PIE Tech

POLLACHI INSTITUTE OF ENGINEERING AND TECHNOLOGY

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Department of Mechanical Engineering

Regulation 2021

III Year – V Semester

CME 354 Failure Analysis and NDT Techniques

UNIT I
OVERVIEW OF NDT

NDT Versus Mechanical testing, Overview of the Non Destructive Testing, Methods for the detection of manufacturing defects as well as material characterization. Relative merits and limitations, various physical characteristics of materials and their applications in NDT, Visual inspection – Unaided and aided.

Non-destructive testing

NDT means testing of materials without destroying them.

Non-destructive testing is the process of inspecting, assemblies for discontinuities, or differences in characteristics without destroying the serviceability of evaluating materials, components or testing, or the part or system.

Objectives of non-destructive testing

NDT can have several objectives which includes:

- Materials sorting
- Materials characterization
- Property monitoring (for process control)
- Thickness measurement
- Defect detection/location
- Defect characterization

Uses of NDT methods.

The NDT methods are most commonly used to achieve the following purposes:

1. Flaw detection and evaluation
2. Leak detection
3. Location measurement
4. Dimensional measurement
5. Structure and microstructure characterization

Necessity of Testing :-

Testing of materials is necessary :

1. To detect defects in material.
2. To determine physical, chemical, mechanical properties of material.
3. To determine breaking stress, hardness, strength of material.
4. To check suitability of material.

Classifications of Materials tests

1. Destructive testing
2. Non- destructive testing

Destructive tests

In destructive testing, the component or specimen to be tested is destroyed and cannot be reused. After being destructively tested, the component or specimen either breaks or remains no longer useful for future use.

- Tensile test
- Compression test
- Hardness test
- Impact test

Advantages of destructive testing

- ✓The destructive test provides direct and reliable measurements.
- ✓It provides quantitative measurements.
- ✓Result interpretation is easy.
- ✓It can be performed without very high skilled personnel.
- ✓Correlation between test measurements and material properties is direct.

Disadvantages of destructive testing

- ✓Tests are performed only to a sample (ie., not suitable for 100% inspection).
- ✓Tested parts are destroyed during testing.
- ✓Usually cannot repeat a test on the same specimen.
- ✓Usually cannot use the same specimen for multiple destructive testing.
- ✓Difficult to apply to parts in-service; if done, testing terminates their useful life.

Non-destructive testing

Non-destructive testing is the process of inspecting, assemblies for discontinuities, or differences in characteristics without destroying the serviceability of evaluating materials, components or testing, or the part or system.

Or

The method of testing or inspection of a component or material to detect the presence of any defect without damaging it is called Non-Destructive Testing

Types of Non-destructive testing

- Visual Testing (VT)
- Penetrant Test (PT)
- Magnetic Particle (MT)
- Thermography Testing (TT)
- Ultrasonic Testing (UT)
- Radiographic Testing (RT)
- Eddy Current Testing(ET)
- Acoustic Emission (AE)
- Leak Testing (LT)
- Laser testing

Advantages of non-destructive testing

- Tests are done directly on the object.
- 100% testing (or representative samples) on actual components can be performed.
- Different non-destructive tests can be applied on the same component and hence many or all properties of interest can be examined.
- Test can be repeated on the same specimen
- Can be performed on components which are in-service. non-destructive testing.

Limitations of non-destructive testing

- Measurements are indirect.
- Reliability is to be verified.
- Measurements are often qualitative or comparative.
- Result interpretation is often difficult.
- Different observers may interpret the test results differently.

COMPARISON BETWEEN DESTRUCTIVE AND NON-DESTRUCTIVE TESTING

SL. No	Destructive test	Non Destructive test
1.	Destructive testing is the method where the specimen is broken to determine the physical and mechanical properties.	Non-destructive testing is the process of determining the characteristics of materials to locate the defect without destroying the material.
2.	Mainly used to detect the properties of the material.	Mainly used to find out the defects of the material.
3.	Measurements are direct and reliable.	As the measurements are indirect, reliability is to be verified.
4.	Load is applied on the material.	Load is not applied on the material.
5.	Mainly involves quantitative Measurement	Mainly involves qualitative measurement.
6.	Special equipments are required.	Special devices and instruments are needed.
7.	Correlation between the test measurements and material properties are direct.	Skilled labours are required to interpret the result.
8.	A destructive test can not be repeated on the same specimen as it is being destroyed.	A non-destructive test can be repeated on the same specimen.
9.	Testing is not made on the object directly.	Testing is made 100% on the actual component.
10.	Test equipment are not portable.	Test equipment is often portable.
11.	Using a single specimen, only a one (or) few properties of the material can be measured.	Many proper ties of the specimen can be measured as many NDT methods can be applied on the same specimen.
12.	Tests are not made on the objects actually used in service.	Tests are made directly upon the objects to be used in service.
13.	Measurement of properties over a cumulative period of time cannot be measured in a single unit.	Non-destructive tests permit repeated checks of a given unit over a period of time.
14.	It is very costly for the preparation of test specimen.	It is very costly for the preparation of test specimen.
15.	The time and man – hour requirements of many destructive tests are very high.	Most NDT methods are rapid and require fewer man − hours.
16.	(e.g) Tensile test, compression test, hardness test, impact test, torsion test, etc.	(e.g) Visual inspection, liquid penetrant test, eddy current test, radiographic testing, etc.

Overview of destructive testing methods

- (i) Tensile test.
- (ii) Compression test.
- (iii) Hardness test.
- (iv) Impact test.

Overview of NDT testing methods

- Visual Testing (VT)
- Penetrant Test (PT)
- Magnetic Particle testing (MT)
- Thermography testing (TM)
- Ultrasonic Testing(UT)
- Radiographic Testing (RT)
- Eddy Current Testing (ECT)
- Acoustic Emission Testing (AET)
- Leak Testing (LT)

Visual Testing (VT)

- Visual Inspection is one of the simplest, fastest and most commonly used non-destructive testing method.
- It may be done by direct viewing (or) with the help of optical instruments such as magnifying glasses, mirrors, borescope (or) microscope to inspect closely the subject area.
- Corrosion, misalignment of parts, physical damage and cracks are some of the discontinuities which can be detected by visual inspection.

Applications

- Checking of the surface condition
- Checking of alignment
- Checking of shape
- Checking for internal defects

- **Advantages**

  Inexpensive; fast; simple; apply during processing; testing speed high

- **Limitations**

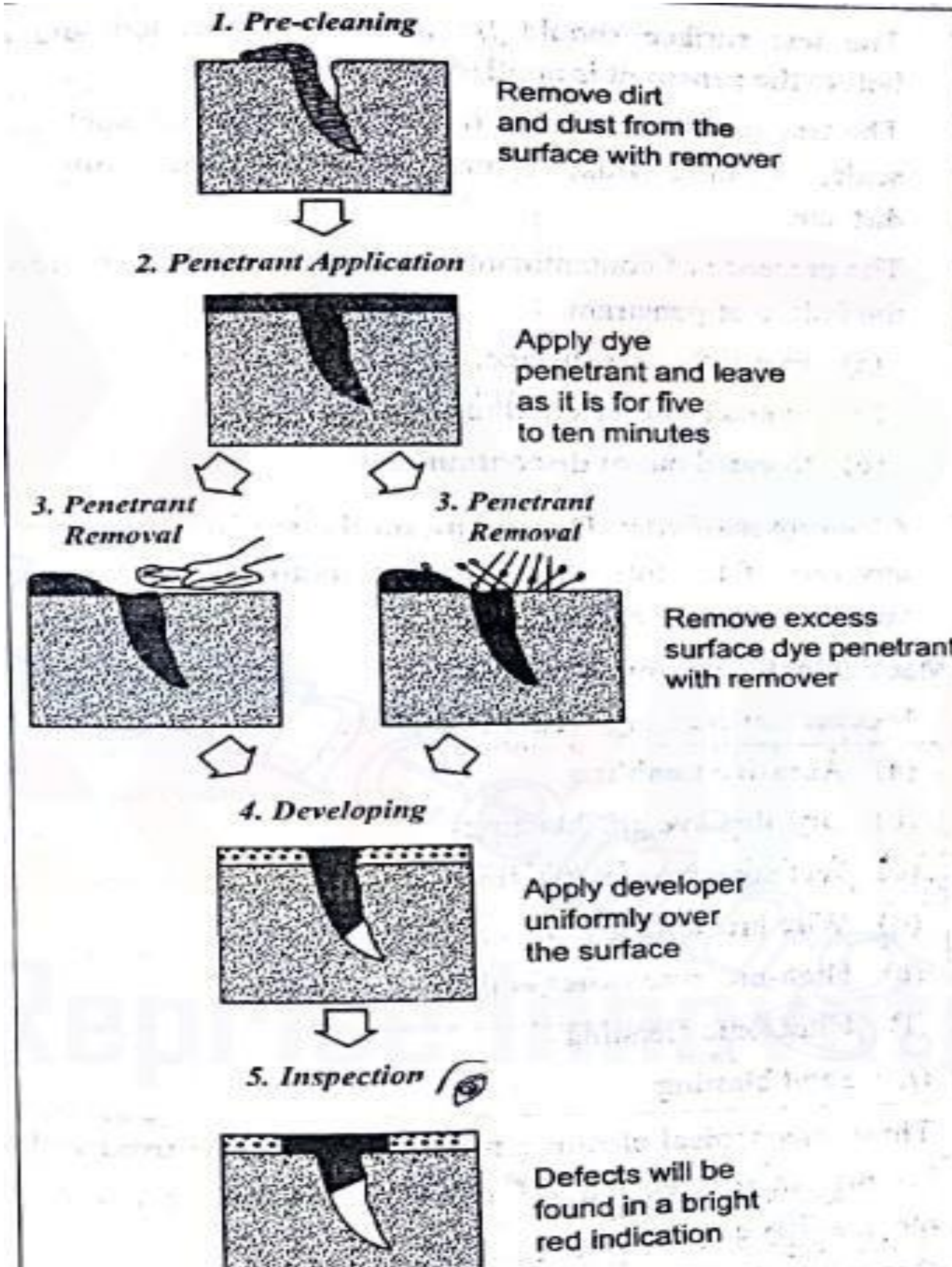
  need skill; Surface only; limited detection of flaws; eye fatigue; Need good illumination.

Liquid Penetrant Inspection

- Liquid Penetrant Testing is also known as **Dye Penetrant Inspection (DPI)** or **Penetrant Testing (PT)**.
- As the name implies, liquid called penetrant is used for detecting cracks, fractures, porosity, laps and other flaws which are open to the surface of the test specimen.
- It can be used to detect flaws on ferrous and non-ferrous metals.
- Liquid penetrant testing can be used effectively on non-porous and non-metallic materials like glass, plastics and ceramics.

Procedure for Penetrant Testing:

- 1. Pre-cleaning.
- 2. Application of penetrant.
- 3. Removal of Excess penetrant.
- 4. Application of Developer.
- 5. Inspection.
- 6. Post-cleaning.


1. Pre-cleaning
Remove dirt and dust from the surface with remover
2. Penetrant Application
Apply dye penetrant and leave as it is for five to ten minutes
3. Penetrant Removal
3. Penetrant Removal
Remove excess surface dye penetrant with remover
4. Developing
Apply developer uniformly over the surface
5. Inspection
Defects will be found in a bright red indication

- **Applications**

  Inspection of tanks, vessels, reactors

  Surface discontinuities

  Cracks, porosity, seams, laps, leaks.

  Inspection of truck, automobile parts, cylinders

  Aircraft engine parts, propellers

- **Advantages**

  inexpensive; easy to apply; more sensitive than visual alone; use on most materials; portable.

- **Limitations**

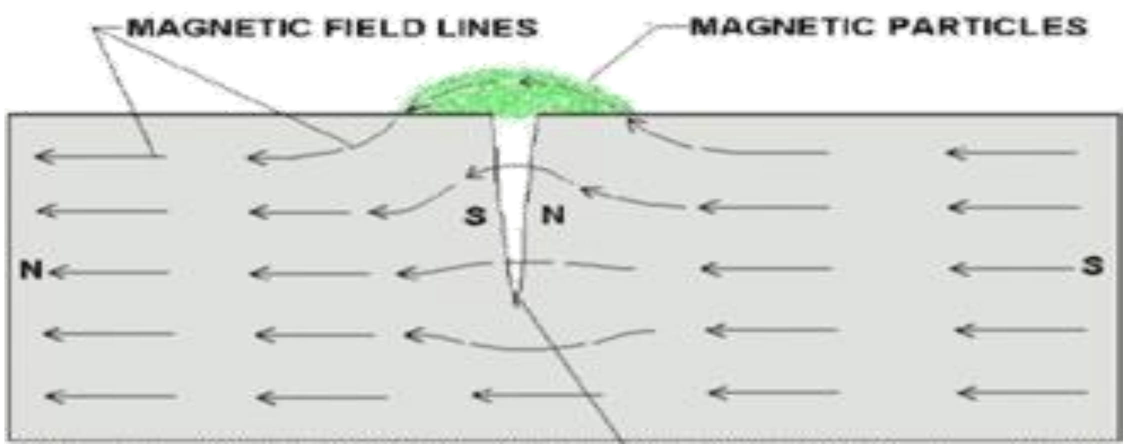
  Surface only; not useful on hot, dirty, painted, or very rough surfaces.

  Surface preparation needed,

  Post cleaning required

Magnetic Particle (MT)

- Magnetic Particle Testing (MPT) is used for detecting surface and near surface discontinuities in ferromagnetic materials such as iron, nickel, cobalt and their alloys.
- If iron particles are sprinkled on a cracked magnet, the **particles will be attracted** to the poles at the edges of the crack.



- **Applications**
  Surface and near surface discontinuities:
  Cracks, voids, porosity, inclusions, seams, laps.

- **Advantages**

  Low cost; fast; more sensitive to tight cracks than PT; can do near subsurface; portable.

- **Limitations**

  Material must be **ferromagnetic**; surface must be clean; part may be demagnetized; alignment of field is important.

Thermography Testing

- It is also known as **“infrared inspection”** (or) **“thermal imaging”** where the test instrument detects the infrared energy emitted from the object and convert into either a temperature value or a thermal image.

Advantages

- It can be carried out during normal operating condition without stopping the systems.
- The non-contact test method can be used from a safe distance
- Visual picture of the components can be identified
- Permanent record is possible
- IR cameras are relatively easy to use.

Limitations

- Interpretation of results needs a certain experience and knowledge.
- Higher accuracy on detection of defects can be difficult due to varying emissivity of the different materials.
- Comparatively cost of the equipment is high.

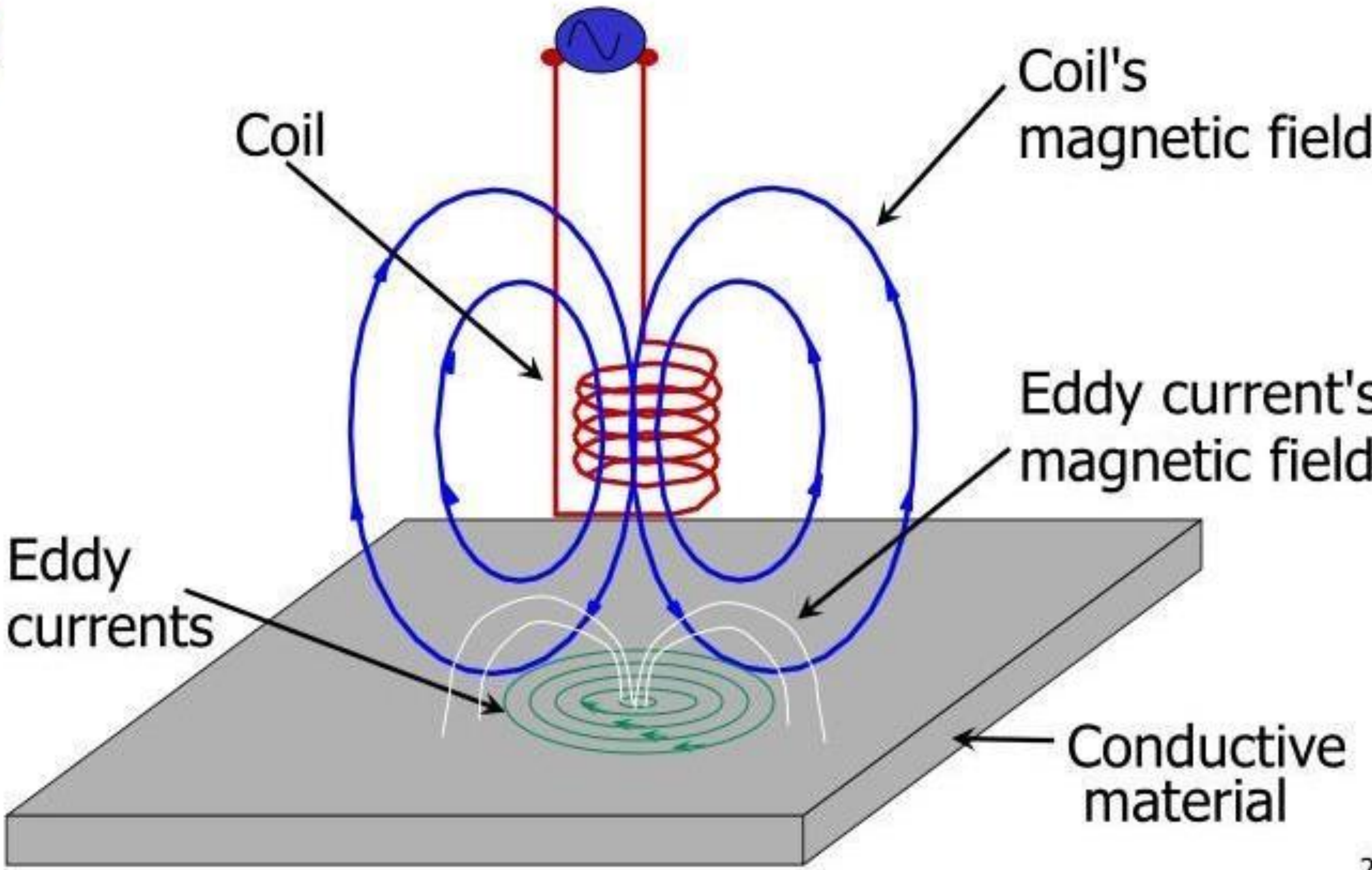
Applications

- Detection of defects in composites.
- Inspection of impact damages in CFRP (carbon fibre reinforced polymer) panels.
- Detection of cracks in turbine components.
- Detection of corrosion in air craft parts.
- Inspection of drilling induced defects in laminates.
- Inspection of motors and rotating equipment.
- Inspection of surface cracks in method structures.

