds) matched the experimental data points (circles) extremely well. In each case the predictions for a full fillet matched the experimental data the best, correlating well with the nominal fillet dimensions that were present in the test sample. The model predicted maximum contrast at 0.102 seconds and this was confirmed in the experimental data.

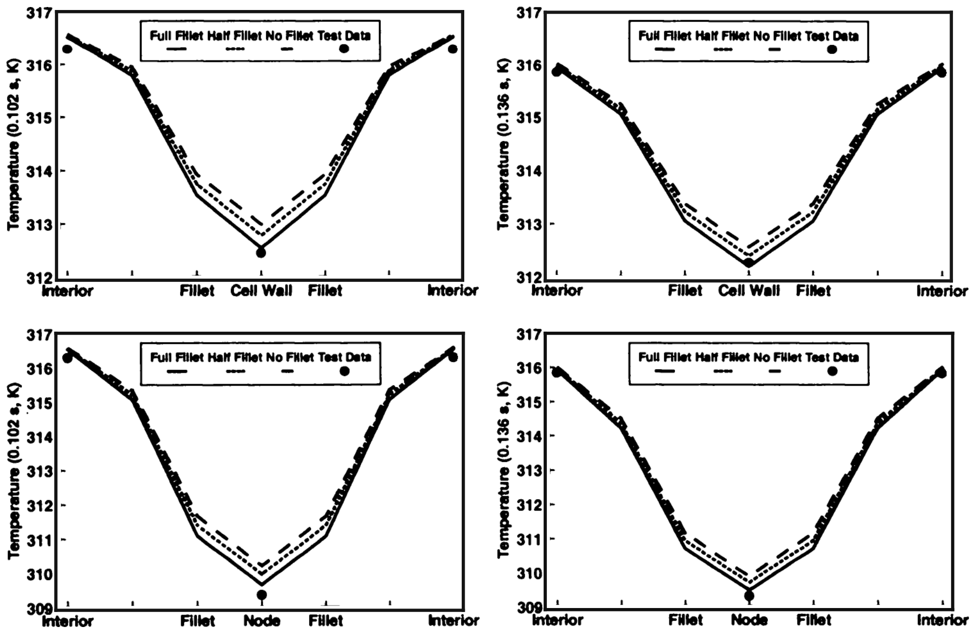


Figure 3 Validation of the model against test data from a 150 pm skin honeycomb panel.

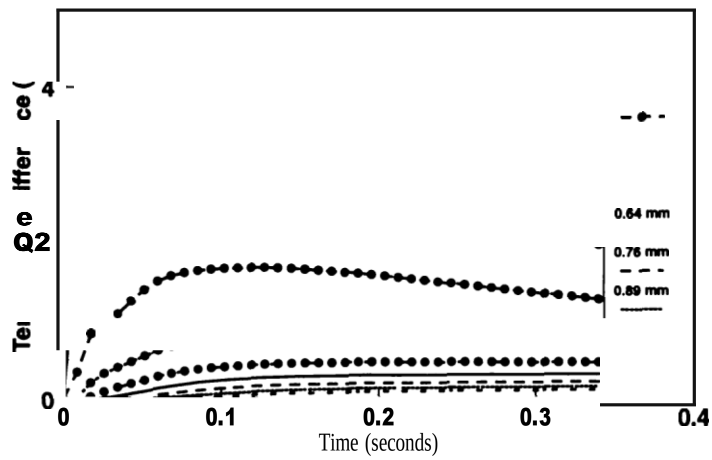


Figure 4 Model predictions for lnconel honeycomb parts with different skin thicknesses.

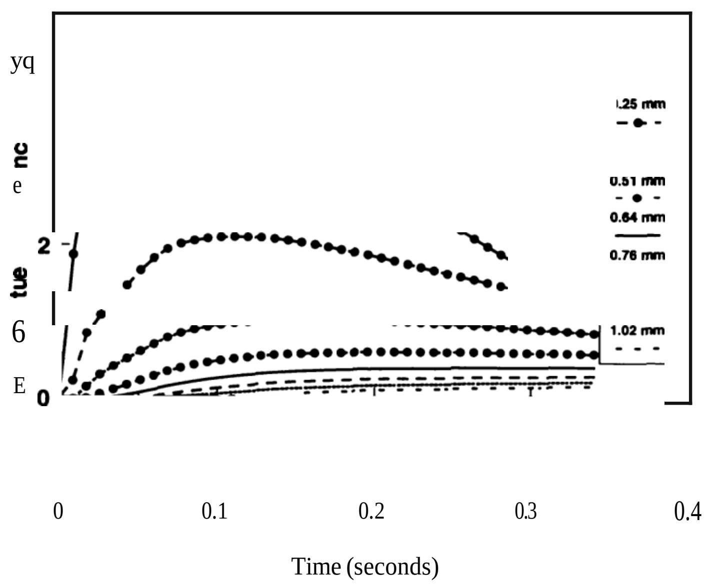


Figure S Model predictions for titanium honeycomb parts with different skin thicknesses.

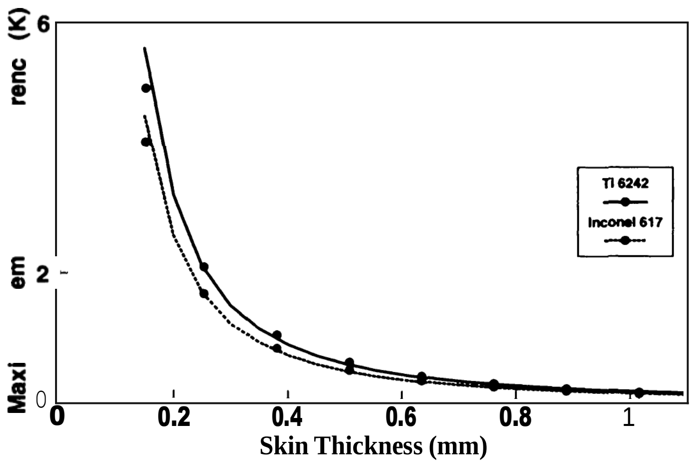


Figure 6 Maximum temperature differences as a function of skin thickness.

The model was then run for a variety of skin thicknesses in both Inconel 617 and Titanium 6242 materials. The results are shown in Figures 4 and 5 where the temperature difference is that between the skin above a cell wall and that above the center of a cell.

Previous modeling had determined that the temperature of the skin above a disbond is identical to that above the center of a cell (where there is no cell wall). As expected, the data show that the thinner the skin, the higher the contrast (temperature difference).

The data can be summarized as plots of maximum temperature difference (contrast) as a function of skin thickness as shown in Figure 6. It can be seen that the contrast falls rapidly with increasing skin thickness, as has been determined experimentally . Theoretical considerations have lead to a prediction that the contrast will be inversely proportional to the cube of the depth. For the model presented here, the contrast is proportional to the square of the skin thickness (actually proportional to the power -1.89 for both materials).

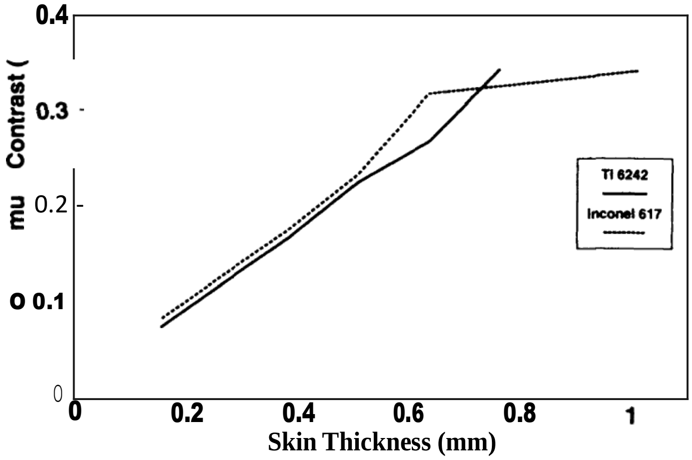


Figure 7 Times of maximum temperature difference as a function of skin thickness.