Eddy Current Inspection (ECT)

- Eddy current inspection is one of several NDT methods that use the principal of "electromagnetism" as the basis for conducting examinations.

Eddy Current Testing



Applications

- Detection and measurement of flaws in steering mechanisms, airplane landing gears, engine parts, reactor and steam generator turbines, aircraft wheels, aircraft wing structures, condenser pipes, turbine blades, etc.
- Measurement of coating and plating thickness.
- Determination of the hardness and depth of case hardening in bearing rings and other parts.

- **Advantages**

  can be automated; very sensitive; surface contact not necessary; permanent record.

- **Limitations**

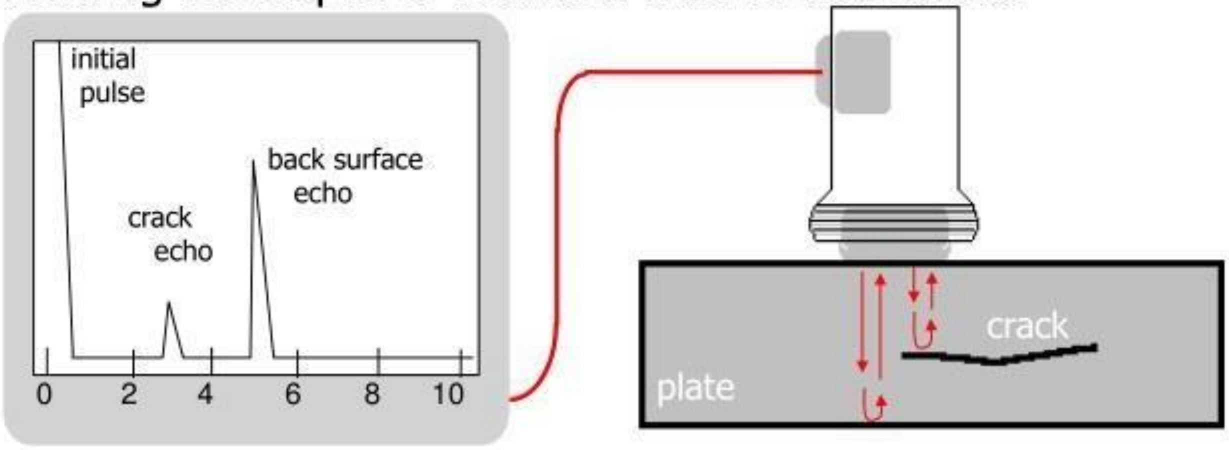
  Conductive materials only; difficult interpretation sometimes, may require special equipment; sensitive to geometry.

Ultrasonic Testing (UT)

- **Ultrasonic Testing (UT)** uses piezoelectric Crystals to produce high frequency sound energy to conduct examinations and make measurements.
- Ultrasonic pulse – waves ranges from 0.1 to 15 MHz are transmitted into the materials to detect the internal flaws.

Ultrasonic Inspection (Pulse-Echo)

- High frequency sound waves are introduced into a material and they are reflected back from surfaces or flaws.
- Reflected sound energy is displayed versus time, and inspector can visualize a cross section of the specimen showing the depth of features that reflect sound.



Oscilloscope, or flaw detector screen

- **Applications**
  Surface and deep subsurface discontinuities: Cracks, laminations, porosity, lack of fusion, inclusions, thickness.

- **Advantages**

  Rapid if automated but manual is slow; applicable to very thick specimens; can give location and size of discontinuity; good sensitivity; inspect from one side; portable.

- **Limitations**
  - Entirely dependent on operator skill
  - Unsuitable for welding of complex shape or configuration
  - Requires surface contact
  - Surface must be clean and smooth

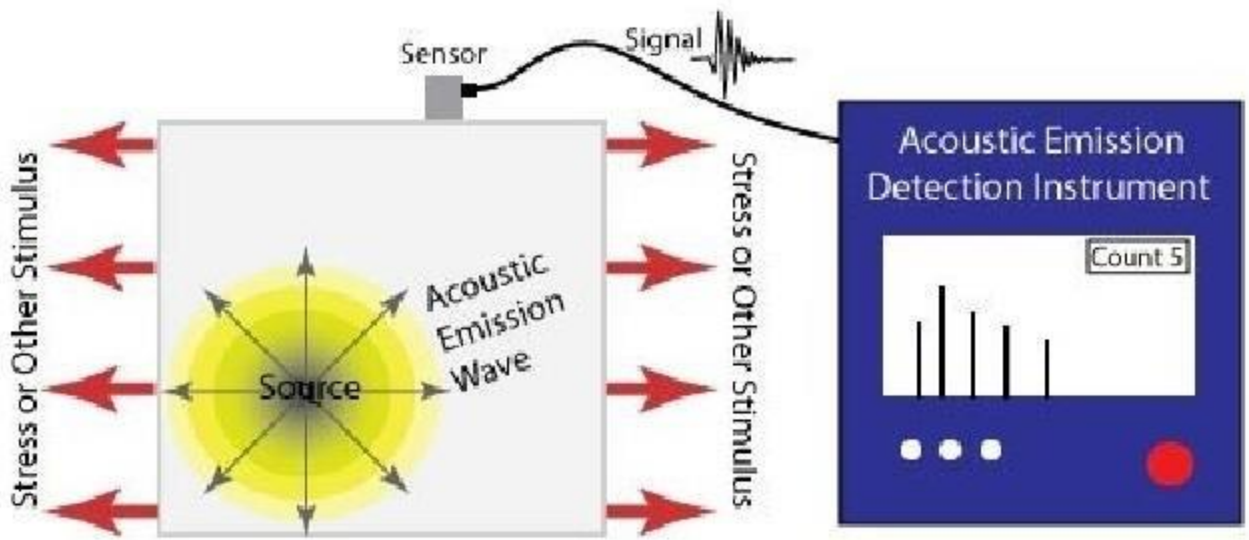
Acoustic Emission Testing (AET)

Acoustic Emission differs than other techniques in two regards.

1. AET simply **listens** for the energy released by the object.

2. AET deals with dynamic processes (Leaks), or changes (Phase Change), in a material.

TESTING PROCESS



Materials "talk" when they are in trouble: with Acoustic Emission equipment you can "listen" to the sounds of cracks growing, fibers breaking and many other modes of active damage in the stressed material.

Applications

- Surface and subsurface discontinuities:
- Crack initiation and growth, leaks, phase changes.
- Detecting and locating faults in pressure vessels or leakage in storage tanks or pipe systems,
- Monitoring welding applications

- **Advantages:**

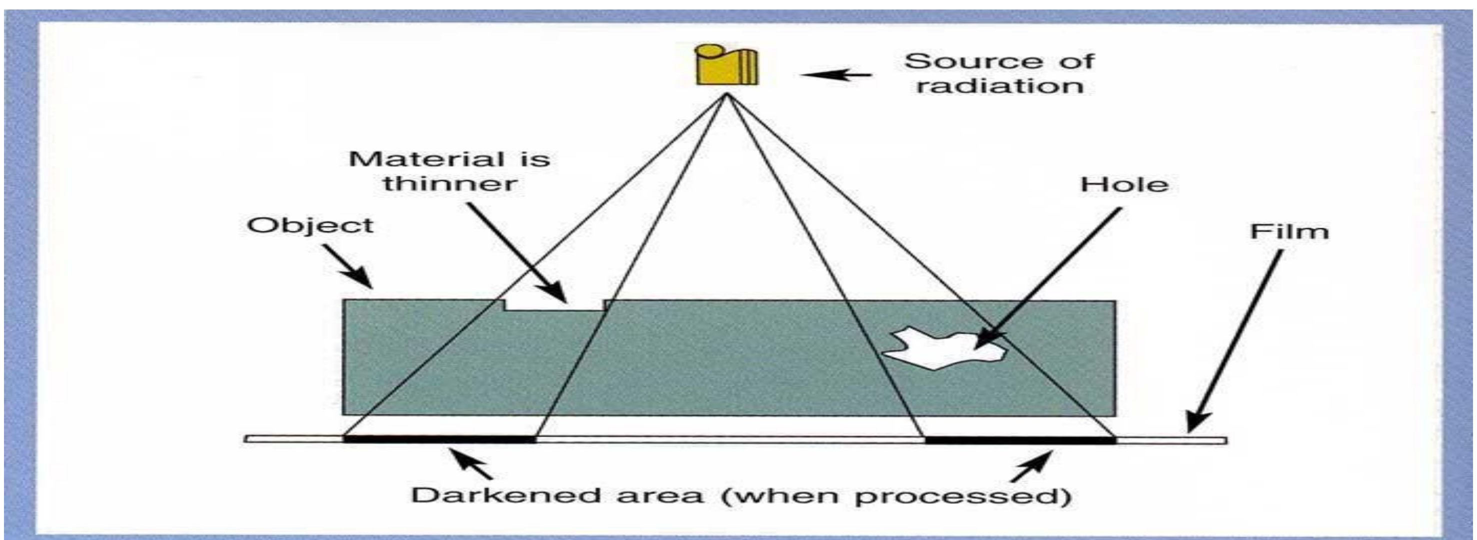
  Remote and continuous surveillance, location, severity, permanent record. Tests an entire vessel or system.

- **Limitations:**

  Contact with system; may need many contact points; complex interpretation; system must be stressed; usually expensive; some systems are too complex.

Radiographic Testing (RT)

- This method uses X or Gamma radiation using a radiographic Film as a recording medium.
- In order to get maximum sensitivity the defect must be imparallel to the radiation beam.



Applications

- Subsurface discontinuities.
- Cracks, voids, inclusions, thickness variation, lack of fusion, incomplete penetration, corrosion, missing components.

- **Advantages**

  Easily understood permanent record; usually moderate cost; can be portable; applicable to a wide range of materials.

- **Limitations**

  Cannot detect laminations; radiation hazard and regulations; access to both sides can be high cost; requires trained operators.

Leak Testing

- Leakage occurs through a leak (passage) when there is a pressure differential between two sides of a leak.

- Leaks can be detected by using electronic listening devices, pressure gauge measurements, liquid and gas Penetrant techniques.

- **Applications**
  - Leaks in systems or subassemblies.
  - It includes hydraulic and hydrostatic tests
  - Hydrostatic tests can produce damage.

Discontinuity

- Discontinuity is an interruption in the normal physical structure or configuration of an article. A discontinuity may or may not affect the usefulness of the article.

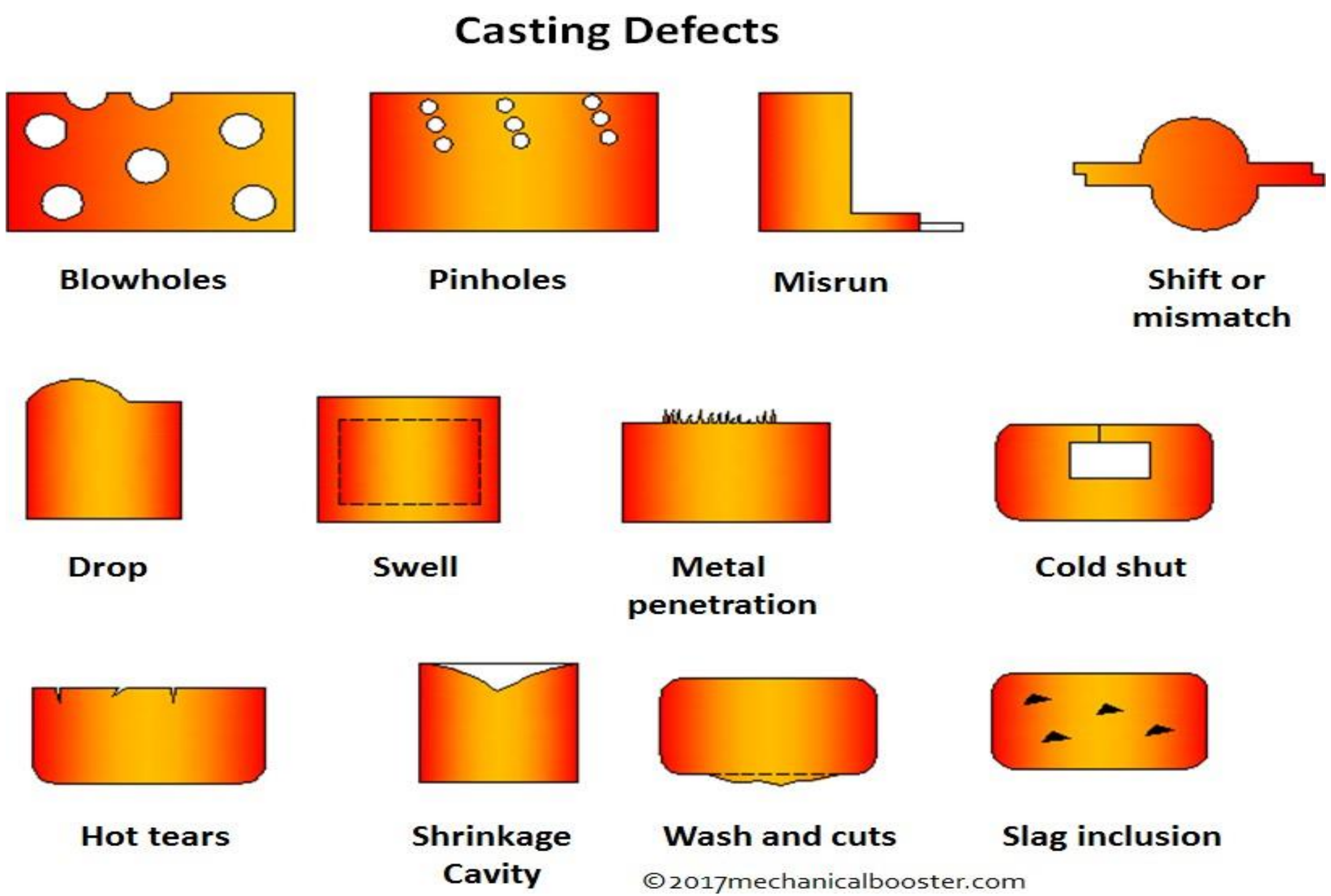
Examples of discontinuities

- Cracks
- Laps
- Seams
- Inclusions
- Porosity
- Hydrogen cracks
- Fatigue
- Tears

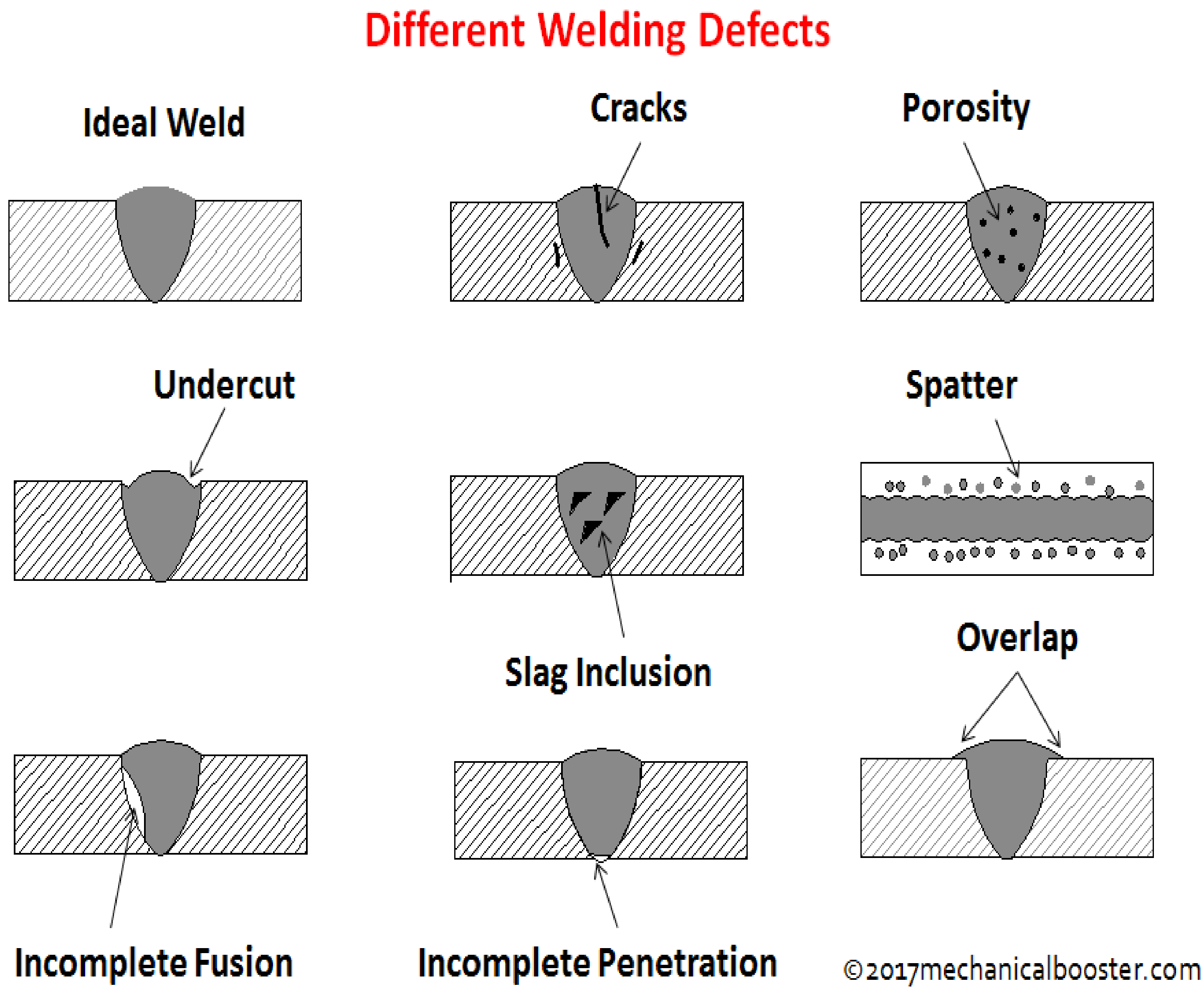
TYPES OF DISCONTINUITIES

- **Inherent Discontinuities**
- **Processing Discontinuities**
- **Service induced discontinuities**

Inherent Discontinuities



Processing Discontinuities



Service induced discontinuities

- **Fatigue Cracks**
  - Develop at areas of high stress concentrations such as holes, fillets, keyways, etc.
- **Thermal Fatigue**
  - Due to repeated heating and cooling of a part – Cracks resulting from large thermal gradients are usually multiple and often have an alligator skin appearance
- **Corrosive Environments**
- **Material Losses**

VISUAL INSPECTION

- Visual Inspection is one of the simplest, fastest and most commonly used non-destructive testing method.
- As the name implies, Visual Inspection involves the visual observation of test specimen to detect the presence of surface discontinuities
- It may be done by direct viewing (or) with the help of optical instruments such as magnifying glasses, mirrors, borescope (or) microscope to inspect closely the subject area.

APPLICATION OF VISUAL INSPECTION:

- It is used to inspect whether there is a misalignment of parts in the equipment.
- It checks for corrosion, erosion, cracks and deformities of machine components.
- It inspects the plant components for any leakage (or) abnormal operation.
- It is used in pumps, compressors, turbo generator to check for minute discontinuities.
- It is used to identify the defects in weldments.
- Monitoring of the operational condition of the systems or machine.
- Monitoring of oil level, greasing and greasing apparatus.

ADVANTAGES OF VISUAL INSPECTION:

- Simple and easy to use.
- Relatively inexpensive.
- Testing speed is high.
- Testing can be performed on components which are in service.
- Permanent records are available when latest equipments are used
- Almost all materials can be inspected

LIMITATIONS OF VISUAL INSPECTION:

- Using unaided inspection, only large discontinuities are identified.
- Limited to detection of only surface discontinuities.
- Skilled labour is required.
- Results depend on the eye resolution of the inspector.
- It may cause eye fatigue to the inspector.

TYPES OF VISUAL INSPECTION:

1. Unaided Visual Inspection - with the help of naked eye
2. Aided Visual Inspection - performed using any optical aids

OPTICAL AIDS USED IN VISUAL INSPECTION:

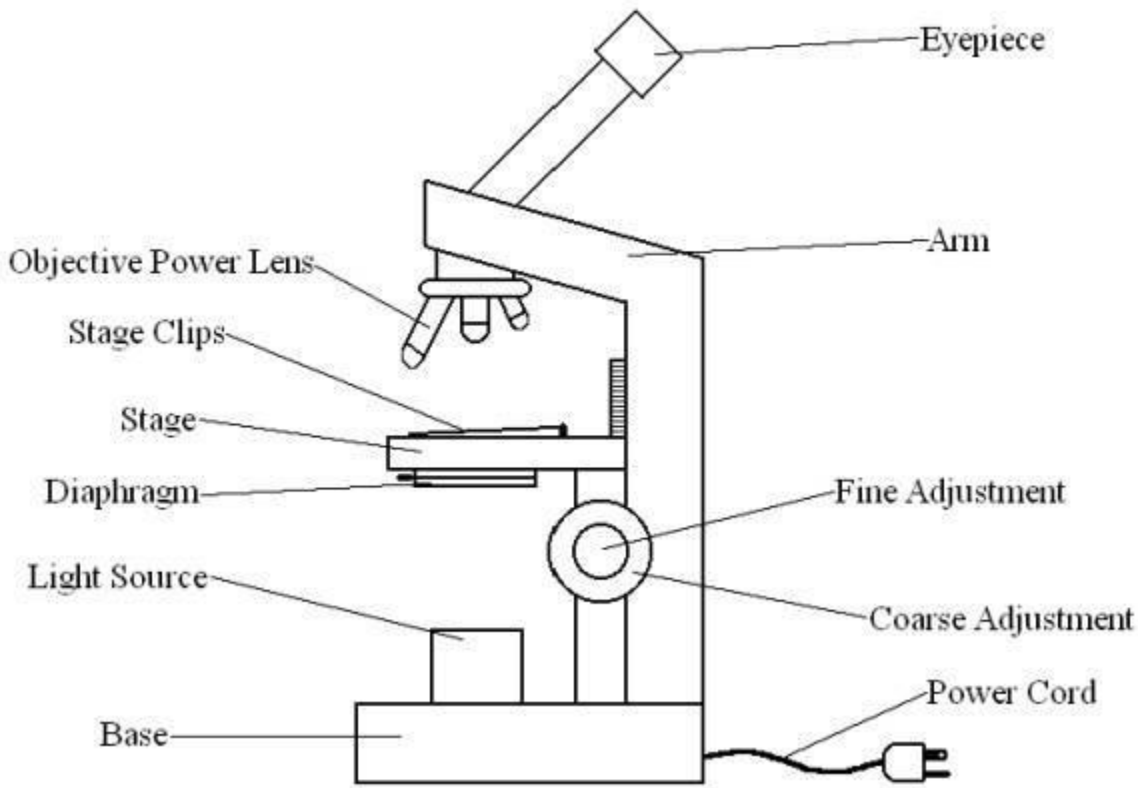
- Mirrors.
- Magnifying glasses.
- Microscopes.
- Borescope.
- Endoscope.
- Flexible Fibre –Optic Borescope.
- Telescope.
- Holography.
- Optical comparators.
- Closed –Circuit Television (CCTV) system.
- Computer enhanced systems.

Magnifying Glass:

Fig: Magnifying glass

- It is also known as **hand lens**.
- It is a convex lens which is used to produce a magnified image.
- It works on a principle that if an object is placed on one side of a convex lens closer to it than the focal point, then the image will be formed on the same side as the object and the resultant would be a magnified one.
- Magnification of a magnifying glass depends on the position where it is being placed between the human eye and the object.

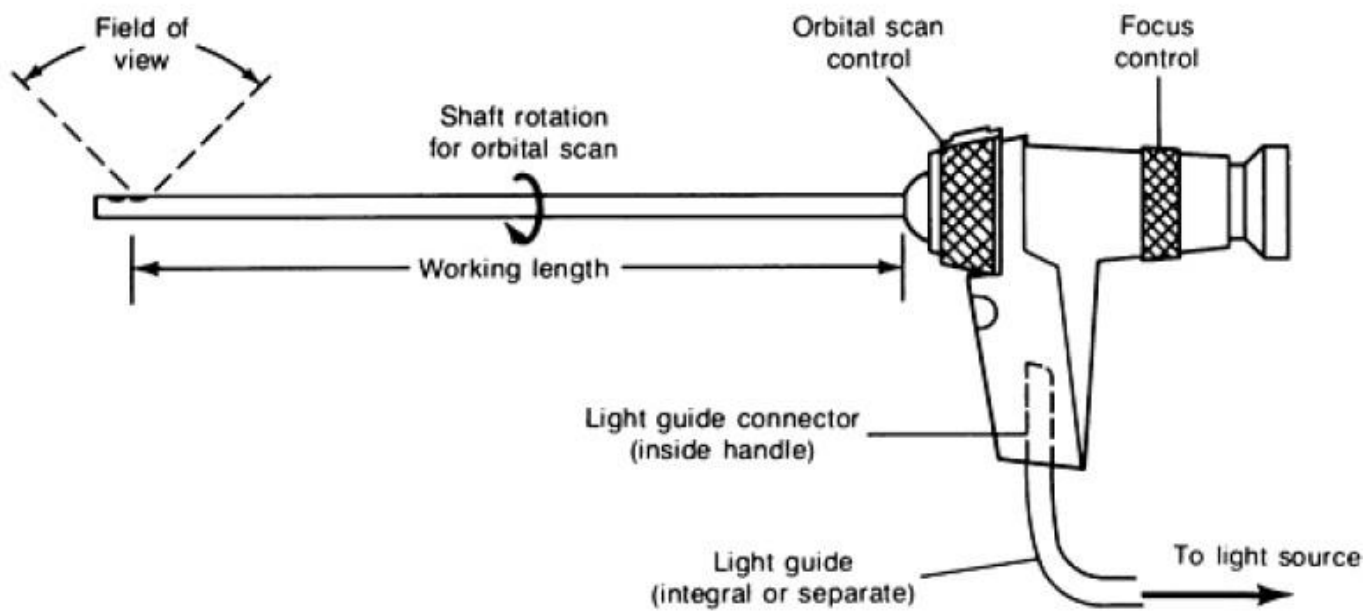
Microscope


Eyepiece
Arm
Objective Power Lens
Stage Clips
Stage
Diaphragm
Fine Adjustment
Light Source
Coarse Adjustment
Power Cord
Base

- Microscope is an optical instrument having a magnifying lens or a combination of lenses which is used to magnify the image of a small object.
- The simplest form of a microscope is a single converging lens which is also known as **simple magnifier**.
- The object is placed between the lens and the focal length of lens and the distance from lens to object is adjusted until a clear image is obtained.
- Magnification power of the lens is given by the equation, where f is the focal length of the lens and 10 represents the average minimum distance where the image is seen clearly by the unaided eye.

Borescope

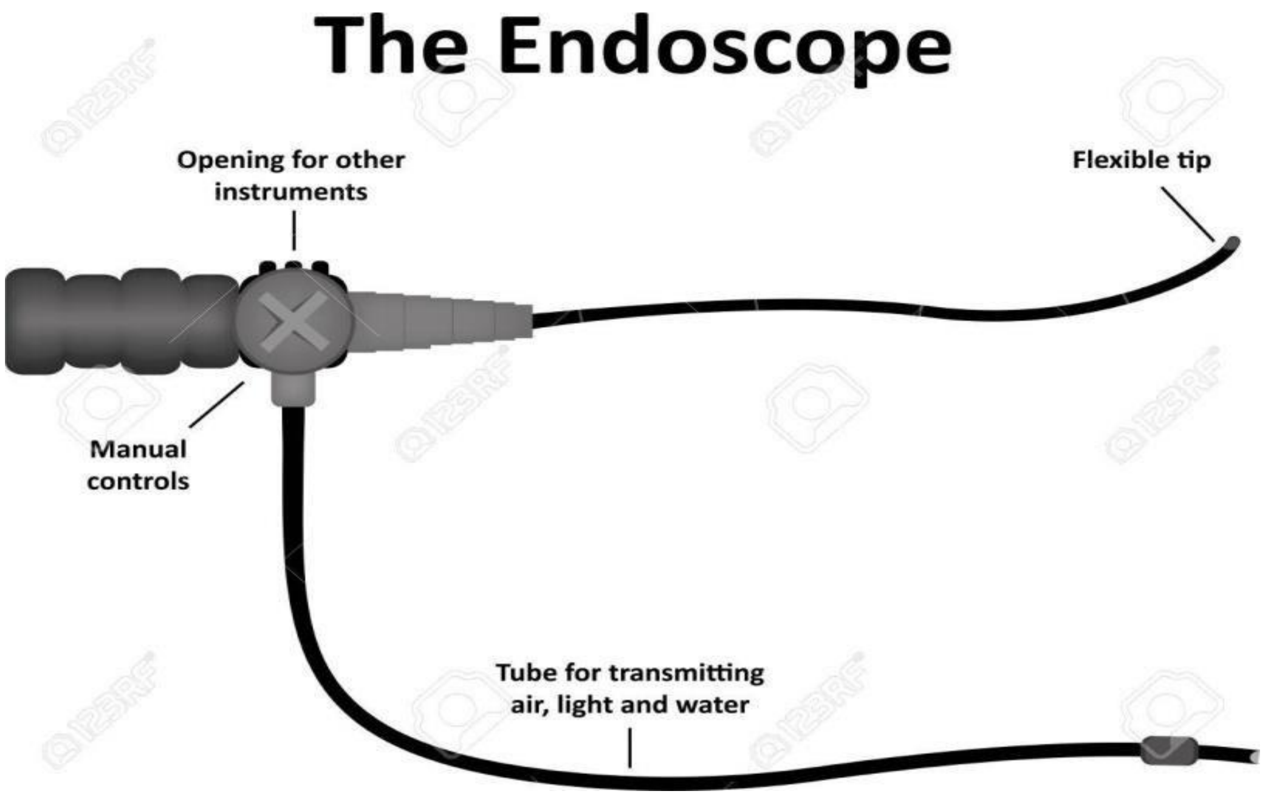
(b)



(c)

- Borescope is an optical instrument which is used to inspect the inside of a narrow tube, bore or chamber.
- It consists of a rigid or flexible tube with an eyepiece at one end and an objective lens on the other end.
- It consists of a complex arrangement of prisms and plain lenses through which the light is passed to obtain a clear image.
- It is available in diameter which ranges from 2.5 to 19 mm and of smaller length, as the length of borescope increases, brightness of the image decreases due to loss of light.

Endoscope



The Endoscope
Opening for other instruments
Flexible tip
Manual controls
Tube for transmitting air, light and water

- It is same as the borescope but it has a superior optical system and a high-intensity light source.
- It is also used to examine the interior of an object.
- Objects are in focus from 4 mm to infinity, where a magnification factor of ‘10X’ is obtained when it is at 4 mm distance.
- ‘No focusing’ feature is the one which makes it preferable than borescope.
- Endoscope are available in smaller diameter upto 1.7 mm which makes it comfortable for viewing smaller objects and ranges to a length of about 100 to 150 mm.

Fibroscopes

- It is also known as **flexible fibre-optic borescope** (or) **flexiscopes**.
- It is used to provide clear and sharp images of parts and interior surfaces which are not easily accessible.
- Fibre optics is used to carry the information and it permits several dimensional changes depending on the object.
- Tip can be adjusted using rotating control mechanism depending on the object size and it also has a wide-angle objective lens with a 100 micron field of view.
- It ranges to a diameter of about 3 to 12.5 mm with a length which varies from 60 to 365 cm.

Telescope

- Telescope is a device which makes the faraway objects to appear much closer.
- It consists of two lenses called objective and eyepiece.
- Glass lenses are provided at the refractor telescopes and mirror replaces the glass lenses in case of reflector telescopes.
- The objective lens (in refractors) (or) primary mirror (in reflectors) collects light from the object and focuses as it to a point.
- An eyepiece lens takes the light from the focus and magnifies it.

UNIT III

THERMOGRAPHY AND EDDY CURRENT TESTING (ET)

Thermography- Principles, Contact and non contact inspection methods, Techniques for applying liquid crystals, Advantages and limitation - infrared radiation and infrared detectors, Instrumentations and methods, applications.

Eddy Current Testing-Generation of eddy currents, Properties of eddy currents, Eddy current sensing elements, Probes, Instrumentation, Types of arrangement, Applications, advantages, Limitations, Interpretation/Evaluation.

INTRODUCTION

- Thermography is a non-contact , non-destructive test method that utilizes a thermal image to detect, display & record thermal patterns and temperatures across the surface of an object.
- Thermography is widely used in industries for predictive maintenance, other Applications include, tank & concrete inspection, NDT, condition monitoring , night vision medical and veterinary sciences.

WHAT

- IRT is the technique that used for producing a visible image of invisible IR energy emitted by objects.
- Since wavelength is too long for the sensors in our eyes, IR cameras are used.

Where it is used?

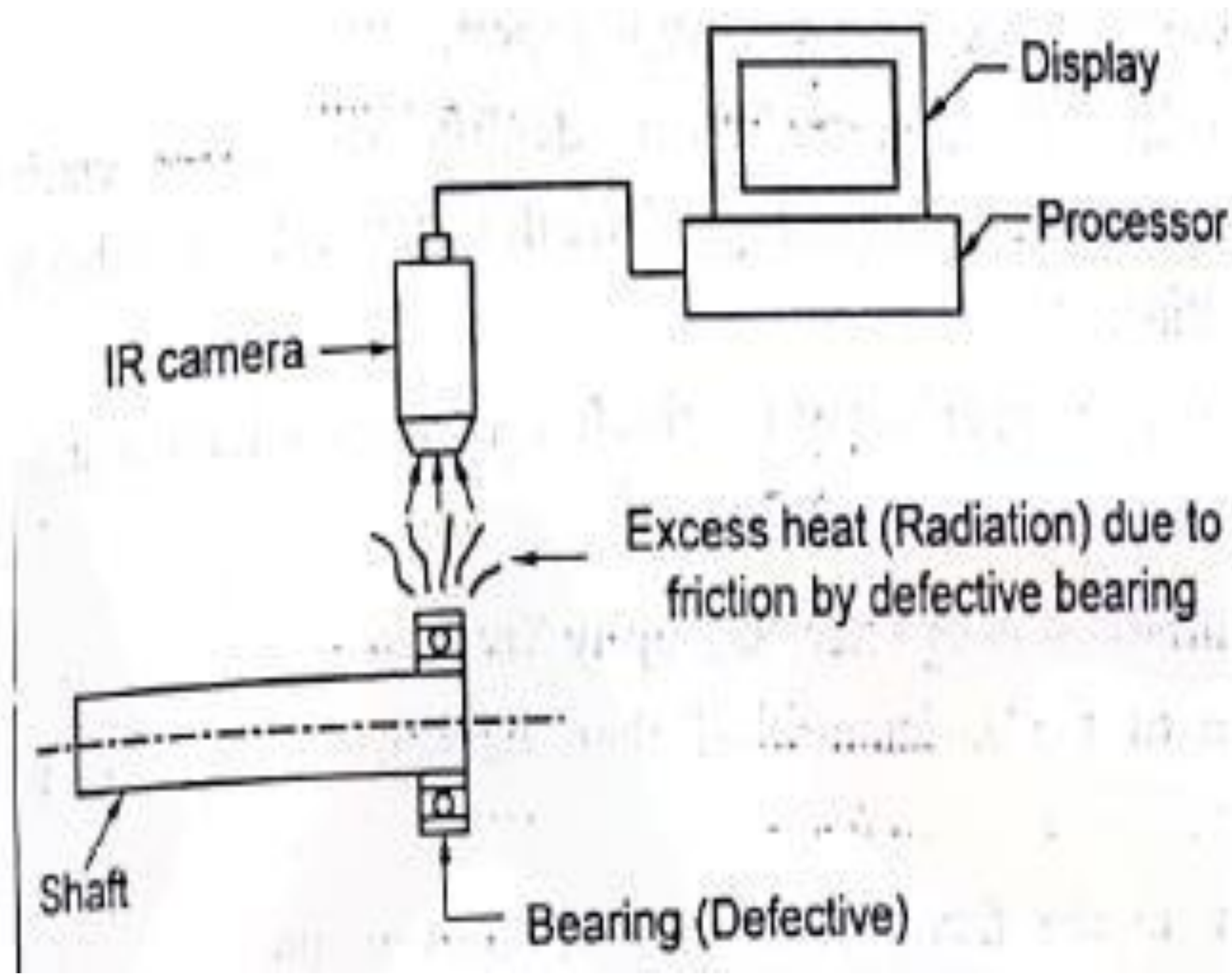
- It can be applied in any situation where a problem or condition can display itself by means of a “thermal difference”.
- For example, firefighters use it to see through smoke, find persons, and localize hotspots of fires.
- Cooled IR cameras can also be found at most major astronomy research telescopes

What makes it useful?