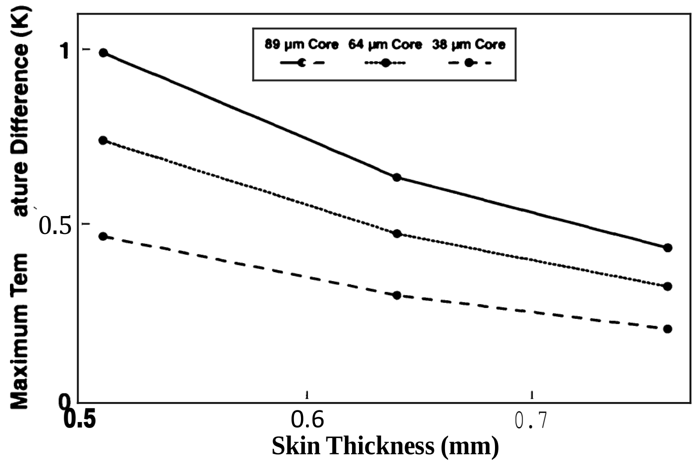


Figure 8 Model contrast predictions for different titanium skin and core thicknesses.

The predicted variation of the time at which the maximum contrast occurs is predicted to be proportional to the square of the depth but the model data in Figure 7 show that the dependence is approximately linear. It can also be seen that the materials had little effect on the model predictions, despite their thermal diffusivities varying a factor of two. Another parameter that was examined was that of the thickness of the material used for the manufacture of the core. In typical manufacturing, this varies from 38 to 89 pm and the results of the model for these core configurations, and various skin thicknesses in Titanium 6242, are shown in Figure 8. In the range of thicknesses examined, an increase in skin thickness of 50% resulted in a decrease in the contrast of 56%. Increases in the core thicknesses (gauges) of 67% and 133% resulted in increases in the contrast of 59% and 13% respectively.

The practical limits of contrast detectability are yet to be determined but a reasonable assumption would be in the range of 25 to 50 times the Noise Equivalent Temperature Difference (NETD), which is 10 mK for this system. The maximum skin thicknesses for different core configurations in the two materials analyzed are shown in Table 2.

Table 2 Maximum inspectable skin thickness for different core configurations.

	Maximum Skin Thickness (mm) for Contrast of	
	0.5K (50 x NETD)	0.25K (25 x NETD)
lnconel 38 pm Core	0.48	0.69
Titanium 38 qm Core	0.45	0.70
Titanium 64 pm Core	0.63	0.82
Titanium 89 pm Core	0.72	0.87

It can be seen from Table 2 that typical brazed lnconel and diffiision bonded Titanium structures with skin thicknesses ranging up to approximately 0.8 mm should be inspectable with a state of the art PIRT system such as that employed at BFGoodrich.

CONCLUSIONS

Pulsed infrared thermography has been shown to be an effective method for inspecting honeycomb sandwich structures. It has an inspection limit equivalent to that for pulse echo ultrasonic testing and can be further improved, at the expense of inspection time.The practical limitations of pulsed infrared thermography in honeycomb sandwich structures lies in the skin thickness; thicknesses of up to 0.8 mm are predicted to be inspectable.

THERMO-MECHANICAL PROPERTIES OF MATERIALS

The behavior of real materials under thermal and mechanical loading is described by a set of physical characteristics, which can be separated conditionally in four groups. The first group of characteristics, including specific heat capacities, thermal conductivity and melting point, describe the behavior of materials under thermal loading without relation to their mechanical properties. The second group of characteristics, including elastic modulus, yield constants, viscosity etc., describes rheological behavior of materials under mechanical loading without fracture. The third group of characteristics, including density, coefficients of thermal expansion and activation energy, describes thermo-mechanical behavior of materials. The forth group of characteristics describes fracture behavior of materials. The dependencies of all characteristics from the temperature describe thermo-mechanical properties of materials.

1. Introduction

Thermo-mechanical properties of materials are studied for the prediction of material behavior in wide range of parameters characterizing their internal state (for example, temperature and deformations) and structure (for example, porosity or permeability). Changes of state parameters and structural characteristics of a material are caused by energy exchange and mechanical interaction of a material with environment. Thermo-mechanical properties of materials which study is required for many practical applications are heat capacity, thermal conductivity, rheological properties, thermal expansion, strength, fracture, freezing point, latent heat, thermal durability, hardness, resistance for abrasion.

Heat capacity and thermal conductivity are the main properties characterizing heat transfer in materials. Heat capacity characterizes material property to absorb heat energy under the heating and to emit heat energy under the cooling. The amount of heat energy absorbed or emitted under the heating or the cooling of material sample with unit mass over a temperature change of 1^oK is called specific heat capacity. Thermal conductivity characterizes material capacity to conduct heat energy under certain temperature gradient. Thermal conductivity is equal to the heat flux through material layer with unit thickness when the temperature of the material on opposite sides of the layer differs by 1^oK. Since specific heat capacity and thermal conductivity are related to unit mass and unit volume of a material the density is also comes into the equation defining conductive heat transfer.

Rheological properties of materials describe relations between internal stresses of materials and their deformations or strains. Constitutive equations are used to describe rheological properties quantitatively. Most known rheological properties are elasticity, viscosity and plasticity. Basically the elasticity assumes that the stresses are proportional to the strains and the work of elastic stresses over closed cycle in stress space is equal to zero. The last property introduces the reversibility of elastic deformations. Physically elasticity is related to the deforming of molecular bonds without their destruction. In the case of small deformations elastic properties of isotropic material are described by Hook's law, Young's modulus and Poisson's ratio. Hook's law sets up linear dependence between stresses and strains. Young's modulus and Poisson's ratio determine deformations of material in longitudinal and transversal directions in relation to applied load. One dimensional model of elastic material is performed by a spring with stiffness equaling to the Young's modulus (Fig 1a). Thermo-elasticity takes into account effects of material deforming under the influence of temperature variations and material heating or cooling under the influence of material deforming. Thermally induced volumetric deformation of isotropic continuum is proportional to temperature variation with the coefficient of thermal expansion.

Viscosity assumes that stresses are proportional to strain rates. Viscous deformations are unbounded and irreversible. All work of viscous stresses is transformed into the heat. Physically viscosity is related to displacements of molecular layers in liquids. In the case of small strain rates of isotropic material the coefficients of rheological equations are reduced to two coefficients: shear and bulk viscosity. The resulting stress and strain-rate relations are linear. One dimensional model of a linear viscous material is performed by a dashpot with certain viscous modulus equaling to the bulk viscosity (Fig. 1b). Some solid materials are deformed as liquids in conditions of high pressure or under long-term loading. The last property is called creep. Constitutive equations describing the creep of materials are nonlinear. There are three constants describing the creeping behavior of materials: activation energy, coefficient of self-diffusion and the power of strain rates in the constitutive equations.