- Its non contact. -uses remote sensing, keeps the user out of danger.
- It is two dimensional. -thermal patterns can be analyzed, comparison between areas of target is possible.
- It is real time.-fast scanning of stationary targets, capture of fast moving targets & fast changing thermal patterns.

Principle

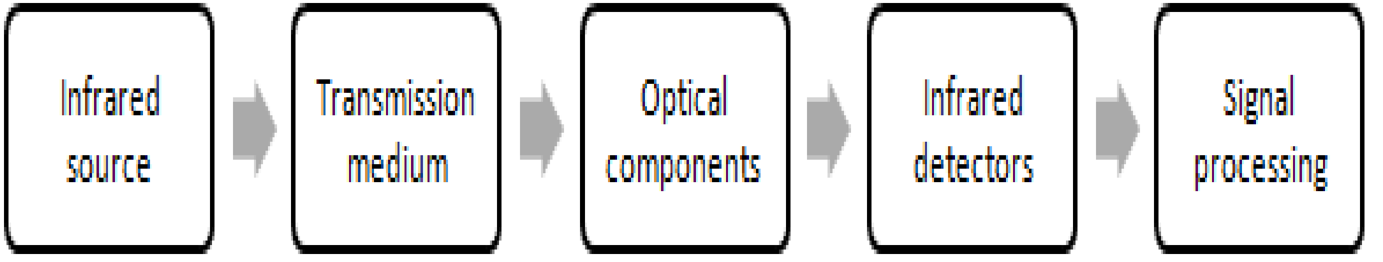
- Black body radiation-Black body is that which absorbs completely all the radiations falling on it.
- The law is associated with “Thermodynamics”.
- Every object whose surface temperature is above absolute zero (-273 °C) radiates energy at a wavelength corresponding to its surface temperature.
- Colorizing IR images- it assigns black to coolest area & white to hottest area.


Display
Processor
IR camera
Excess heat (Radiation) due to friction by defective bearing
Shaft
Bearing (Defective)

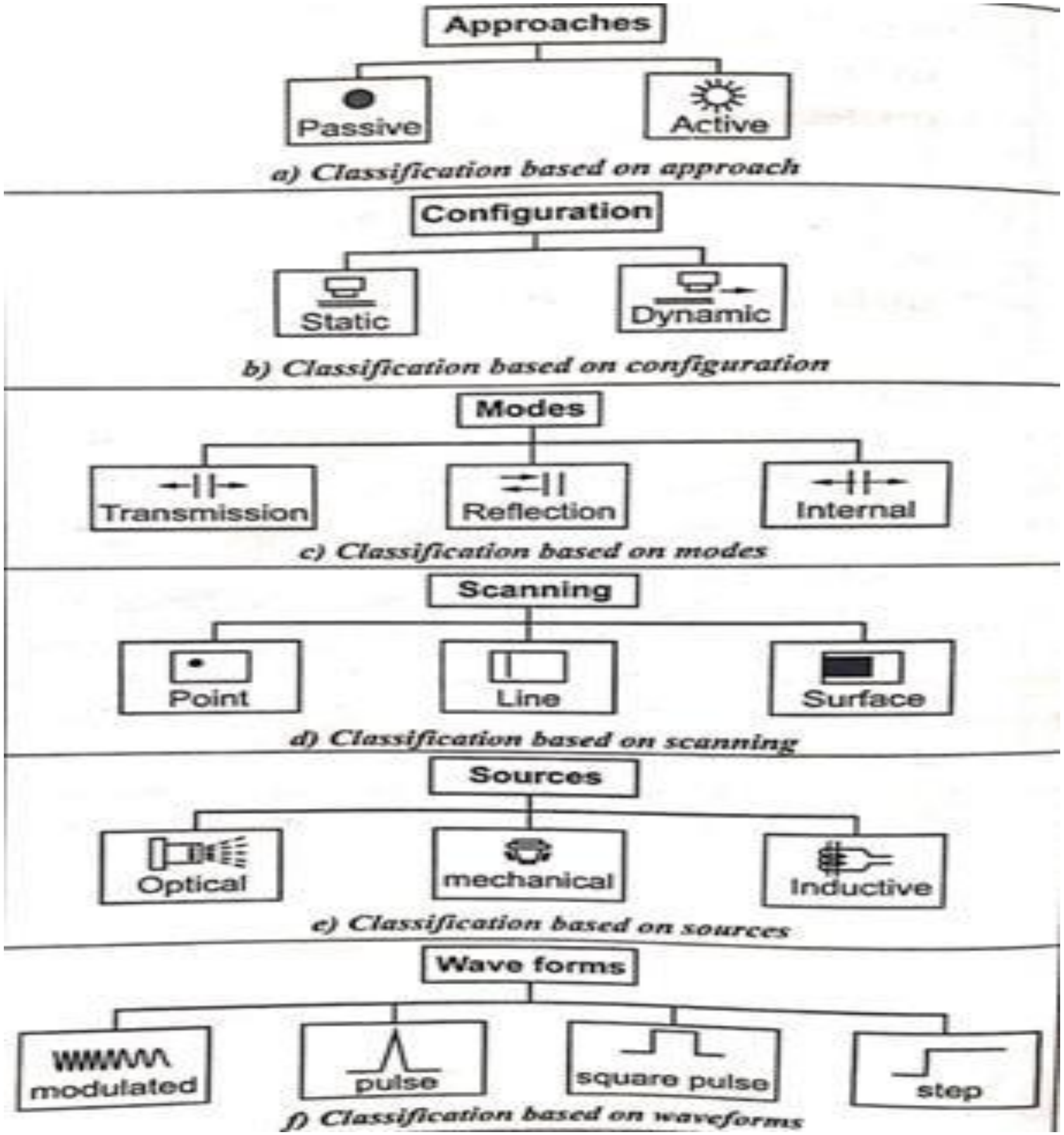
Elements of infrared detection system

Basic elements of infrared detection system are:

- Infrared source
- Transmission medium,
- Optical components,
- Infrared detectors, and
- Signal processing.



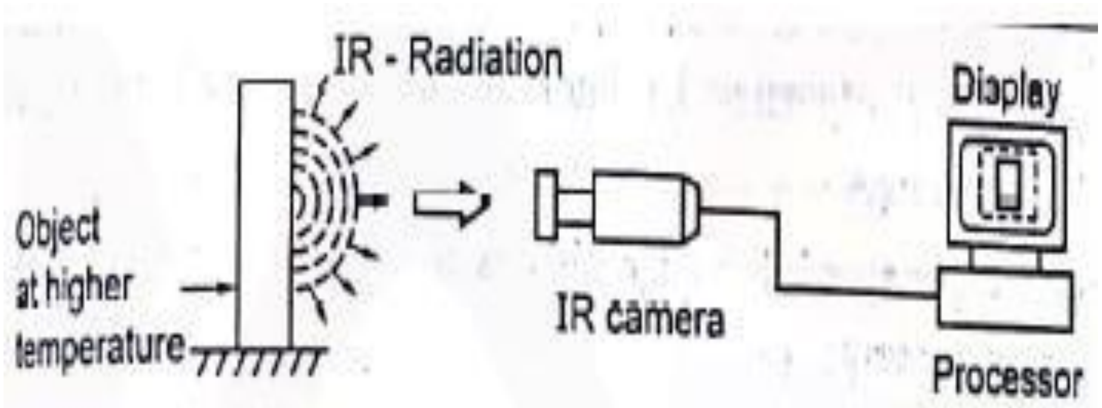
classification of the thermography testing



THERMOGRAPHY TESTING-PASSIVE APPROACH

Principle

- In passive approach of thermography testing, materials and structures are naturally at different (higher or lower) temperature than the background.
- For example, the human body is normally at a temperature higher than ambient temperature, hence it is easily detected by an IR camera without any additional stimulation or source.



Configuration of passive approach

Fig. shows the configuration of passive approach. An object, at elevated temperature with respect to environment can be monitored using an IR camera without an aid of additional external source of energy.

A computer system is used to display and process images. The passive approach is often qualitative, such as the diagnosis of the presence of a given abnormality (hot/cold spots) with respect to surroundings.

Advantages

- Passive thermography provides unique opportunities to quickly test large areas.
- Testing of a structure is possible without taking the equipment out of service.
- This method is most effective when looking for strong thermal indications that have persistence, such as water or other fluid flowing through conduits.
- It does not always require expensive thermal imaging equipment.

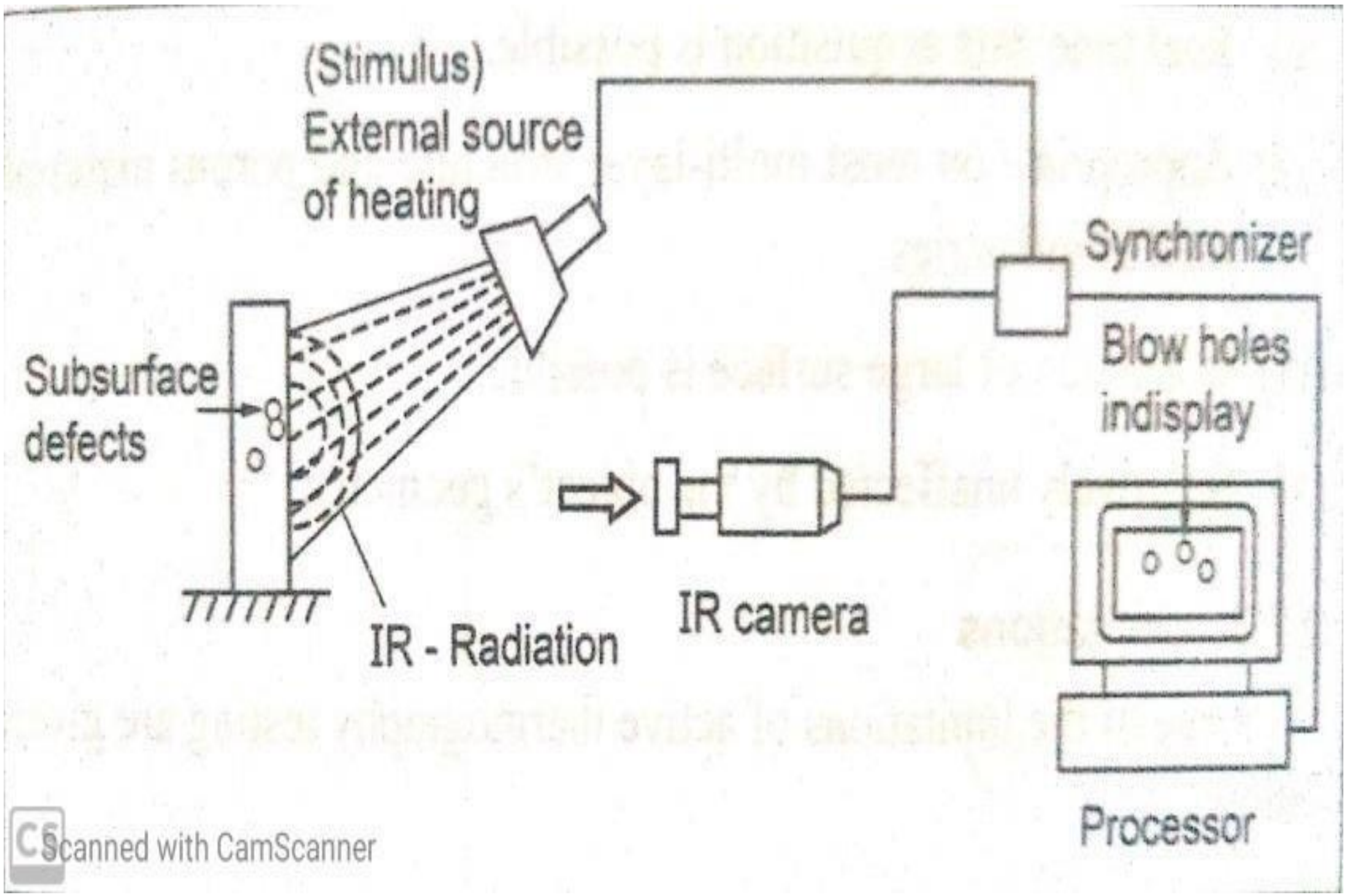
THERMOGRAPHY TESTING - ACTIVE APPROACH

Principle

In active thermography approach an external stimulus is needed to produce a thermal contrast in the object surface.

When external source of heat is applied the thermal state the object to be inspected is destabilized.

ACTIVE APPROACH

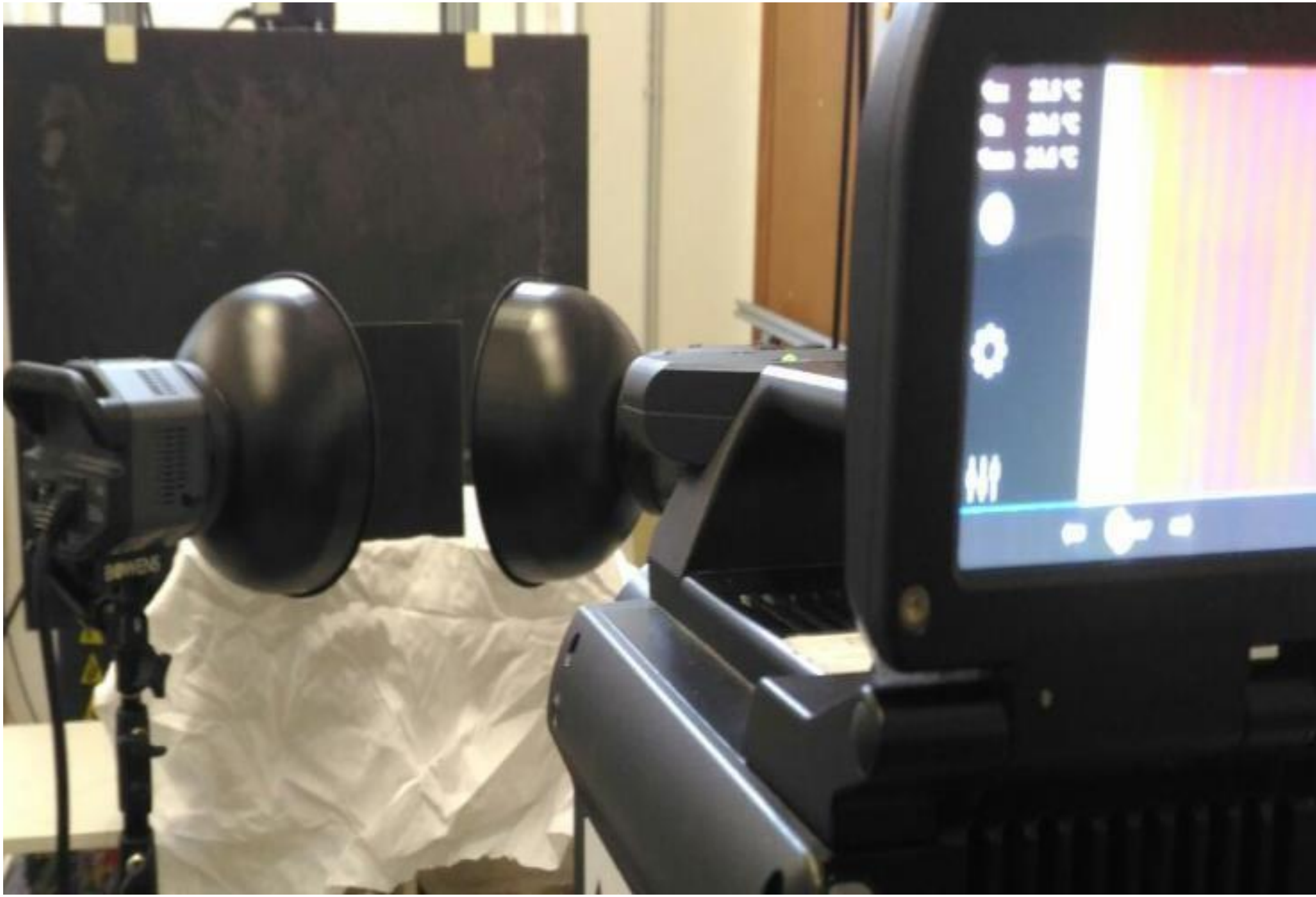


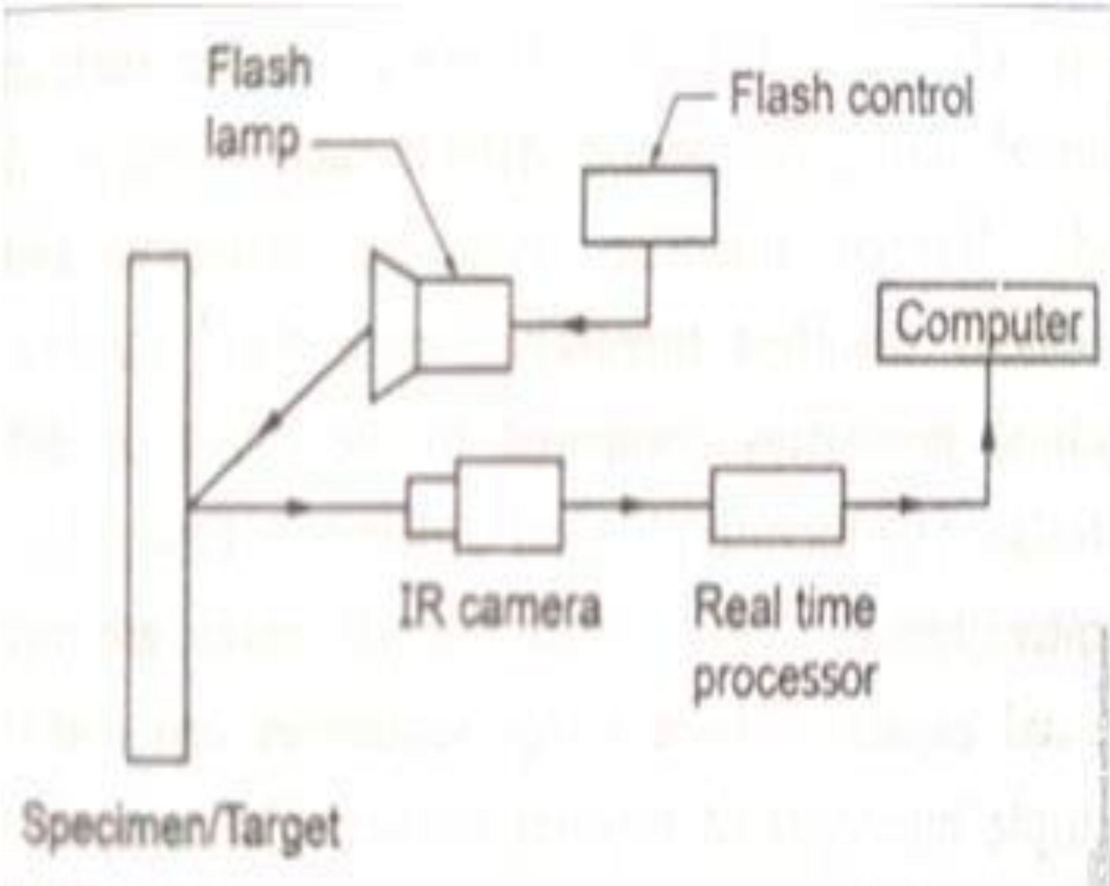
- In this technique, the sample is heated by an external source (optical, mechanical, electromagnetic or other).
- Controlled heat source and its surface temperature is monitored as a function of time through changes of emitted infrared radiation.
- The specific thermal properties of material under test influence transport of heat thus causing surface temperature to change with respect to areas with different thermal properties.
- Due to the thermo physical properties of the testing material defective and non-defective surface produces a measurable thermal constant.
- IR camera acquires data on thermal emissions and is displayed in the computer. The appearance of subsurface defect is proportional to its depth.

PULSED THERMOGRAPHY (FLASH THERMOGRAPHY)

Concept

- In this technique, energy sources (xenon flash tubes) are used to pulse-heat the specimen surface. The duration of the pulse may vary from a few microseconds by using flashes to several seconds by using lamps.
- The duration and energy source depends on the thermo physical properties of both, the specimen and the flaw.




Flash lamp
Flash control
Computer
IR camera
Real time processor
Specimen/Target

Thermography

- pulsed thermal experimental test usually consists of a thermal source, with one or more flash lamps, to provide instantaneous heating of the component and an infrared camera to monitor the surface temperature decay for a fixed period of time after the thermal impulse.
- The defects block the flow of heat from the flash heated surface, causing are duction in the cooling rate of the surface above the defects that is revealed as an area of thermal contrast in the thermal images of the surface.
- The temperature contrast between the defected and sounded regions enables defect detection based on thermographic data.

Modes of thermography

The specimen is heated from one side while thermal data is collected either from the same side (reflection mode) or from the opposite (transmission mode).

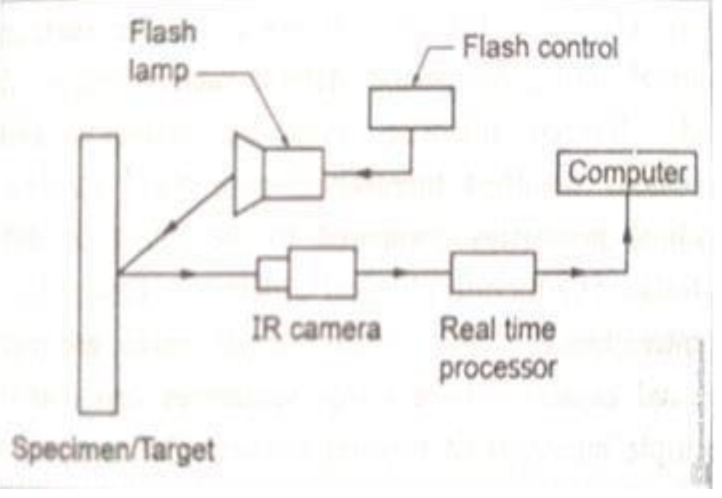
Reflection mode:

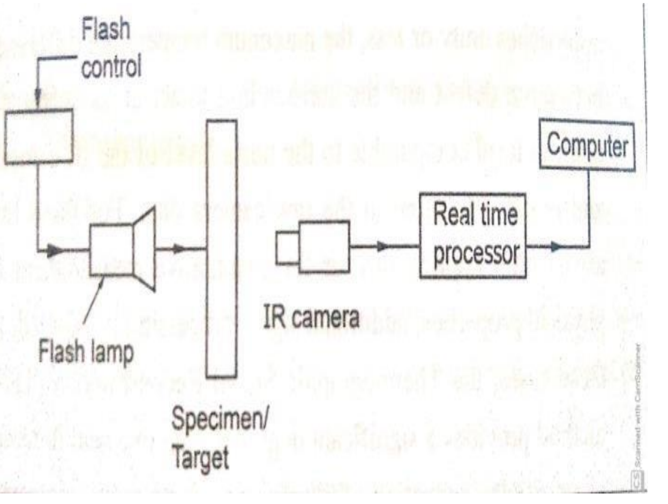
In this mode, inspecting defects closer to the heated surface.

Transmission mode:

In this mode, inspecting defects closer to the non-heated surface (Deeper defects).

Modes of thermography





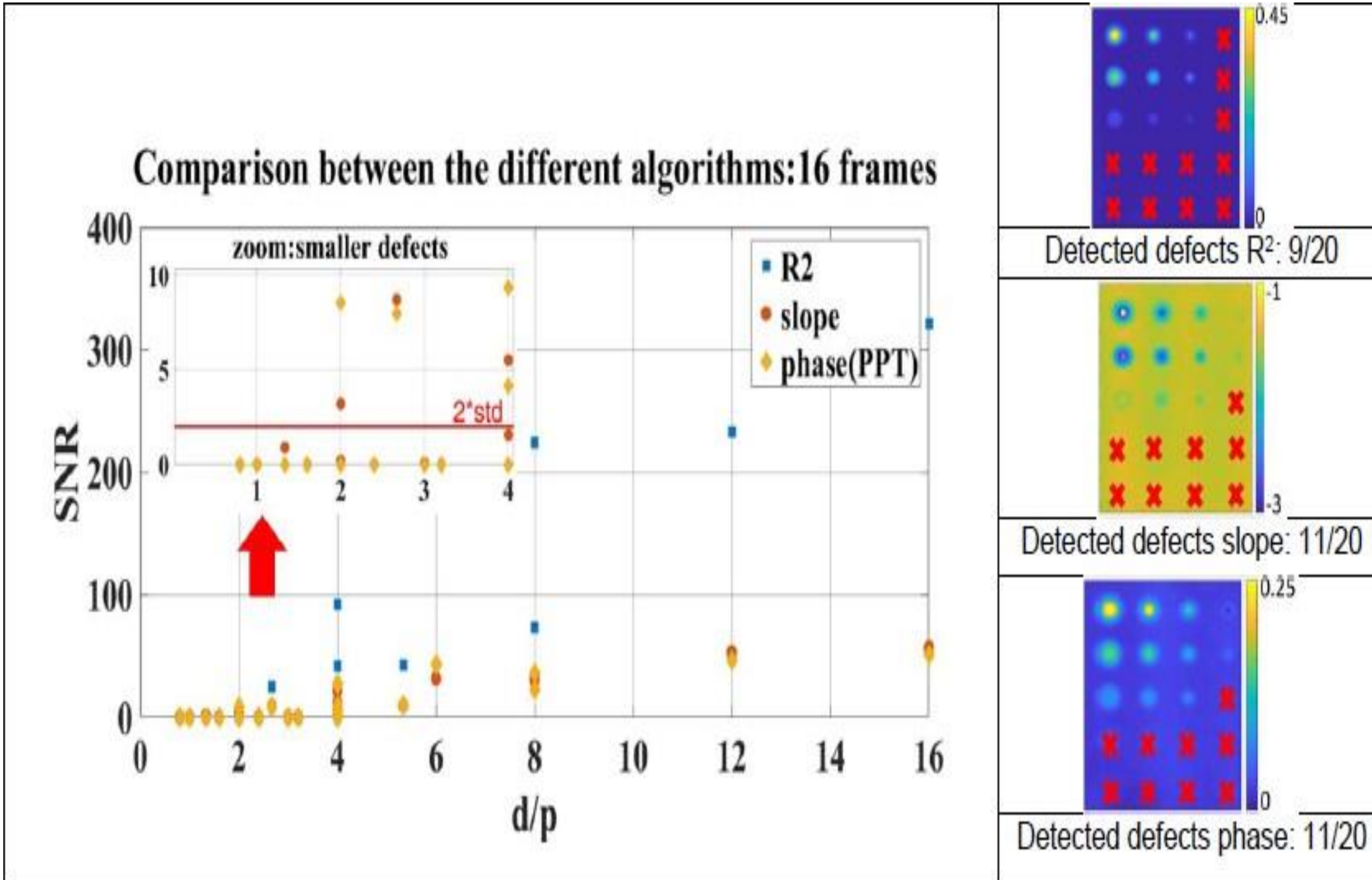
Methods: Pulsed Thermography

- The pulsed infrared thermography consists of a short heat pulse to stimulate the surface of tested material; after this thermal heating, the thermal response of the material is analysed.
- Immediately after the heat pulse, in fact, it is possible to observe the cooling behavior of tested sample, different between defected and sounded zones.
- Assuming that the thermal behavior of the analysed component is the same of a semi-infinite homogenous sample characterized by an effusivity in *z direction ez and a homogeneous heating of the same*, *the surface temperature time evolution follows the law:*

$$\Delta Txy = Qxy/ez\sqrt{\pi t}$$

The steps of the proposed procedure can be summarized as follows:

- Importing of the thermographic sequence (3D matrix);
- Subtracting of the average of the first ten cold frames to the whole sequence to obtain the ΔT values over time Adding an offset ΔT value to avoid ΔT values close to zero;
- this step is applied pixel by pixel to each temperature decay curve and allows to avoid negative values in the logarithmic scale;
- the local temperature values are normalized at any time by dividing them to the values evaluated at time t' sufficiently near of the pulse occurrence
- the 3D final temperature matrix is divided in 7 intervals in order to process the data with the proposed algorithms.


Comparison between the different algorithms:16 frames
zoom:smaller defects
2*std
R2
slope
phase(PPT)
SNR
d/p
0.45
Detected defects R²: 9/20
-1
-3
Detected defects slope: 11/20
0.25
Detected defects phase: 11/20

Advantages

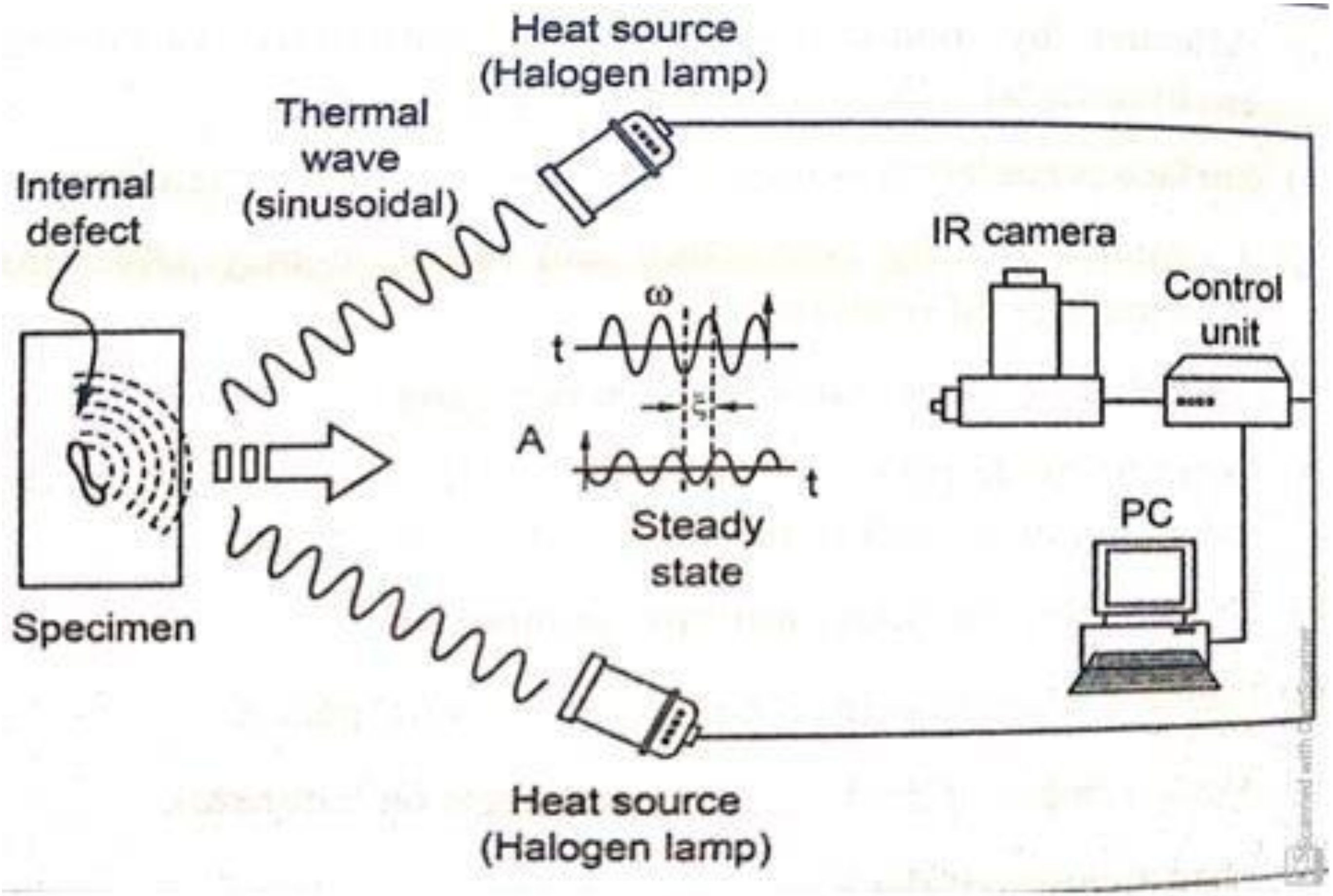
- Pulsed thermography is a faster technique and easy to deploy.
- Numerous processing techniques are available.
- Highly suitable to detect voids and inclusions.
- Quantitative assessment of detect is possible.

Applications

- Defect detection under multiply composite.
- Determination of impact damages on CFRP panels.
- Measurement of drilling induced defects on laminates.
- Identification of the cracks in turbine components.
- Detection of water accumulation, corrosion in aircraft passes.

LOCK-IN THERMOGRAPHY (LT)

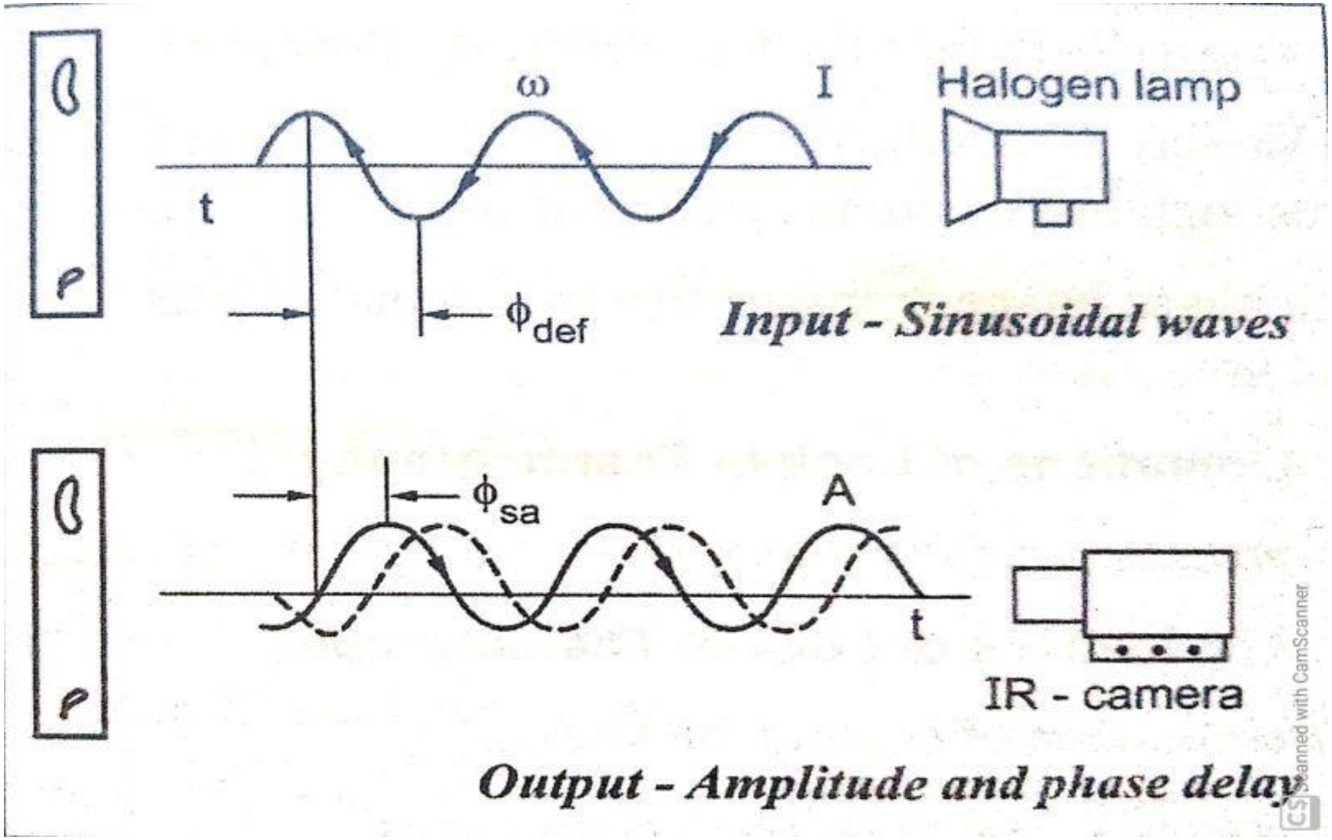
- Lock in thermography is also called as modulated thermography.
- In this technique, the specimen surface is periodically illuminated by modulated heating source like halogen lamps, to inject thermal waves in to the specimen.
- Heat is produced and propagates through the material by radiation caused by periodic waves. Internal defects act as barrier for heat propagation, which produces changes in amplitude and phase of the response at the surface.
- The thermal response is recorded of the same time using an infrared camera capable of monitoring the whole surface


Heat source
(Halogen lamp)
Thermal
wave
(sinusoidal)
Internal
defect
IR camera
Control
unit
ω
t
A
t
Steady
state
PC
Specimen
Heat source
(Halogen lamp)

Input and Output of Lock-in Thermography

- Several lamps are used to reduce non-uniform heating and to increase amount of energy delivered to the surface. The lamp send periodic waves (sinusoidal) at a given modulation frequency o, for atleast one cycle, until a steady state B achieved.
- If the wave reaches areas of the object, with in which the thermo physical properties, it is partly reflected.
- The reflected part interferes with the wave created at the surface, whereby interference pattern in the local surface temperature and thus in the surface radiation is caused, which oscillates with the frequency of the thermal wave.
- By evaluating the amplitude and the phase of the local surface temperature one gets information about the subsurface structure and defects.