Plasticity assumes the existence of yield stresses, below which the behavior is purely elastic. It is impossible to create stresses higher than yield stresses in plastic material. When stresses reach the threshold a part of strains becomes irreversible. In models of plastic materials threshold stresses lie at the yield surfaces in stress space. Materials have elastic behavior if the stresses are inside the yield surface. Yield surface extends in stress space under plastic deforming of hardening materials and shrinks in case of plastic deforming of softening materials. One dimensional model of a pure plastic material is performed by a nonlinear plastic unit having viscous properties in the case when the load reaches threshold value. Plastic deformation of monocrystals occurs by dislocations movement. In polycrystalline materials plastic deformations are accompanied also by grains reorientation and deformation. Plasticity models are used to describe the behavior of granular materials. There are different types of constitutive equations describing plastic deforming of materials. In classical case the principle of maximal power of energy dissipation for actual stress state is used to calculate strain rates when the stresses are located at the yield surface. Constants describing the shape of yield surface in stress space determine plastic behavior of materials.

Visco-elasticity describes history dependent material behavior. Viscous-elastic behavior is a property of multigrain materials mainly. A general constitutive equation for a visco-elastic material says that a linear combination of time derivatives of stresses equals to a linear combination of time derivatives of strains. Coefficients in this equation describe rheological properties of a viscous-elastic continuum. Visco-elastic rheology describes stress relaxation and delayed elasticity. Relaxation means that stresses inside a material decrease with the time when strains are constant. Relaxation is explained by sufficiently small relative displacements and rotations of grains causing the reducing of internal stresses. Delayed elasticity is related to elastic unloading of grains because of their regrouping due to viscous deformation along the grain boundaries. One dimensional model of visco-elastic material is performed by linear (Maxwell unit) or parallel (Kelvin unit) connections of spring and dashpots or their combination (Fig. 1c,d). Maxwell unit describes relaxation, while Kelvin unit is responsible for the performing of delayed elasticity.

Some materials deform similar liquids under long term loading, i.e. their deformation can take sufficiently high values under applied constant load. This property is called creep. Creep is realized by the same physical mechanisms as plasticity. Typically the dependence between stresses and strain rates is nonlinear by the creep. One dimensional model of creep material should include Maxwell unit with nonlinear dashpot characterizing by several rheological constants. The nonlinear behavior of creep materials is called visco-plasticity.

Thermal resistance is a capacity of materials to keep their internal structure and strength under sharp changes of the temperature. Thermal resistance is characterized by a number of temperature cycles during which a material keeps its internal structure and strength. Frost resistance is a capacity of water saturated materials to keep their internal structure and strength under consecutive freezing and melting. Frost resistance depends on material porosity. Materials with higher porosity have lower frost resistance. Physically frost resistant is related to the formation of tensile stresses in porous space due to the freezing water.

The fracture of materials is related to the nucleation of initial cracks and the growth of existing cracks. Ductile fracture of material sample is accompanied by plastic deformation, i.e. it is realized when stresses reach the level of yield stresses. Typically ductile fracture is associated with big shearing deformations and significant changes of the shape. Brittle behavior occurs before stresses reach the level of yield stresses. It is associated with fast growth of one or several cracks and sudden separation of a sample into a set of smaller pieces. The resistance of a material against brittle fracture is an important material property. The resistance is proportional to the energy of inter-atomic bonds in transversal direction to some plane. Measurement of this quantity is carried out under low temperatures or using material samples with small cuts, since it is very difficult to avoid the influence of plastic deformations in natural conditions.

In many practical applications the concept of material strength is used to simplify the description of materials under loading. The strength characterizes critical stresses when material becomes destroyed in ductile or brittle modes. Typically compressive, tensile and flexural strengths are considered. The strength is determined in experiments with material samples of certain shape and size according to standards used for different types of engineering constructions. For example, compressive strength is measured by the compression of cubic or cylindrical samples in a press. It is assumed that compressive strength is equal to maximal load measured in the experiment divided on the area of the surface over which the load was applied to the sample. Experiments for determining the tensile strength are organized in the same way. Bending strength is measured by the bend of beams which length is greater their transversal dimensions in certain number of times. In design simulations it is assumed that admissible stresses should be smaller than the strength of construction elements. The strength reserve is designed to take into account heterogeneity, damage and fatigue of real materials.

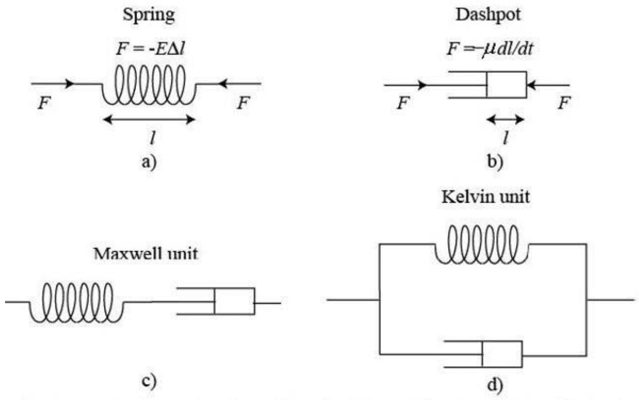


Figure 1. Units used for the performing of rheological models of materials. E is elastic modulus (Young’s modulus), μ is bulk viscosity.

2. Thermal properties of materials

Specific heat capacity

Specific heat capacity of inorganic building materials (concrete, break, natural stone) is varied within 0.75-0.92 kJ/(kg°C), for wood it is 0.7 kJ/(kg °C). Since water has very high specific heat capacity of 4 kJ/(kg °C), the specific heat capacity of materials increases with the increase of their humidity. Specific heat capacity of composite materials can vary significantly if temperature variations are accompanied by phase changes. Typical example is related to sea ice consisting fresh ice and brine cells. The heating of sea ice is accompanied not only by the increasing of sea ice temperature but also by the melting of fresh ice around brine cells. This process becomes more important with increasing sea ice temperature.

<table>
<tr><th rowspan="7">Specific heat capacity, kJ/(kg°C)</th><th>Solids</th><th>Liquids</th></tr>
<tr><td></td><td>Ammonia (4.19); Water (4)</td></tr>
<tr><td>Paraffin (2.72); Ice (2.14)</td><td>Aquafortis (2.77); Hexane (2.51); Phenol (2.35); Kerosene (2.1); Azote liquid (2.01)</td></tr>
<tr><td>Plastic (1.76; Cork, Rubber (1.68); Wool (1.63); Cellulose (1.55); Coal, Naphthalene (1.3); Concrete (1.13)</td><td>Benzene (1.84); Turpentine (1.7); Luboil, Liquid oxygen (1.68); Nitrobenzene (1.38)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Aluminum, Clay, Brick (0.92); Coke (0.84); Sand (0.8); Glass (0.84-0.42); Slag (0.75); Wood (0.7); Iron, Steel (0.5); Copper (0.385); Zinc (0.38); Lead (0.13)</td><td></td></tr>
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Table 1. Mean specific heat capacities of solid and liquid materials in temperature range 0-100°C

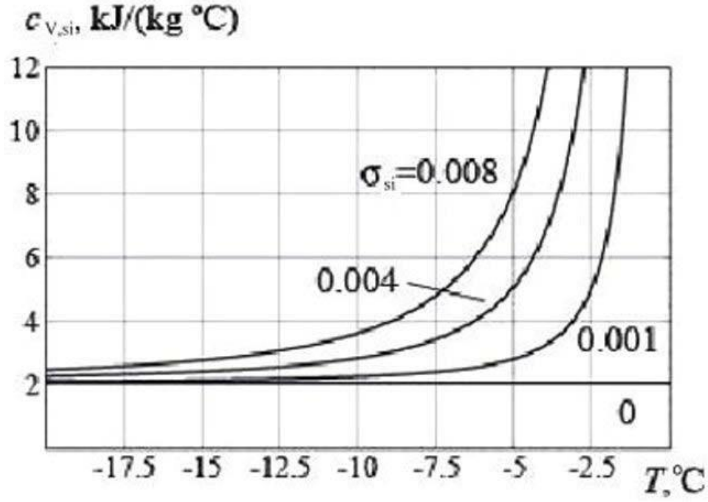


Figure 2. Specific heat capacity of sea ice versus its temperature for different values of sea ice salinity

Thermal conductivity

Thermal conductivity of materials with simple chemical composition is greater than thermal conductivity of materials of complicated chemical composition. Thermal conductivity of materials with crystal structure is higher than thermal conductivity of materials with mixed or amorphous structure. For example, mean thermal conductivities of single crystal of quartz is 7-8 W/(m °C), for sand-rock with impurities it is 2.1-2.9 W/(m °C), and for normal glass with amorphous structure it is 0.76 W/(m °C). Porous materials conduct heat through the continuous material and through the pore space. Porous material has smaller thermal conductivity than continuous materials when the pores are filled by air. Thermal conductivity of materials with small closed pores is smaller than thermal conductivity of the same material with bigger pores under the same overall porosity. It is because heat transfer due to convection is reduced in the material with smaller pores.