Input and Output of Lock-in Thermography



Advantages of Lock-in Thermography

- It is possible to best thick or thermally slow parts.
- Relatively simple heat source is sufficient (small energy input is enough to execute the examination of the object).
- The phase image is insensitive to external effects like sunlight and reflections.

VIBRO THERMOGRAPHY TESTING

Vibro thermography (VT), also known as ultrasound thermography or thermosonics, utilizes the mechanical waves to directly simulate internal defects and without heating the surface as in optical methods (pulsed thermography or lock in thermography).

Principle

In vibro thermography, ultrasonic waves will travel freely through a homogeneous material, whereas internal defect will produce a complex combination of absorption, scattering, manifestation will be in the form of heat. Heat then will travel by conduction in all directions, an IR camera is used to capture the defects in the specimen.

Types

They are basically two configurations for vibro thermography.

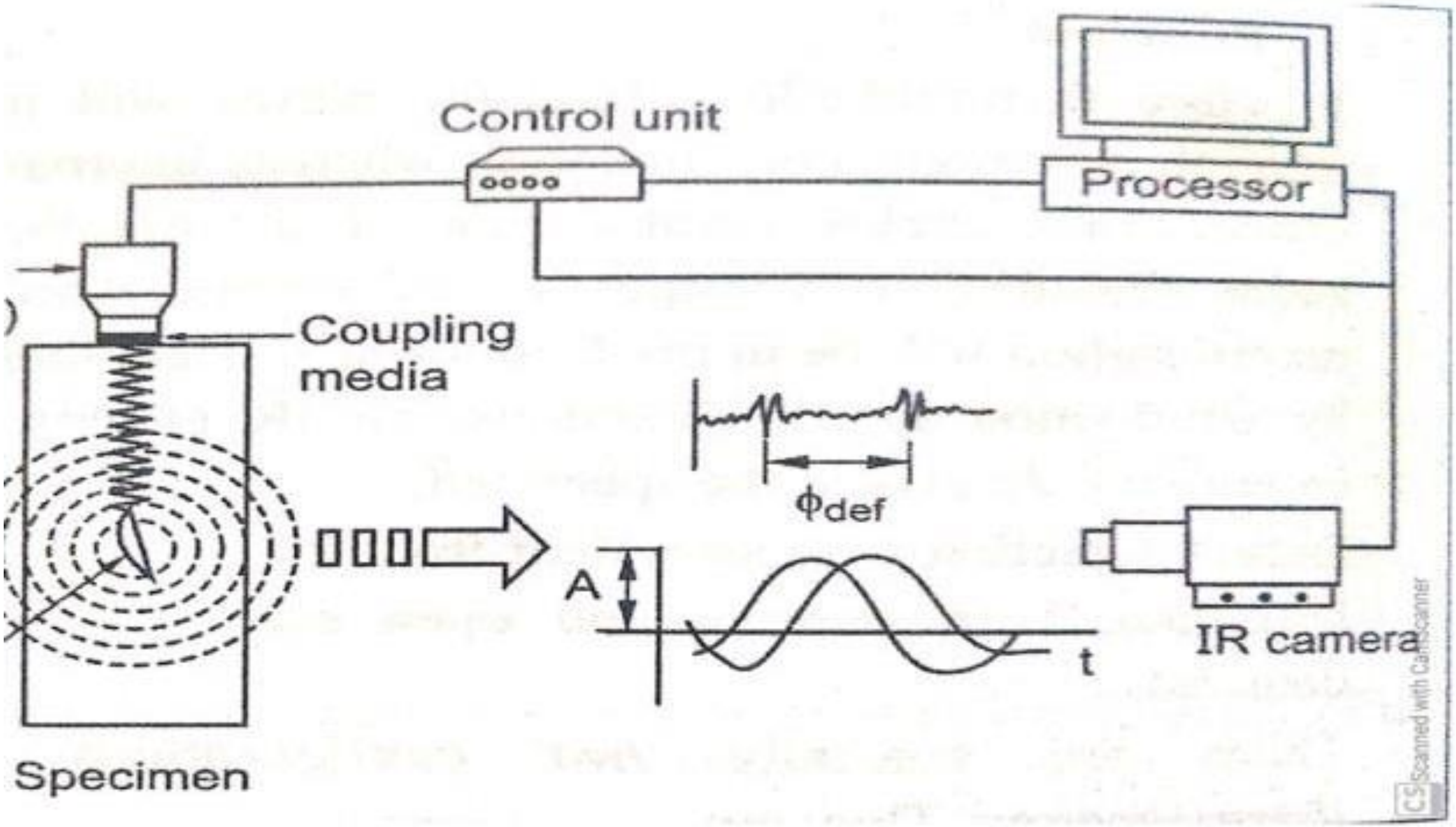
1. Burst vibro thermography (similar to pulsed thermography), and

2. Lock-in vibro thermography (similar to optical lock-in

Burst Vibro Thermography

In burst vibro thermography, a burst of ultrasonic waves are injected into the test specimen for a short time and it varies from milliseconds to few seconds.

Burst Vibro Thermography



Lock-in vibro thermography

- Lock-in vibro thermography, also called as amplitude modulated Vibro Thermography, is similar to optical lock in thermography with a difference in excitation source.
- ln this technique mechanical elastic wave at higher frequency is injected to the specimen.
- This equipment consists of ultrasonic vibration source, IR camera, control unit, computer with processing software and display unit.
- The frequency and shape of the response curves are preserved; the change is amplitude and phase delay is processed and recorded for analysis.

Lock in Vibro thermography

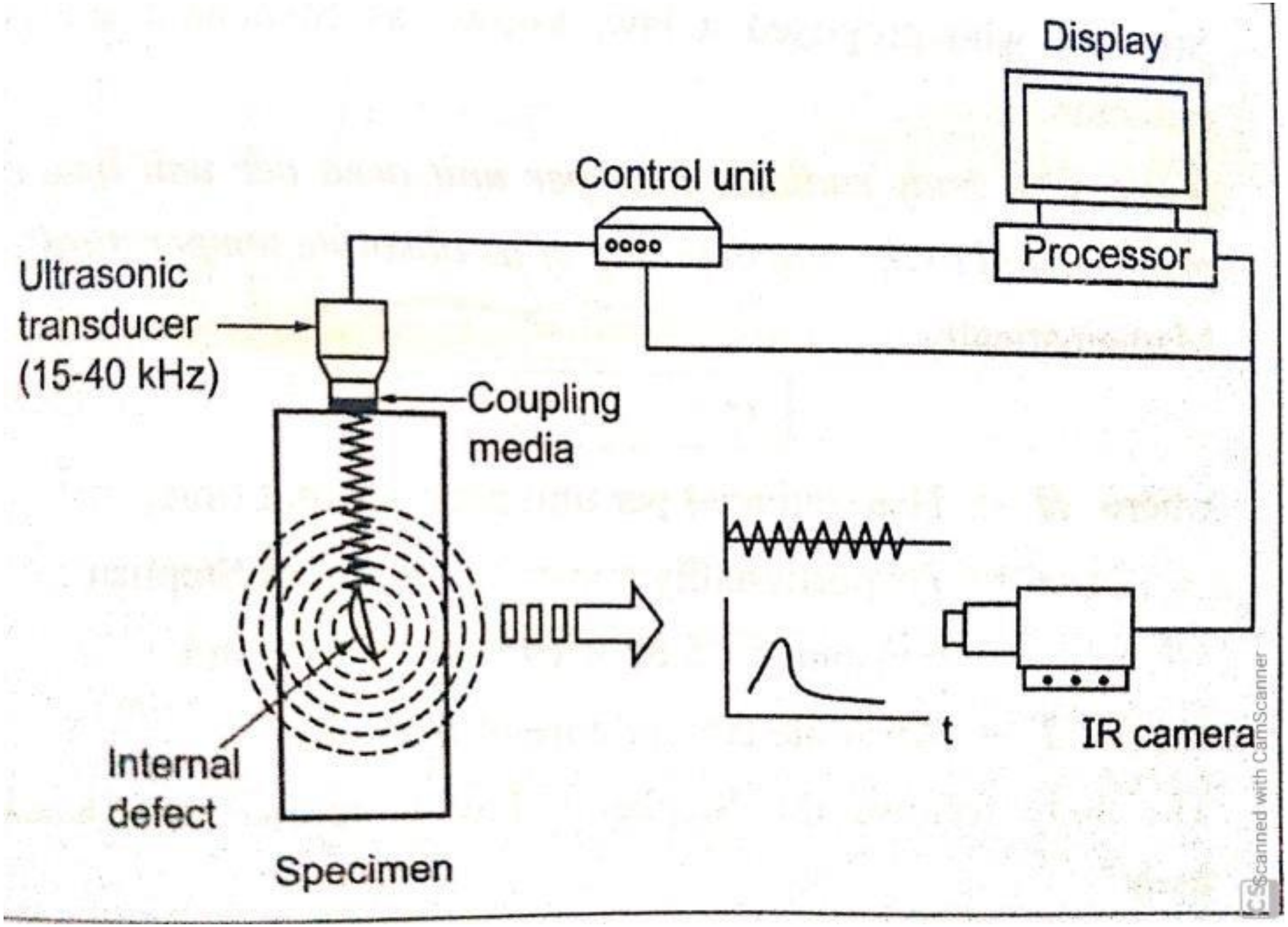


IMAGE PROCESSING IN THERMOGRAPHY

- In thermography testing the specimen is stimulated with energy source, which can be of many types, such as optical, mechanical or electromagnetic.
- Irrespective of the excitation source, the thermal image can be recorded by the IR camera
- Thermal image processing involves preprocessing and processing stages to record "thermogram" at regular interval.
- Before processing the received data with the help of IR camera, it is necessary to fix some problems related to de acquisition system.

Preprocessing Techniques in Thermography Testing

1. **Fixed Pattern Noise**
2. **Bad Pixels**
3. **Vignetting**
4. **Temperature Calibration**
5. **Noise Smoothing**

UNIT IV

ULTRASONIC TESTING (UT) AND ACOUSTIC EMISSION (AE)

Ultrasonic Testing-Principle, Transducers, transmission and pulse-echo method, straight beam and angle beam, instrumentation, data representation, A/Scan, B-scan, C-scan. Phased Array Ultrasound, Time of Flight Diffraction.

Acoustic Emission Technique – Principle, AE parameters, Applications

Ultrasonic Testing

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

Ultrasonic Testing(continue)

- Ultrasonic Testing (UT) uses high frequency sound waves (typically in the range between 0.5 and 15 MHz) to conduct examinations and make measurements.
- In general, ultrasonic testing is based on the capture and quantification of either the reflected waves (pulse-echo) or the transmitted waves (through-transmission).

Ultrasonic Testing

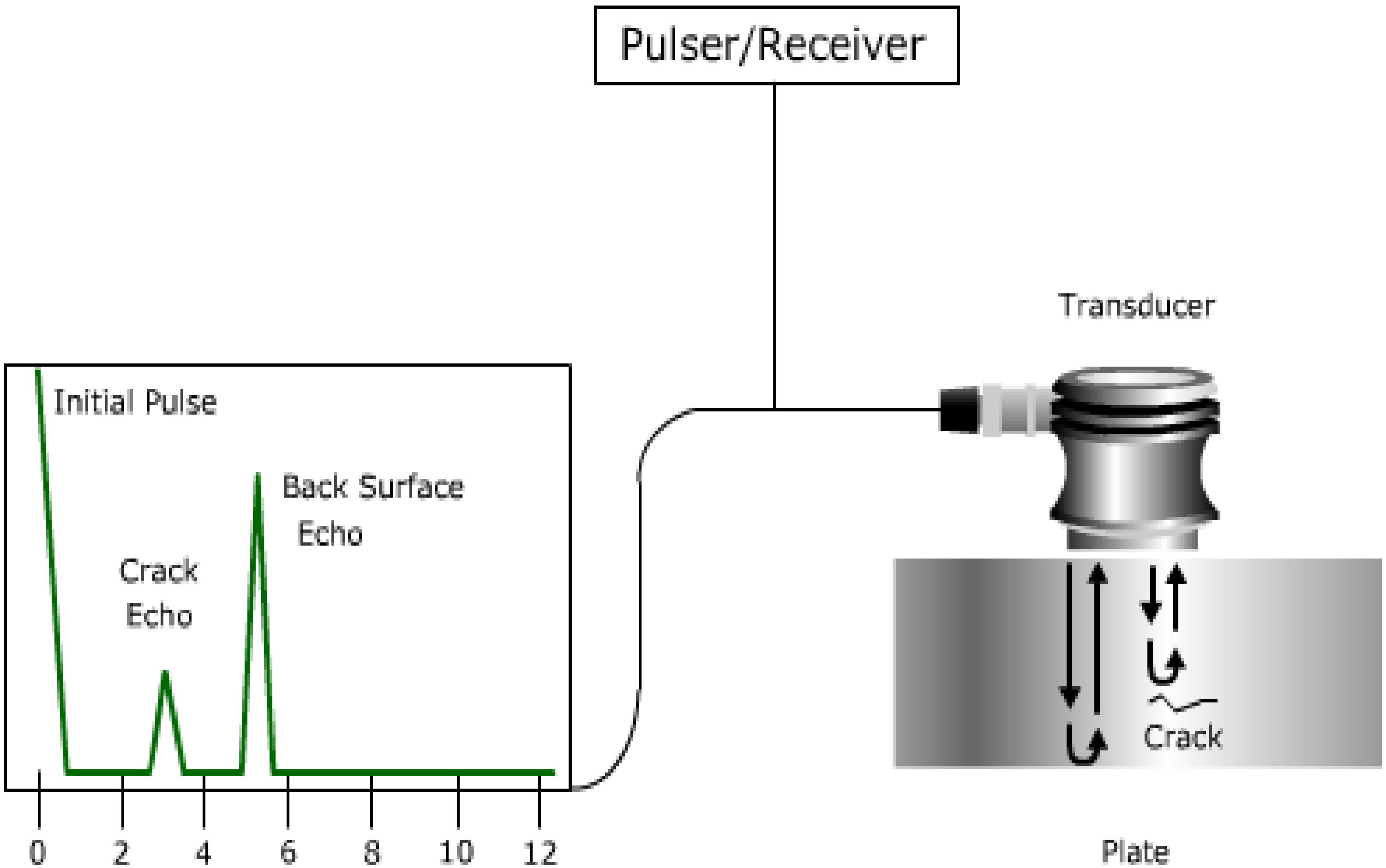
- A typical UT inspection system consists of several functional units, such as the pulse/receiver, transducer, and display devices.
- A pulse/receiver is an electronic device that can produce high voltage electrical pulses.
- Driven by the pulse, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves.

Ultrasonic Testing

- When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface.
- The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen.
- Signal travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

Principles

- A typical pulse-echo UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and a display device.
- A pulser/receiver is an electronic device that can produce high voltage electrical pulses.
- Driven by the pulser, the transducer generates high frequencyultrasonic energy.
- The sound energy is introduced and propagates through the materials in the form of waves.
- The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. Knowing the velocity of the waves, travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.



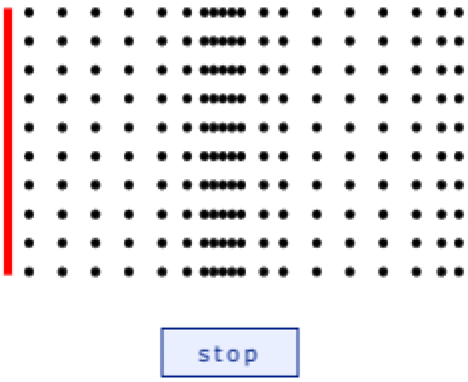
Pulser/Receiver
Transducer
Initial Pulse
Back Surface
Echo
Crack
Echo
0
2
4
6
8
10
12
Crack
Plate

Wave Propagation

- Ultrasonic testing is based on time-varying deformations or vibrations in materials, which is generally referred to as acoustics.
- All material substances are comprised of atoms, which may be forced into vibrational motion about their equilibrium positions.
- Many different patterns of vibrational motion exist at the atomic level, however, most are irrelevant to acoustics and ultrasonic testing.

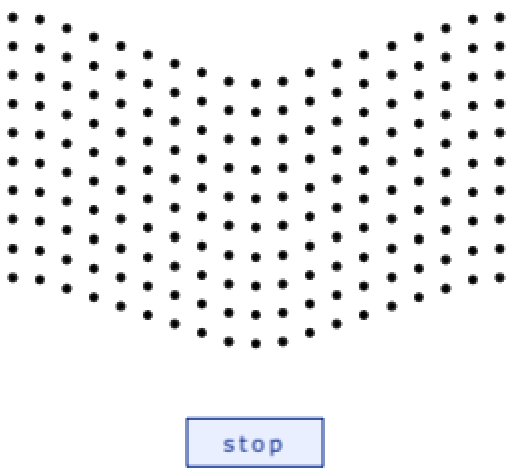
LONGITUDINAL WAVES

- the oscillations occur in the longitudinal direction or the direction of wave propagation. Since compressional and dilational forces are active in these waves, they are also called pressure or compressional waves.
- They are also sometimes called density waves because their particle density fluctuates as they move.
- Compression waves can be generated in liquids, as well as solids because the energy travels through the atomic structure by a series of compressions and expansion (rarefaction) movements.



TRANSVERSE OR SHEAR WAVE

- the particles oscillate at a right angle or transverse to the direction of propagation.
- Shear waves require an acoustically solid material for effective propagation, and therefore, are not effectively propagated in materials such as liquids or gasses.
- Shear waves are relatively weak when compared to longitudinal waves. In fact, shear waves are usually generated in materials using some of the energy from longitudinal waves.



Terminologies used in ultrasonic wave

1. **Wavelength**

   The distance between successive crests of a wave, especially points in a sound wave. It is represented by letter

2. **Sensitivity**

   Sensitivity is the ability to locate small discontinuities (defects).

   Sensitivity, generally increases with higher frequency (shorter wavelengths)

3. **Resolution**

   Resolution is the ability of the system to locate defects that are close together with in the materials or located near the part surface.

   Resolution also increases with increase in frequency.

4. Penetration Depth

Penetration depth is the maximum depth in a material, the flaws can be located by the ultrasonic waves in testing.

5. Scattering

Scattering is the reflection of sound beam from its original direction of propagation.

6. Absorption

Absorption is conversion of sound energy from one form to some another form.

ULTRASONIC TESTING SETUP AND METHOD

- Ultrasonic inspection techniques are commonly divided into three primary classifications.

1. **Pulse-echo and Through Transmission**

   (Relates to whether reflected or transmitted energy is used)

2. **Normal Beam and Angle Beam**

   (Relates to the angle that the sound energy enters the test)

3. **Contact and Immersion**

   (Relates to the method of coupling the transducer to the test)

Ultrasonic Testing Methods

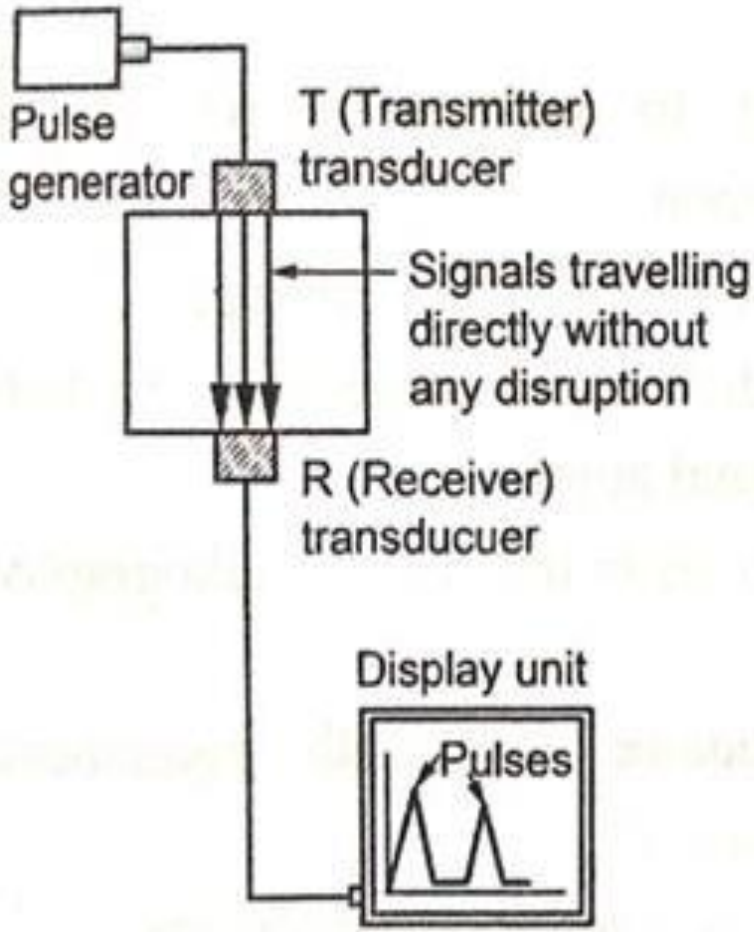
- The ultrasonic testing procedure for the detection of flaws in the material is based on two methods. They are:

  1. Transmission method, and

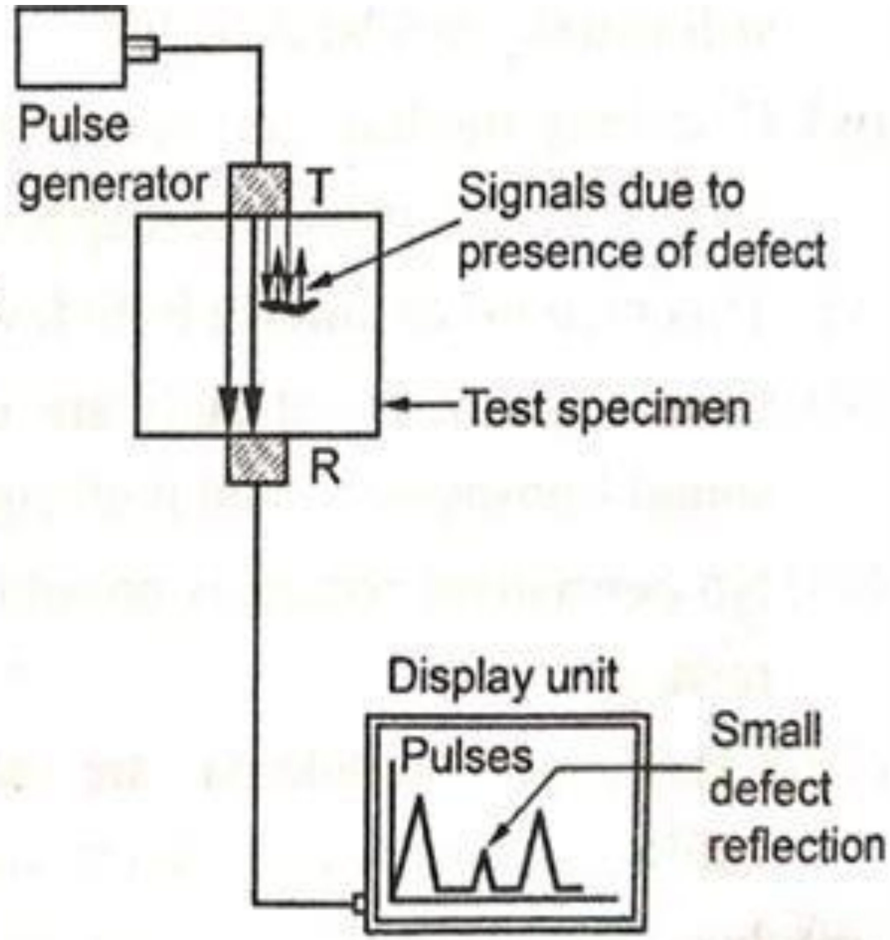
  2. Pulse-echo method.

Transmission Method

- In transmission method, two ultrasonic transducers are used. One is used to transmit the sound wave and other one to receive them.
- Transmitter sends, the ultrasound through one surface, and a separate receiver detects the amount that has reached another surface after traveling through the medium.
- Imperfection in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing the presence of defect.



(a) Transmission of waves through defect free specimen



(b) Transmission of waves through specimen with defect giving small signal for defect

Steps Involved in Through Transmission Method

- Two transducers are placed opposite to each other on the surface of the test specimen.
- A transducer (T) on one side of the specimen transmits an ultrasonic pulse to a receptor (R) transducer on the other side.
- When the test piece without defect is tested, the signal received by the receiver transducer is relatively large.
- If there is a flaw, then received signal by the receiving transducer will be reduced.
- Using the couplant increases the efficiency of the process by reducing the losses in the ultrasonic wave energy due to separation between the surfaces.

Transmission Method

Advantages

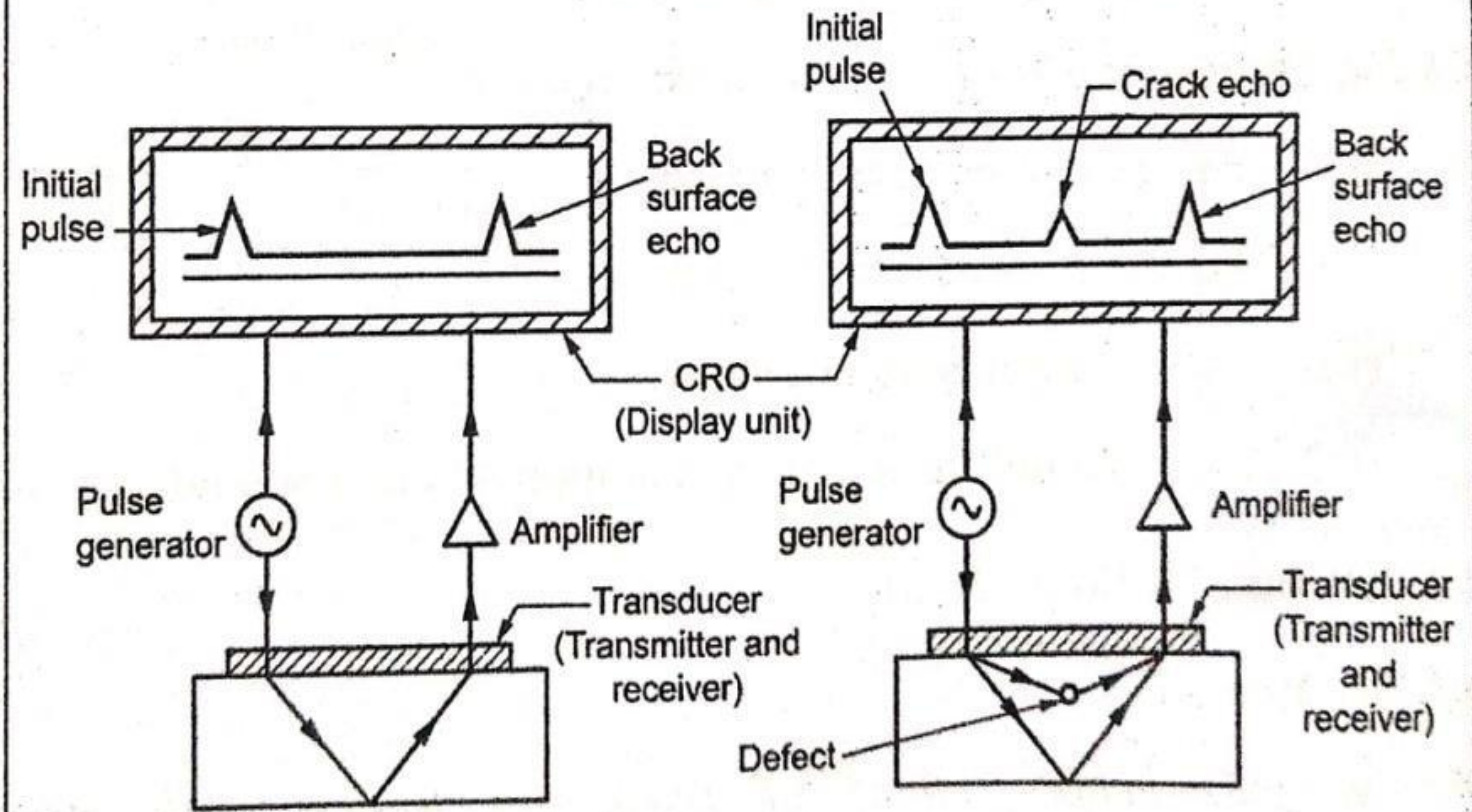
- Less alternation of sound energy.
- No probe ringing.
- No dead zone on the display screen.

Disadvantages

- The defect cannot be located.
- The component surfaces must be parallel.
- Vertical defects do not show.
- Access to both sides of the components is essential.

Pulse-Echo method

- In pulse-echo method of ultrasonic testing, only one transducer is used which acts as a both transmitter and receiver.
- A typical pulse-echo ultrasonic inspection system consists of a frequency generator, display unit (CRO), transmission and receiving transducer and an amplifier.
- Couplant is used to separate the test object from transducer.
- High frequency generator sends ultrasonic pulses through transmitting and is passed over the object to be inspected. The sound energy is introduced and propagates through the materials in the form of waves.
- When there is a discontinuity (cracks) in the wave path, part of the energy will be reflected back from the flaw surface.
- The reflected wave signal is transformed into an electrical signal by the receiver transducer and is displayed in the screen.
- From the signal, information about the flaw location, size and orientation can be identified.



(a) Specimen without defect   *(b) Specimen with defect*

Advantages of Pulse-Echo Method

1. High penetrating power, detection of flaws deep in the part is possible.
2. High sensitivity, permitting the detection of very small flaws.
3. To place transducer, access to one side of the specimen is enough.
4. Capable of portable and automation is possible.

Disadvantages of Pulse-Echo Method

1. Highly skilled and experienced technicians are required to assess the defects.
2. Part with rough surface, irregular shape, very thin are difficult to inspect.
3. Surface preparation is essential to remove loose scale, and paint etc.
4. Couplants are needed to provide effective transfer of ultrasonic wave energy.

Ultrasonic Transducers

- The function of the transducer is to transfer electrical energy to mechanical energy and vice versa.
- In ultrasonic testing, transducer is the actual front end of the system.
- Transducers are also called as probes, search units and test heads.
- The ultrasonic transducers are the devices used to generate and detect ultrasonic waves.

Types of Ultrasonic Transducers (or Probes)

Types

A. On the basis of construction principle involved, and

B. On the basis of applications employed.

Ultrasonic Transducers on the Basis of Construction

Principle Involved are:

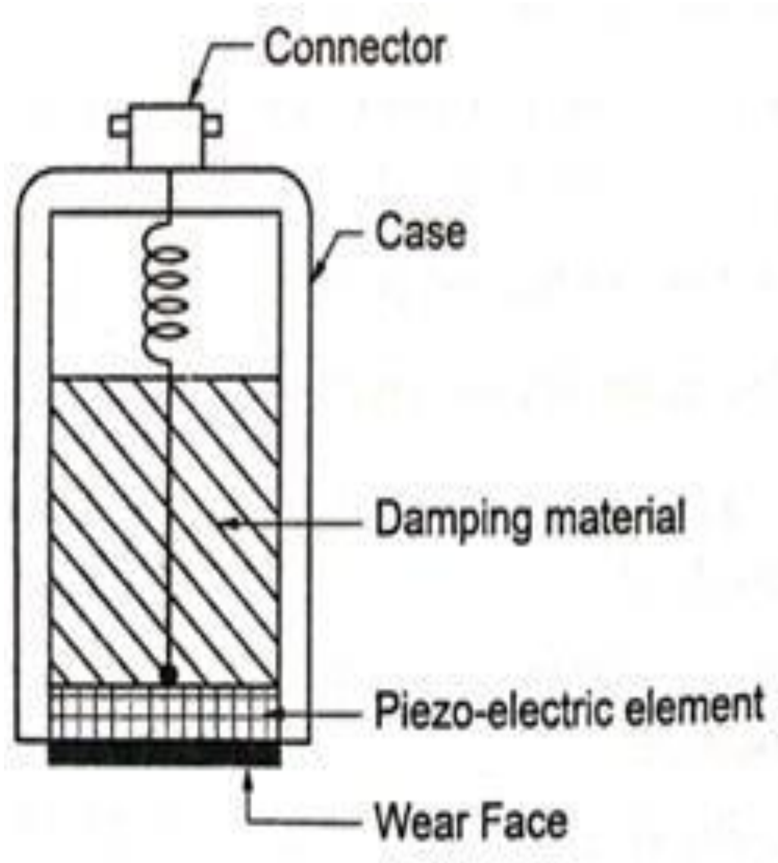
1. Piezo-electric transducers,
2. Electro Magnetic Acoustic Transducers (EMAT) (non-contact ultrasonic transducers), and
3. Laser generated ultrasound.

Ultrasonic Transducers on the Basis of Applications

Different types of ultrasonic transducers on the basis of applications employed are:

1. Contact transducers,
2. Dual element transducers,
3. Angle beam transducers,
4. Delay line transducers,
5. Protected face transducers,
6. Immersion transducers,
7. High frequency transducers, and
8. Phased array transducers.

Piezo-Electric Transducers



Piezo-electric ultrasonic transducer consists of:

- A case,
- A piezo-electric element,
- Backing material,
- Electrodes,
- Connectors, and
- Protection for the piezo-electric elements from mechanical damage.

Working:

- Piezo-electric transducers employ materials which generate electric charges when mechanically stressed. Conversely piezo-electric materials became stressed when electric charge is applied to them.
- These piezo-electric materials are suitably mounted of the front end of the ultrasonic probes.
- When electric pulse is applied to piezo-electric crystal housed in the probe, high frequency ultrasonic waves are generated there is a discontinuity (crack) in the wave path, part of the energy will be reflected back from the flaw surface.
- These reflected wave signal is transformed into an electrical signal by the transducer and displayed in the screen.

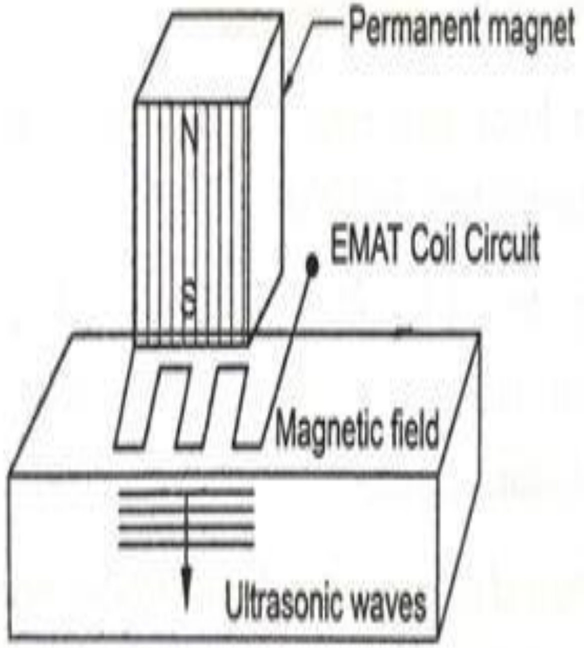
Advantages :

- High frequency response.
- They offer high output with suitable electronic circuits.
- Smaller in size and simple in construction.

Disadvantages :

- Auxiliary circuits are required to reduce impedance.
- Difficult to give the required shape to the piezo-electric element.

Electro Magnetic Acoustic Transducers (EMAT)



- Electro Magnetic Acoustic Transducer (EMAT) technology is an alternative method of generating and receiving ultrasonic energy.
- These are transducers that are made up coils that are placed in close proximity to the test piece.
- The coils produce a magnetic field that interacts with metal, surface of the material. This deformation produces the wave of ultrasonic energy.

Advantages :

- EMAT is a non-contact transducer, hence no couplant is required.
- Examination of high temperature components is possible.
- Focusing of the beam is possible, as is steering the beam at various angles.