Material	**Density, kg/m^3**	**Thermal conductivity, W/(m°C)**
Foam plastic	30	0.047
Cork fines	110	0.047
Glass-wool	200	0.35-0.047
Cinder-wool	250	0.076
Felt-wool	300	0.47
Wood cross fibers	600	0.14-0.174
Wood along fibers	600	0.384
Asbestos	600	0.151
Insulation brick	600	0.116-0.209
Textolite	1380	0.244
Dry sand	1500	0.349-0.814
Brick lining	1700	0.698-0.814
Fire brick	1840	1.05
Concrete	2300	1.28

Aluminum	2700	203.5
Cast Iron	7500	46.5-93
Steel	7850	36.5
Stainless steel	7900	17.5
Bronze	8000	64
*Latten	8500	93
Copper	8800	384
Lead	11400	34.9

*Bronze-like yellow alloy used to make church utensils in the middle ages by beating it into thin sheets by virtue of its malleability and ductility.

Table 2. Density and thermal conductivity of solid materials

Melting point

Crystal materials have certain melting points above which their crystal structure is destroyed. Below their melting point crystal materials are solid and above it they become liquids. The softening of amorphous materials occurs gradually with increasing temperature, evolving into viscous fluids with decreasing viscosity under increasing temperature (Fig 3a).

Material	**Melting point, ^oC**	**Material**	**Melting point, ^oC**
Water	0	Zinc	419
Wolfram	3370	Lead	327
Gold	1063	Tin	232
Iron	1535	Mercury	-39
Copper	1083		

Table 3. Melting points of some materials

Physical properties of many materials depend on the proximity of their temperature to the melting point. This property is characterized by homologous temperature calculated as a ratio of the actual temperature to the melting point. Homologous temperatures of some materials are shown in Fig. 3b) in natural range of actual temperature from -100^oC to 100^oC.

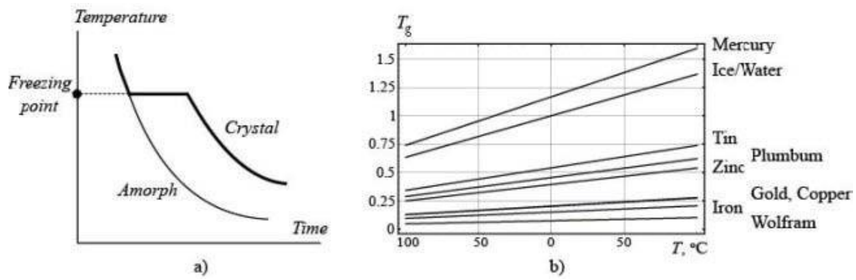


Figure 3. Temperature-time curves for the cooling of amorphous and crystal materials (a). Homologous temperature of some materials (b).

Latent heat

Latent heat is equal to the amount of energy necessary for the melting of unit mass of crystal material at the freezing point. Materials with high latent heat are more stable.

Material	Latent heat, J/kg
Ice	334000
Lead	23100
Copper	214000
Iron	270000
Mercury	11800

Table 4. Latent heat of some materials

3. Thermo-elastic properties of materials

Young's modulus

Isothermal Young's modulus is equal to the ratio of uniaxial stress applied to material sample with unit area of transversal cross-section to its relative lengthening under constant temperature. Young's modulus is measured in Pa/m^2. Adiabatic Young's modulus is determined in the same way but without heat exchange of a sample with the surrounding. Adiabatic Young's modulus (E_{ad}) is related to isothermal Young's modulus (E) as follows: $E_{\mathrm{ad}} = E(1 + E\kappa^2 T_0 / (\rho c_{\mathrm{V}}))$, where κ is the coefficient of thermal expansion, T_0 is the initial temperature of material sample in $^{\mathrm{o}}$K, ρ is the density and c_{V} is the specific heat capacity. Adiabatic Young's modulus is bigger isothermal Young's modulus since in adiabatic process the work of external stresses spends for mechanical deforming and heating or cooling of a material, while in isothermal processes all work of external stresses spends for mechanical deforming. As a result adiabatic strains will be smaller isothermal strains for the same stresses. In natural conditions the difference between adiabatic and isothermal Young's modulus for metals is about 1-2%, for polymers it can be much greater. Difference between E and E_{ad} is important for the damping of high frequency elastic oscillations in materials. Isothermal Young's modulus typically increases with decreasing temperature.

Application Fields of Infrared Thermography

There is more to this world than can be seen with the naked eye. The human eye is only capable of capturing certain light ranges and is also limited in its ability to capture certain high-speed movements or invisible forces. From the heat of a human body to invisible gases, human sight has limitations that can be solved by infrared and thermal imaging technology.

Below you can learn more about the basics of infrared cameras and thermal imaging. In addition to reading more about the basic tenets of the field, you'll learn more about some of the exciting and commonplace applications of infrared cameras in the world today.

What is Infrared and Thermal Imaging?

The human eye, as mentioned above, is only capable of capturing a very small portion of the greater electromagnetic spectrum. Short, intense wavelengths of light and long, slow wavelengths are outside the capability of the human eye. This is where infrared cameras and thermal imaging can fill in the gaps in human sight. Thermal energy has a much longer wavelength than visible light. It is so long in fact that the human eye can't even see it.

Thermal imaging with infrared cameras expands the "visible" spectrum of the human eye by doing the work an eye cannot. It perceives these longer wavelengths and captures them in a color-coded world that the human eye can understand. Everything in the world with a temperature above that of absolute zero emits some level of heat which can be detected and measured.

FLIR

Also known as Forward Looking Infrared, these cameras are very common in police helicopters, military aircraft to spot heat sources and displayed via video output. FLIR cameras are very different from other night-vision devices and conventional infrared cameras however, since these only display a certain infrared range.InfraTec offers a flexible thermography software for every application field, stationary or mobile, thus satisfying the most specific of customer demands.

Active Thermography for Non-Destructive Material Testing

Active thermography is mostly referred to as induction of a heat flow by energetically exciting a test object. Heat flow is influenced by interior material layers and defects, which can be captured by high-precision infrared cameras. This makes different evaluation of algorithms and improves the signal-to-noise-ratio which detects even the smallest defect. The uses in this field include:

- Non-destructive and contact-free material testing, for both automated in-line and off-line solutions
- Detection of layer structures, delamination and inserts in plastics
- Detection in CFRPs of the automotive and aerospace industry
- Investigation of interior structures or impacts on honeycomb lightweight constructions
- Recognition of deeper material deficiencies, such as blowholes in plastic parts or ruptured laser welding seams

Aerial Thermography

Aerial Thermography's history begins with military applications starting as early as the Korean war, used to detect enemy forces and resources on the ground. High geometrical resolution of the infrared camera system allows detection of even the smallest detail from a great height, which can then be used for both observation and monitoring. While this is always being developed by the US military for continuous improvement, these are some examples of its varied usage within other fields:

- Enhance the visual clarity of small items on the ground
- Assess the extent of environmental damages without risking human lives
- Fast infrared camera systems offer low smearing
- Integration of GPS data and visual images
- Wide range of accessories like gimbal systems
- Monitor large geologic properties for changes
- Inspect the thermal storage capabilities of biotops on industrial complexes

Thermography in Aerospace Industry

Aerospace sets the greatest demands on Infrared camera systems due to the high safety and material requirements presented. Often, high thermal resolutions of 20 mk and/or high frame rate of 100 Hz and more are necessary. Aerospace firms can use thermography to test active heat flows on new composite materials to ensure the next generation of lighter, more fuel-efficient aircraft

Thermography in Automotive Industry

Deconstructing parts of the car can be cumbersome, and thermography offers a non-invasive and non-destructive approach testing which saves time and effort. Tight competition and the chase for better performing, fuel-saving, and lighter automobiles inspires thermography to provide the needed efficiency through doing quality checks on every electrical system, motor assemblies and window heating elements. It provides detection of defects and deficiencies of multiple products for the automotive industry only detected through temperature changes and allows reconciliation of thermal behavior of components with their standard behavior.

High-Speed Thermography

High speed image capturing opened doors to new possibilities in thermal imaging, allowing observation of high-speed thermal processes. This allows for minute observation of parts and systems and helps in understanding rapid acting chemical processes and combined with powerful measurement and reporting software provides a vast wealth of information. These cameras utilize special detectors and acquisition units called snapshot detectors, and their ability to acquire and display data in parallel provides precise thermographic measurements down to the millisecond range.

Thermography in Chemical Industry

Industries dealing with hazardous and non-hazardous chemical materials can benefit from infrared cameras helping to detect the resulting heat flow from chemical processes. Thermal imaging makes it easier to capture and measure the temperature distribution with greater accuracy, and also enable the analysis of chemical reactions through the entire process chain. Best of all, the non-invasive and contactless nature of thermal imaging means people are kept at a safe distance while thermal imaging cameras do all the legwork to collect relevant data.

Thermography in Electronics and Electrical Industry

Electrical systems and electrical distribution equipment can benefit from the application of infrared cameras and thermography technology. Not only does it prevent humans from having direct contact with these systems and circuits, testing and detection can be conducted without interrupting the flow of power.

Common problems that can be detected in the electrical field courtesy of infrared imaging include:

- Loose connections
- Poor contacts
- Overheated bushings
- Blocked cooling passages

Manufacturing industries can also benefit from electrical thermography to monitor possible overheating, keep a close eye on tank levels, process line inspections, and even assess the condition of circuit boards.

Inspections of Mechanical Components

Infrared cameras can safely inspect mechanical systems from various industries to detect issues before they become major problems. Thermal imaging applications as it pertains to mechanical inspections are diverse and include, but are not limited to:

- Detecting blocked air coolers and radiator tubes in internal combustion engines
- Finding air leaks and clogged condenser tubes in refrigeration systems
- Locate and identify overheating bearings, increased discharge temperatures, and excessive oil temperatures in pumps, compressors, fans, and blowers

Thermography for Material Testing

Infrared thermography cameras offer a powerful alternative when studying structural situations or testing materials in a non-destructive manner. Since everything in this world emits infrared as long as its temperature is above absolute zero, non-destructive material testing is possible with infrared because it can capture measurements and readings from any surface upon which heating or cooling takes place. Using infrared cameras for thermal imaging in these settings is not only non-destructive, it is non-invasive as well.

For example, building inspections can be completed using infrared testing. When looking to improve upon energy efficiency and lead the world forward in the fight against climate change, improving building structure to combat energy loss and resource wasting is greatly aided with the use of infrared cameras.

Thermography in Medicine

Thermal imaging applications abound in the field of healthcare, both for humans and animals. Infrared thermography in thermography is being used to help detect cancer earlier, locate the source of arthritis, and even catch circulation issues before they become too problematic. Doctors and veterinarians alike can use infrared cameras to discover muscular and skeletal problems early on. One example of thermal imaging in this field is the growing use of infrared cameras to fit horses with safer saddles.

Thermography in Metallurgy

The field of metallurgy is entirely dependent upon the right materials heated to the right temperature to ensure a proper outcome. In this case, infrared cameras and thermal imaging offer a number of benefits. First and foremost, infrared thermography in metallurgy can help reduce energy consumption by detecting defects in the insulation of heating chambers, cracks in pans, or issues with similar devices. The speed and precision of thermal imaging make it easy for metallurgy to benefit from infrared cameras.

Microthermography

Many of the thermal imaging applications discussed on our site focus on large-scale operations. Given that infrared cameras can not only show mankind things it cannot see with the naked eye, it can also examine processes that cannot be seen or analyzed properly by the naked eye. There are many microthermography applications, which is to say, those which take place on microscopic scales.

A common example comes from the field of mobile technology as circuit boards and processors continue to shrink to fit modern devices. However, there are other popular thermal imaging applications at the microscopic level. For example, it can be used to visualize and detect the latent heat of freezing for a cluster of biological cells, aiding in cryopreservation and the advancement of biotechnology. Microthermography can also be used to observe the crystallization of organic materials.

Infrared Cameras for Plant Inspections

Plant inspections require the highest quality in monitoring to check all possible faults that may cause accidents or pose a threat to safety of its employees. Using thermography in predictive maintenance is often used to find faults in both electronics ad manufacturing companies. Infrared systems provide efficient inspection without contact or interfering with the normal / daily operations or risking maintenance personnel. Infrared cameras provides overview and initial results and makes the process safer and efficient.

Infrared Cameras for Security

Infrared cameras deliver more to the field of security than simple threat detection and enemy movements on the field of battle. Thermal imaging applications in security can be used to detect smoke-filled rooms, provide effective home security, or even to locate weapons and chemicals being smuggled into prisons or county jails.

UNIT - 6

INDUSTRIAL APPILICATIONS OF NDE

Railways :-

A Number of railway Components and assemblies are tested and evaluated using "NDT" methodologies during manufacture for freedom from unacceptable defects and anomalies. The major Components subjected to Various NDE methods are : Wheels, axles, bearings, rails, welded rail joints, bridges etc.,

The test methods Commonly used during fabrication are Visual examination, the magnetic particle test, the liquid penetrate test, ultrasonics and radiography. These are used to detect and evaluate surface, sub-surface & internal defects.

During service, NDE methods are used to monitor Components to ensure their Continued usage. However, it is essential to take account of the fact that these Components are subjected to extreme Conditions of several loads, frictional wear, high temparature and Corrosive environment. These factors are led to the initiation of Cracks, breakage of Components, guage spreading, unacceptable residual stresses & deterioration of material. It leads to accidents, derailments and failure of individual Components. To minimize the Occurence of accidents or the deterioration of components and assemblies beyond acceptance limits. Components and assemblies are subjected to periodic NDE checks & records are maintained, keeping in the view the traceability requirements.

Usually, specific test and evaluation techniques are developed for each situation, depending on the part configuration, assembly condition, test environment & sensitivity required by acceptance standards. Currently, ultrasonic methods in pulse-echo modes constitute the most widely used NDE method, in the frequency range of 2-5 MHz for the detection, location and evaluation of defects. Ultrasonic velocity gives a good idea of material deterioration & unacceptable residual stresses.

Nuclear, Non-Nuclear & chemical industries :-

Welding is the major manufacturing process for various equipment and assemblies in nuclear, non-nuclear and chemical industries. The major equipment & assemblies fabricated by weld and pressure vessels, boilers, heat exchangers, storage tanks, industrial & transmission piping.

The materials used to fabricate these components are comprised of "low carbon steel", "low alloy steels", "stainless steels", ferritic

(3) stainless steels, Nickel base alloys, Copper-nickel alloys, Titanium, admiralty brass etc., The commonly used process of welding are TIG and MIG.

The Role of NDE during fabrication is to ensure the structural integrity of components. NDE methods ensure the acceptability of butt & fillet welds for satisfactory root penetration; proper fusion in fillet welds for joint efficiency & freedom from unacceptable cavities.

During the fabrication of pressure vessels, NDE is required to examine and evaluate longitudinal, circular & Nozzle welds. Radiography, magnetic particle, liquid penetrant & ultrasonic methods are commonly used. The documents are prepared based on universal accepted codes, standards and specifications.

Heat exchangers from vital components in large number of process plants. These are examined during fabrication to control the process of fabrication and during usage to prevent failures & initiate replacement. Usually, the following techniques are used to examine tubes. eddy current, ultrasonics, helium leak test and visual examination.

Bobbin type eddy current probes are inserted into the tube through a probe drive system. Multi-frequency test modes are used to detect local corrosion, erosion and cracks and also to locate foreign materials.

(4) Ultrasonic rotatory inspection using the pulse echo techniques used to examine the circumference of the tube wall. The tube wall techniques is assesed by visual examination with the help of cameras and endoscope. Liquid penetrant methods are also used to assess the presence of corrosion in the tube sheet. These examinations are done by the helium-leak test.

Table 9.1 gives a brief idea of defects introduced in components during fabrication and service and the most commonly used NDE methods for their detection & evaluation.

Components	Defects	Commonly used NDE methods
Pressure vessels and boilers	Lack of penetration, lack of fusion, cavities, cracks, porosity, corrosion, pitting, thermal fatigue check etc.	Radiography, ultrasonics, Magnetic particle, Liquid penetrate, visual check.
Heat Exchangers	General corrosion, pitting, support plate fretting, stress corrosion cracking & mechanical damage.	Eddy current, ultrasonics, p-scan, Helium leak test, visual examination, Magnetic flux leak test.
Pipes (Metallic & Composite)	Inter-granular stress corrosion, pitting, micro biologically initiated cracks etc.	Ultrasonics for surface breaking cracks, radiography, acoustic, visual checks.

(5) Storage tanks (above ground & under ground build tanks)	Corrossion, Wall-thickness change and welding defects.	Radiography, ultrasonics, Visual Checks, Magnetic flu[x] leakage Check, Remo[te] Video Camera mount[ed] on Robotic arm. It used to perform ultrasonic weld inspection.

Aircraft and Aerospace Industries :-

The Role of NDE in aircraft & aerospace industries is Considerably influenced by the following features of design appilications.

* The selection of materials and manufactur-ing processes is dictated by design requirements of high specific strength and stiffness. This means that Components have to be light weight and highly loaded. Tolerance for design stipulated properties and the dimensions, size and distri-bution of defects is very stringent.
* Aircraft and Aero-engine Components operate under Cyclic loading and are prone to fatigue Cracking. Further, Components are subjected to a hostile environment of Corrossion, erosion & extreme temparature variation and ligthing strikes.
* Increasing usage of Composites, foam honey-Comb, and sandwich structure, particularly

(6) for aerospace and aircraft components.

In view of these features, every component needs to be carefully examined and certified below before assembly into the systems. During service, aircraft and aeroengine components are monitorized periodically for continued servicability throughout their useful lives.

The selection of NDE techniques depends on the test environment, assembly condition and the required deflect sensitivity. Test techniques are required to detect, locate & evaluate the defect / damage before it comes as a major problem.

Automotive Industries :-

Automotive industries are using more than 180% steel for fabricating automotive parts and conventional welding methods for producing body structures. However, the situation has undergone drastic changes due to following reasons.

* The industry has become highly competetive, hence cost effectiveness has become a major production strategy.
* There is demand for increased safety and conformance to strict environment regulations
* There is desire to fulfill the needs of car owners for many luxury features.

(7) *, There is demand for light weight design to save as much petrol and deisel as possible.

These demands have necessitated the use of lighter materials like alluminium, magnesium adhesives and composites, coupled with an innovative design approach and new joining techniques.

The introduction of lighter material components like aluminium & magnesium alloys castings, new welding technique, and innovative design features coupled with the introduction of adhesive joint necessities the introduction of commensurate NDE methodologies during manufacturing and maintanence.

The inspection of aluminium and magnesium castings and fiber-reinforced composites is carried out by film radiography and computer tomography.

Tomography allows the detection and location of defects like porosity, shrinkage cavity and the determination of internal wall thickness and core mismatch. Low KV radiography is used to examine fiber-reinforced composites.

Apart from radiography and ultrasonics, other conventional methods are used for evaluating surface and sub-surface defects.

The objective of NDE is to control and monitor the quality, detection and evaluation of defects and wear analysis so that necessary

(8) Action is initiated before premature failure of the component in service.

Offshore Gas and petroleum projects:

NDE methods are extensively used in two major areas in offshore gas and petroleum projects, namely the fabrication of drilling platforms and the inspection of flexible pipes.

The Main Components of a drilling platform are legs and piles, which are tubular sections welded together. The lower sections are larger in diameter and thicker than the upper sections. The structure has longitudinal and circumferential welds, which are examined by gamma radiography. Co 60 is used as the source of penetrating radiation.

Ultrasonic methods are also used to assess various weld joints. However, operators who perform the ultrasonic test must be approved as per the API guidelines for their qualification.

Initially, efforts are made to correlate radiographic and ultrasonic indications to establish confidence levels. Ultrasonic tests method include the pulse echo as well as time of flight techniques. A-, B- and C-scan methods of data presentations are used to indicate the condition of the centre volume

(9) of the welded area. The magnetic particle test and visual examinations are carried out to check for surface and sub-surface defects.

Flexible pipes are used for production, gas lift or water injection. These pipes are composite multi-layered structures and are critical components of offshore exploration activity.

These pipes link the offshore platform and the wellhead on the seabed and are subjected to corrosion, erosion and fatigue. NDE inspection on these pipes includes visual examination using remote-operated vehicles or by divers, eddy current methods and X-ray radiography. Magnetic flux leakage methods are also being tried.

Coal Mining industry: -

Non-destructive test and evaluation methods are widely used in "Coal mining industry" to ensure freedom of mining equipment from harmful manufacturing defects, control of service and environment related defects during life cycle management and providing warning systems for prevention and control of accidents and dust control.

Mining industries use hoisting systems for moving personnel and material in vertical &

(10) inclined shafts through cage. Rope haulage system is used for transporting men, materi-als and waste. The systems are used items like suspension gear pulley. Transportation system either by hoisting (or) haulage are required to the reliable and safe during service.

Effects of various defects depend on their location, service and environment constraints and stress field. To ensure serviceability of components and assemblies, it is important to document acceptable defects depending on their morphology.

In so far as application of NDE is concer-ned following methods are regularly used.

* Visual inspection to detect gross surface defects.
* Magnetic particle test to detect surface and subsurface defects in ferromagnetic components.
* Liquid penetrant test to detect surface defects in all components except highly porous components.
* Eddy current test methods to detect surface and sub surface defects in conducting materi-als specially steel wire ropes for detection

of broken wire and Corrosion.

* Radiography and ultrasonic methods find appilication to test and evaluate castings & weldments.

Life cycle maintanence of Components & assembly require periodic examination depending on the accesability, field Condition and availability of equipment/test facility. Feedback from such tests may be used for risk assesment in allowing some defects for economic reasons.

Another area of importance and Concern where NDE potential can be utilized is safety in Coal mines. parameters requiring regular monitoring are; gas Concentration, underground water level, Oxygen Content, dust level, roof pressure. possibility of toxic gas emission and cave-ins.

When materials are cracking, deforming or otherwise becoming damaged, they produce a kind of sound. Sometimes, these sounds are loud and obvious. Other times, they are much more subtle, and to detect them, you need to use specialized equipment. Detecting these subtler sounds through acoustic emission testing (AET) can reveal cracks and other defects that are forming which may cause significant issues, such as equipment failure, in the future if not corrected.

What are Acoustic Emissions?

The term acoustic emission (AE) refers to the creation of transient elastic waves due to rapid energy release from localized sources in a material. These acoustic waves are emitted by solid materials when they experience deformation or damage. AE is associated with a permanent alteration of the microstructure of a material. A simplified explanation is that AE is the sound produced when a material becomes damaged, although other types of waves, in addition to sound waves, may also be involved.

Various events can generate AE, including:

- The dislocation movement causes by plastic deformation or yielding
- The formation and extension of cracks in an object under stress
- Phase transformation
- Thermal stresses
- Cracking during cooldown
- Stress build-up
- Twinning, a form of crystalline distortion
- Matrix cracking
- Fiber breakage
- Debonding

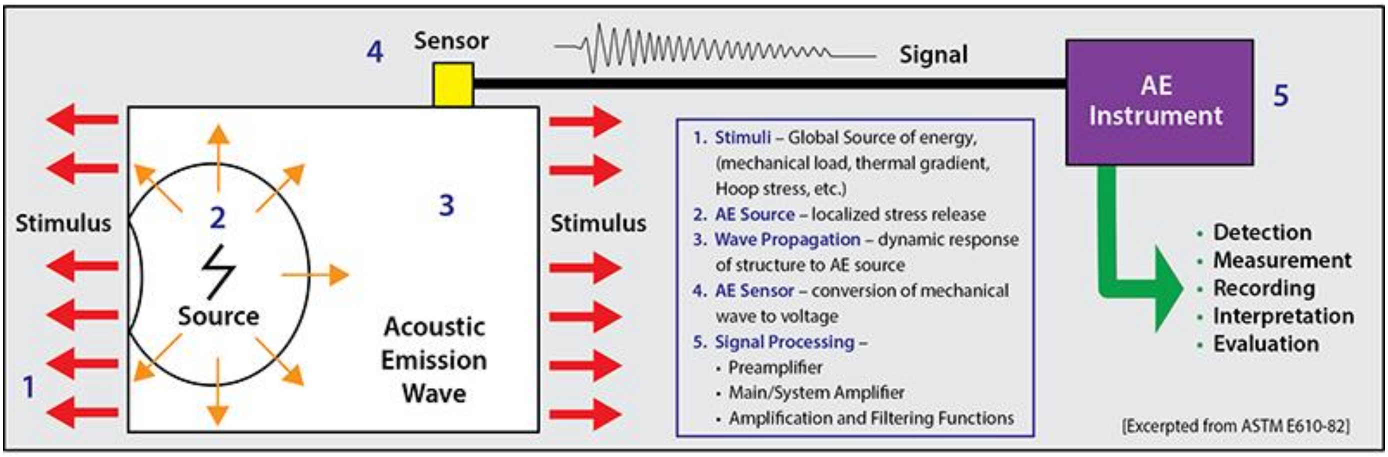
AE can occur in various types of materials, including metals, plastics, polymers, concrete and wood. The characteristics of an acoustic emission depend on various factors, including the event that caused the AE and the material involved. Matrix cracking, for example, tends to produce a low amplitude emission, while crack propagation produces a higher amplitude emission.

What is Acoustic Emission Testing?

The term acoustic emission testing (AET) refers to the process of detecting and recording AE using specialized equipment. AET is a type of nondestructive test (NDT) that has various uses, including ensuring the structural integrity of vessels, monitoring weld quality and more. The process involves using sensors to detect AE and then converting the waves into electrical signals so that they can be recorded. You can then analyze the results to assess a material’s condition and locate any defects. The recorded information can provide potentially valuable information about the origin and significance of a defect in a structure.

There are several slightly different methods used for acoustic emission testing. Some of the main methods include:

- **Global screening:** One method is used to screen all components and involves increasing stress levels to slightly above normal using thermal or pressure gradients to reveal stress risers and cracks. For example, you might increase the pressure in a reactor to 110% of the typical maximum operating pressure. Raising the pressure should reveal active defects that are not apparent under normal operating conditions but will likely continue to worsen over time.
- **Monitoring during Normal Operating Conditions:** Another method involves monitoring known flaws or detecting unknown flaws that can't easily be discovered by increasing stress levels. With this method, the AE signals result from actual damage progression or crack propagation. For example, you might monitor coke drums over time for thermally induced fatigue cracks. In this method, rather than artificially increasing the load for the purpose of testing, you use AET to monitor a vessel for significant damage progression.
- **Proof tests:** The goal of a proof test is to show that a given structure can handle loads up to a certain amount. In the test, you increase the load to the required amount. If successful, the test will not record any significant emissions.
- **Failure tests:** A failure test aims to determine the load at which a structure begins to fail. It involves gradually increasing the load until the system begins to record emissions that indicate failure is beginning to occur.
- **Fatigue tests:** Fatigue tests involve applying a cyclic load to a structure to estimate its working lifetime.



Setting Up the Equipment

For testing a small component, you may only use one acoustic emission sensor. Typically, however, multiple sensors are used and spread across the surface of the object. This is, in part, because different sensors may pick up different signal characteristics for the same emission event, especially in complex structures. When setting up sensors, it's typically ideal that each area of interest is within the acoustic range of at least three sensors. Often, a pattern of interlocking triangles or interlocking rectangles is used to set up sensors.

It's also important to use a fluid couplant to help the sensor obtain a stronger signal, which it does by increasing the surface area that is transmitting the force. Various types of fluid couplants can be used, including resins, greases and sealants. Different types of couplants may work best in different applications. Couplants can also help bond the sensor to the surface, and tape, magnetic hold-downs, springs or other items are used to further secure the sensors.

The sensors are connected to a low-noise preamplifier and a main amplifier, as well as additional electronic equipment used to filter and isolate the sound. These devices help make the reading clearer and easier to analyze accurately. Shielding is also important for reducing electrical noise. The sensors and other equipment are connected using coaxial cables to a computer that records the readings.

Running the Test

After setting up the equipment, the test is begun by applying the required load. For example, the test may require increasing the pressure in a vessel to slightly above the normal operating pressure. The system may also continue to operate as usual if the test aims to monitor performance under normal operating conditions.

Once the test begins, the AET system will record any AE above a pre-determined threshold, along with the exact time it occurred. The system will record data related to emission count, signal length, peak amplitude, emission strength and other chosen parameters. The distance between the emission source and the sensor affects the recorded emission strength, so the strength recorded by multiple sensors is often averaged to help estimate the strength of each emission.

Various techniques can be used in acoustic emission testing. The ideal equipment setup and testing process depend on the type of structure being tested, the material being tested, the type of test being conducted and other factors.

Analyzing the Results

Once the test is complete, the results are analyzed. Alternatively, for some types of tests, you can conduct analysis while the test is taking place. Analysis involves looking for the occurrence of AE, measuring the rate of each emission and determining the location of any defects. With modern computer systems, the results of the test show up as a graph, which helps in interpreting the results. By measuring the arrival time of an AE signal to each sensor, you can determine the defect's location using triangulation. After locating the flaw, you can perform additional inspection or begin taking steps toward correcting the flaw.

What Are the Applications of Acoustic Emission Testing?

AET is very versatile and has many applications across a variety of industries. It's also used as a research tool. Some of the applications of AET include:

- Detection of active sources, including yielding, crack propagation, fatigue, creep, fiber delamination, fiber fracture, and corrosion.
- Structural integrity evaluation
- In-field inspection
- Weld quality monitoring
- Production quality control
- Leak detection
- Monitoring chemical reactions and phase changes
- Laboratory and research and development (R&D) studies

Who Uses Acoustic Emission Testing?

A wide variety of industries can use AET, including:

- **Aerospace:** The aerospace sector can use AET to assess aging aircraft, motors and fuel storage tanks.
- **Alternative energy sources:** AET is useful for testing the structural integrity of alternative energy infrastructure such as wind turbines.
- **Automotive:** Automotive manufacturers may use AET to assess vehicle components, as well as factory equipment.
- **Chemical and refinery:** Companies in the chemical and refinery sector can use AET to test for defects in plant equipment and vessels.
- **Infrastructure:** AET is valuable for testing the structural integrity of bridges, tunnels, dams and other types of infrastructure.
- **Manufacturing:** Manufacturers can use AET to test a wide range of manufacturing equipment types, as well as ensure product quality of certain types of goods.
- **Materials research and development:** Those working in materials research and development can use AET to test the integrity of new and existing materials in various applications.
- **Nuclear power:** AET can be used to inspect nuclear components, such as lift beams, valves and steam lines.
- **Offshore drilling:** AET can provide early detection of faults in offshore drilling platforms and pipelines.
- **Oil and gas:** Oil and gas companies can use AET to test pipelines, vessels and processing equipment.
- **Power distribution:** AET can be used for partial discharge detection in power transformers.
- **Pressure vessels and piping:** Manufacturers of pressure vessels may use AET to ensure product quality. Users of this equipment may also use AET to test the condition of their equipment.
- **Process technology:** Process technology professionals in the fields of wastewater treatment, chemical processing, power generation and more can use AET to test the integrity of system components.
- **Pulp and paper:** AET is used in the pulp and paper industry for testing the integrity of vessels, tanks, piping, tubing and other equipment used in manufacturing operations.
- **Transportation:** AET is useful for testing various types of transportation equipment, including railroad tank cars, marine vessels, motors, tube trailers and more.

What Are the Advantages of AET?

AET can be used for the early detection of flaws as well as real-time monitoring. It is a high-sensitivity test method and offers advantages including:

- **Early damage detection:** Because AET detects the growth of cracks and flaws and is a highly sensitive test method, it can detect relatively small (micro) defects early on. This early detection enables you to repair flaws before they cause significant issues.

- **Global, simultaneous inspection:** With AET, you can inspect an entire unit or system simultaneously, including pressure vessels, reactors, piping and other components. This results in a more efficient, cost-effective testing process and enables you to test even large systems relatively quickly.
- **No need for shutdown:** AET can often be performed on a unit while it is in operation, avoiding the need for a shutdown. You can also perform AET during an in-service over-pressurization or scheduled cool-down. Avoiding a shutdown can reduce costs significantly and help keep productivity levels consistent.
- **Identification of only active defects:** AET only identifies active defects — those that are growing. This feature means that only flaws that are likely to cause significant issues in the future are identified, while stable cracks and old fabrications defects are not. This enables you to focus on the most significant issues, saving your company time and money.
- **Immediate indication of risk:** With AET, you get an immediate indication of the strength of a given component and the risk of failure, enabling you to respond quickly if needed.
- **Minimal disruption to insulation:** Typically, only small holes in insulation are required to mount sensors. You may also be able to place permanent sensors underneath insulation.
- **Compliance assistance:** Several standards recognize AET, and it can help ensure compliance with local, state and federal regulations.
- **Reduced costs:** Using AET can reduce costs significantly by avoiding downtime, reducing test time, requiring minimal disruption to insulation and identifying only the defects that may cause significant issues in the future if not corrected.

What Are the Limitations of AET?

Like any test method, AET also has some limitations, which means it may not be the right choice for every application. In some cases, organizations may benefit from supplementing AET with other test methods. Some of the disadvantages of AET include that it:

- **Can only provide qualitative results:** AET can only provide qualitative results, not quantitative results. It can detect that a flaw exists, but determining the size and depth of a crack, for example, requires other test methods, such as ultrasonic testing.
- **Can only find active flaws:** The fact that AET only identifies active flaws can be an advantage, but, in some cases, you may also want to identify stagnant defects. AET would not work for this purpose. It’s also possible that AET may not detect relatively minor active flaws if the loading is not enough to result in an acoustic event.
- **Loud environments present challenges:** It can be more challenging to get accurate results from AET when it is performed in loud service environments. To filter out excess noise, signal discrimination and noise reduction techniques and technologies are required.
- **Requires specific skills and knowledge:** Performing AET requires an experienced, knowledgeable and skilled operator. It also involves the use of relatively complex and expensive hardware and software

Leak testing:

It is conventional to use the term "leak" to refer to an actual discontinuity or passage through which a fluid flows or permeates. "Leakage" refers to the fluid that has flown through a leak. "Leak rate" refers to the rate of fluid per unit of time under a given set of conditions, and is properly expressed in units of mass per unit time. Modern leak testing is thus based on the notion that all containment systems leak, the only rational requirement that can be imposed is that such systems leak at a rate no greater than some finite maximum allowable rate, however small that may be as long as it is within the range of sensitivity of a measuring system.

There are two basic types of leaks : one is an essentially localized i.e., a discrete passage through which fluid may flow (crudely, a hole). Such a leak may take the from of a tube, crack, orifice, or the like. A system may also leak through permeation of a somewhat extended barrier; such a leak is called a distributed leak. Gases may flow through solids having no holes large enough to permit more than a small fraction of the gas to flow through any one hole. This process involves diffusion through the solid and may involve various surface phenomena such as absorption, dissociation, migration, and desorption of gas molecules.

A distinction may be drawn between "real" and "virtual" leaks. Real leaks are the type described above, "virtual leak" refers to gradual desorption of gases from surfaces or components within a vacuum system. It is not uncommon for a vacuum system to have real and virtual leaks simultaneously.

It is convenient to categorize leak-testing methods according to whether the method is primarily applicable to the testing of internally pressurized systems or to vacuum systems. There are two basic ways to detect leaks in internally pressurized gas systems: (1) any reduction in the total quantity of gas contained within the system may be detected and (2) the escaping gas may itself be detected. For small leaks in pressurized gas systems, some method of directly sensing the escaping gas is usually necessary, especially when it is essential to locate the leak. Some of the methods used for this purpose are described here. The sound produced by the escaping gas may be listened to. The pressurized test system may be submerged in a liquid bath and visually observed. A soap solution may be applied on the outer surface of a pressurized system and bubbles formed due to escaping gas be observed. Detectors which are sensitive to specific gases may be used such as mass spectrometers as helium leak detectors and the radiation detectors for detection of leaking radioactive krypton-85 gas. The leak testing of vacuum systems also makes use of several specially adopted versions of specific gas detectors.

Typical applications of leak testing include testing of metals and non-porous materials, enclosures and seals, vacuum leak test of experimental and operating equipment, testing of welds, testing of brazing and adhesive bonds, testing of vacuum chambers and metal gasket seals, reactor fuel element inspection and testing of liquid-metal containers and components.

The application of leak testing techniques is, however, limited because direct access is required to at least one side of the test system and special type of sniffer or probe is required. Smeared metal or containments may plug the leak passage. Radiation and other residual gas hazards are possible.