Disadvantages :

- Low efficiency when compared with piezo-electric transducers.
- Relatively larger in size.
- Conductive layer is to be applied on the surface of non-conductive material to produce ultrasonic energy.

Laser Generated Ultrasound

- Acoustic propagation is accomplished by briefly heating the surface of the test material.
- This brief heating of the surface causes the generation of thermal expansion on the surface of the material, which is turn results in the formation of a wave front that travels through the material.
- The technology generally employs two separate laser-one to heat the surface and produce the wave, and a second to detect the movement of the surface due to disturbance from the reflected wave.

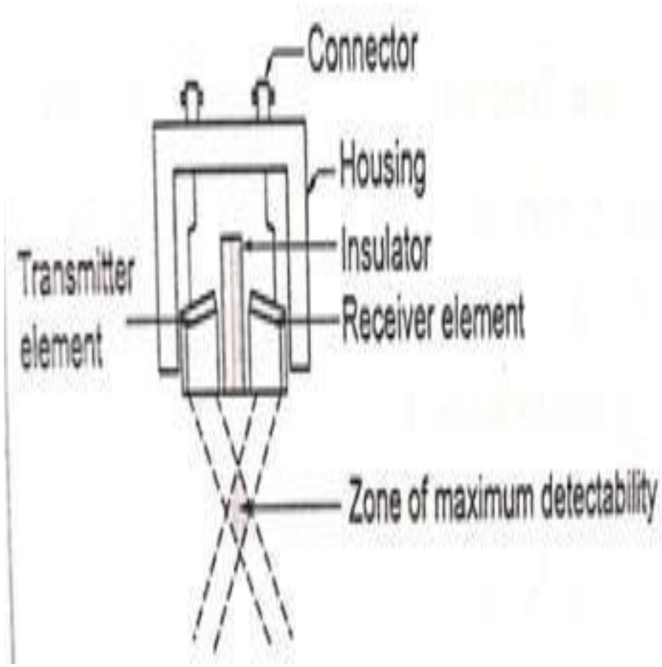
Advantages :

- Laser interferometre is used for reception, hence no need for couplant.
- The laser can be located remote from the test surface.

Contact Transducers

- A contact transducer is a single element transducer, usually a longitudinal wave that is intended for direct contact with a test piece.
- This transducer is designed for general purpose manual ultrasonic inspection where test materials are relatively flat and smooth.
- Contact transducers provide high sensitivity for better Penetration and are ruggedly constructed for extended service life.

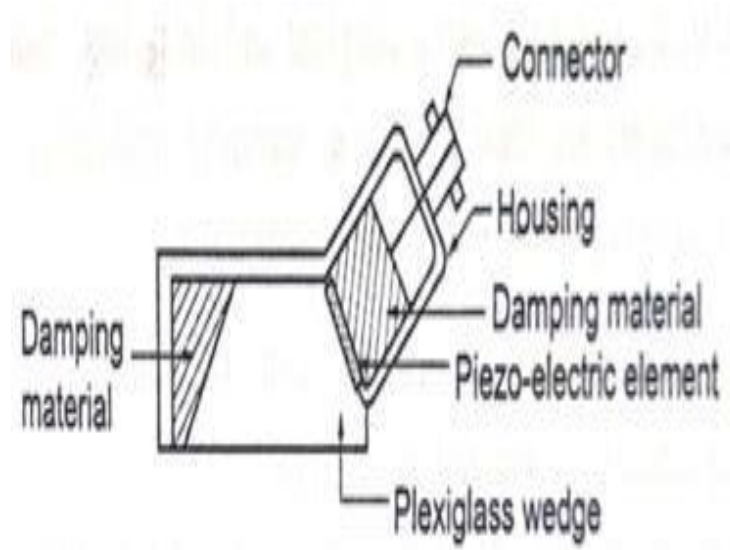
Dual Element Transducer



- A dual element transducer consists of two longitudinal wave crystal elements (one act as receiver) housed in the same housing and isolated from each other by an acoustic barrier.
- The elements are angled slightly towards each other to bounce a signal off the back wall of a part in a V-shaped pattern.
- Dual element transducers typically offer more consistent reading on corroded parts, and can also be used in high temperature environments.

Angle Beam Transducers

- Angle beam transducers are single or dual element transducers used with wedge to introduce longitudinal or shear wave sound in to a part at a selected angle.
- Angle beam transducer allows inspections in areas of a part that cannot be accessed by the ultrasonic path of a normal incidence contact transducer.
- A common application of angle beam transducer is in welding inspection, where weld crown blocks access to the weld zone of interest.



Delay Line Transducer

- Delay line transducer are single element broad band contact transducer designed specifically to incorporate a short piece of plastic or epoxy material in front of the transducer element.
- Delay lines offer improved resolution of the flaws very near to the surface of a part and allow thinner range and more accurate thickness measurement of materials.
- Delay lines can be contoured to match surface geometry of a part and can also be used in high temperature applications.

Protected Face Transducers

- Protected face transducer is single element longitudinal wave transducers with threaded case sleeves, which allow a delay line through wear cap or membrane.
- This makes them externally versatile and able to cover a wide range of application.
- The protective face is a pliable polymeric membrane used to assist coupling to rough or uneven surfaces.

Immersion Transducers

- Immersion transducer is a single element longitudinal wave transducer, whose wear face is impedance matched to water.
- Immersion transducers have sealed cases allowing them to be completely submerged under water when used with a waterproof cable.
- By using water as both a couplant and delay line, immersion transducers are ideal for use in scanning applications where consistent coupling to the pair is essential.
- Fig shows the arrangement of ultrasonic testing inspection with immersion transducer.

Ultrasonic data can be collected and displayed on screens in different formats.

- The three most common modes of data presentation in ultrasonic testing are:

  1. A-scan presentation,

  2. B-scan presentation, and

  3. C-scan presentation.

- Each presentation mode provides a different way of looking at and evaluating the region of material being inspected.

A-Scan Presentation

- The a-scan presentation displays the amount of received ultrasonic energy (amplitude) as a function of time. The relative amount of received energy is plotted along the vertical axis and the elapsed time in horizontal axis.
- In the a-scan presentation, relative discontinuity size can be estimated by comparing the signal amplitude obtained from an unknown reflector to that from a known reflector.
- Reflector depth can be determined by the position of the signal on the horizontal sweep.

B-Scan Presentation

- The B-scan presentation is a cross-sectional view of the test specimen.
- In the B-scan, the time of flight (travel time) of the sound energy is displayed along the vertical axis and the linear position of the transducer is displayed along the horizontal axis.
- In this presentation, echoes produced are displayed in form of bright spots. The position of spot can be indicated on screen by moving oscilloscope from one end to another end with B-scan presentation and, it is possible to measure depth and dimension of the flaws.

C-Scan Presentation

- In this presentation mode, two-dimensional information about the defects can be derived. Energy is displayed in terms of plane view of test specimen with an image parallel to the scan pattern traced by the transducer.
- The relative signal amplitude is displayed as a shade of gray or a color for each of the positions.
- Computer controls with a data acquisition system provides high resolution and very sharp images of the defects.

Acoustic Emission process

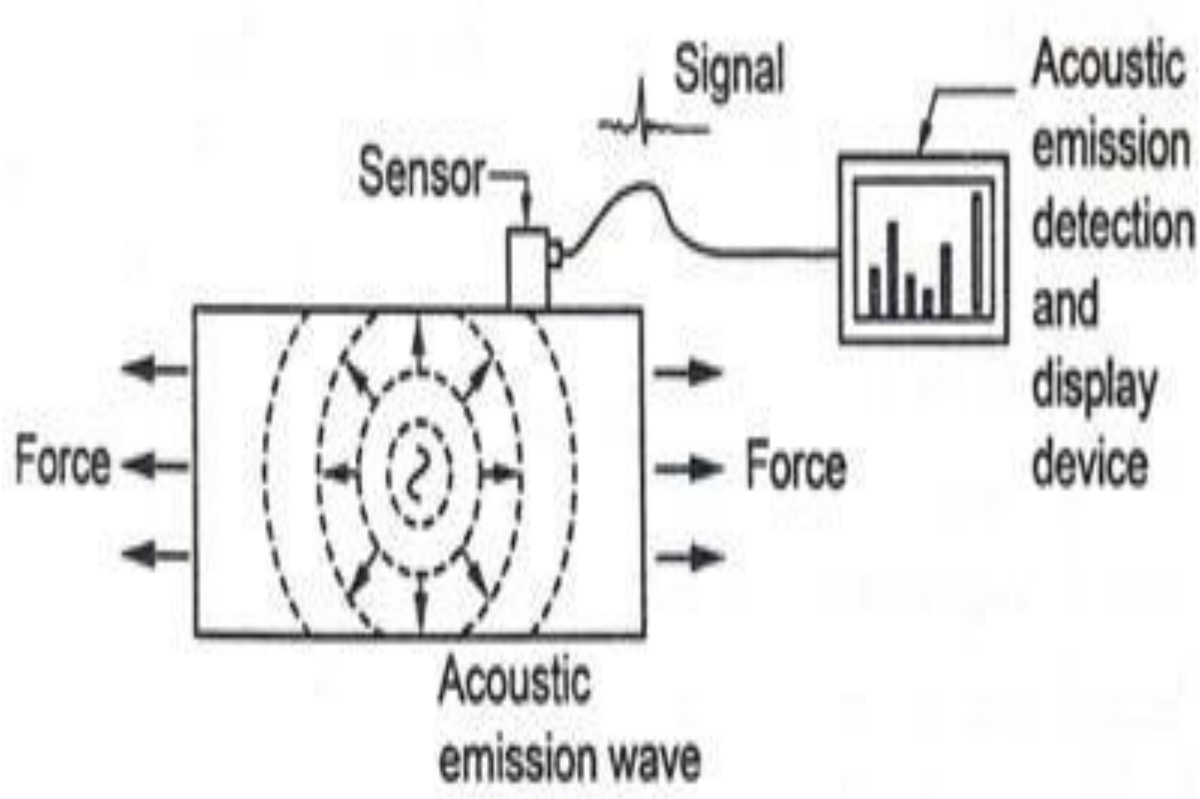
Introduction

- Acoustic Emission Test (AET) is a Non-Destructive Test (NDT) method generally used to detect and locate imperfections in mechanically loaded structures and components.
- Flaw origination and progression in a stressed component can be identified by acoustic emission test method when the component is subjected to repetitive or continuous stress.
- The acoustic emission in the sound form is to the ears what visual inspection is to the eyes.

Principle

- When a component with discontinuities is subjected to mechanical load or stress it release energy.
- This energy travels in the form of high frequency stress waves.
- These waves or oscillations are received with the use of sensors which in turn convert the energy into voltage.
- This voltage is electronically amplified and with the use of timing, circuits is further processed as AE signal data.

Acoustic Emission Testing



Stages in Acoustic Emission Testing

- External forces acting on a body; the resulting stress causes deformation with it.
- The stress on the material causes local plastic deformation and a crack (break down) at specific places. This crack/breakdown produces acoustic emission.
- Acoustic emission is an elastic wave that travels outward from the source (crack) and reaches the sensor.
- Sensor produces electrical signal (voltage), which is processed

Advantages

- Pre-service and in-service testing can be done.
- Online monitoring of components and system is possible.
- Locating defects and leak detecting.
- Less geometry sensitive.
- Less intrusive.
- Real time evaluation and remote scanning is possible.

Limitations

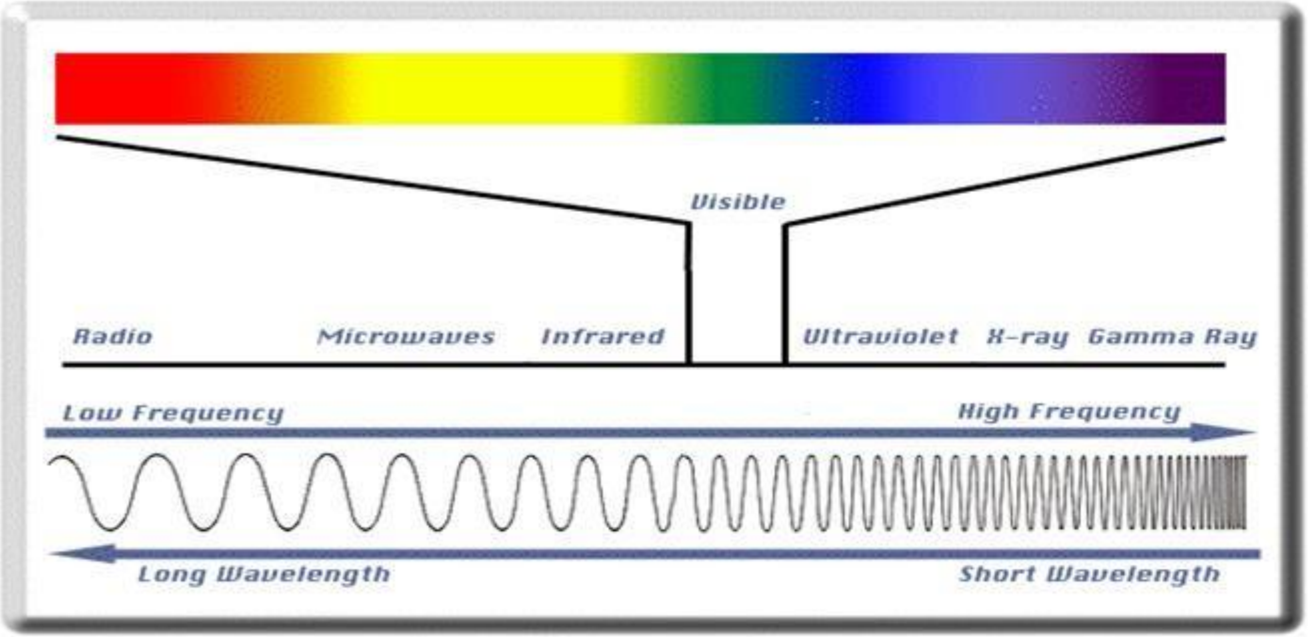
- Poor repeatability.
- Influence of ambient noise and attenuation of signals may result in poor output.
- Sophisticated data processing devices are required.
- AE results are set firmly to the knowledge and experience of the service provider.

UNIT-5
RADIOGRAPHIC METHODS

Principle, interaction of X-Ray with matter, imaging, film and film less techniques, types and use of filters and screens, geometric factors, Inverse square, law, characteristics of films - graininess, density, speed, contrast, characteristic curves, Penetrameters, Exposure charts, Radiographic equivalence. Fluoroscopy- Xero-Radiography, Computed Radiography, Computed Tomography

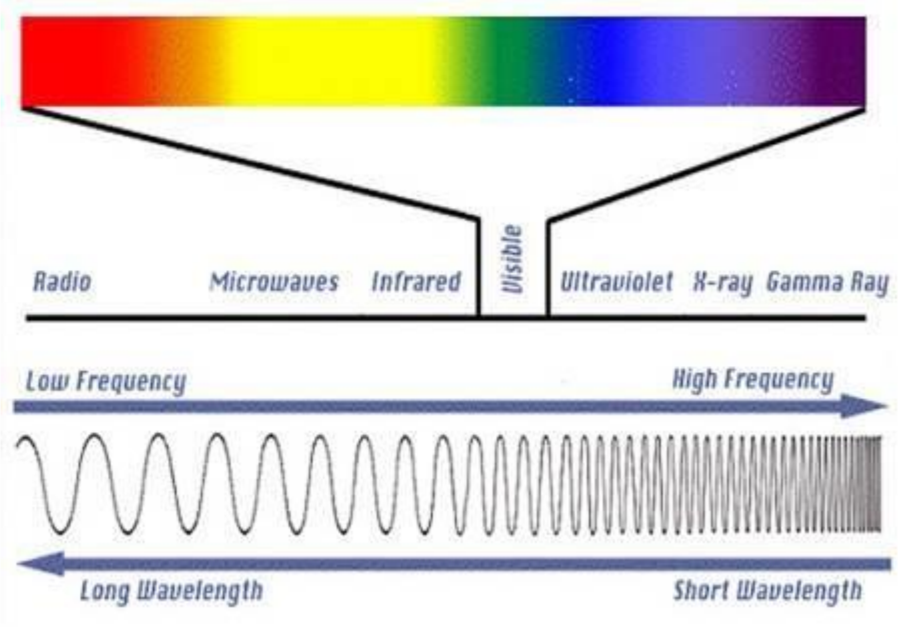
Electromagnetic Radiation

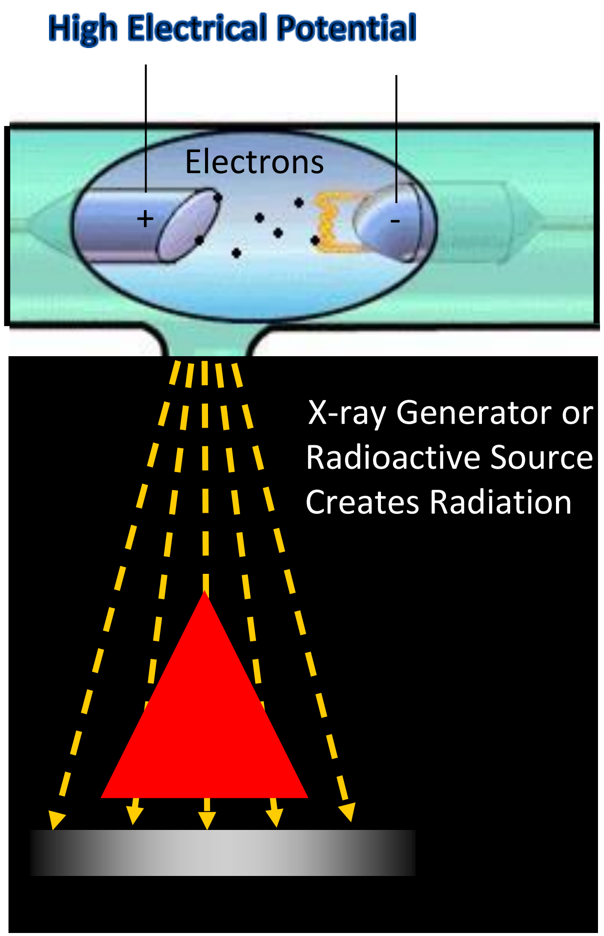
The radiation used in Radiography testing is a higher energy (shorter wavelength) version of the electromagnetic waves that we see every day. Visible light is in the same family as x-rays and gamma rays.



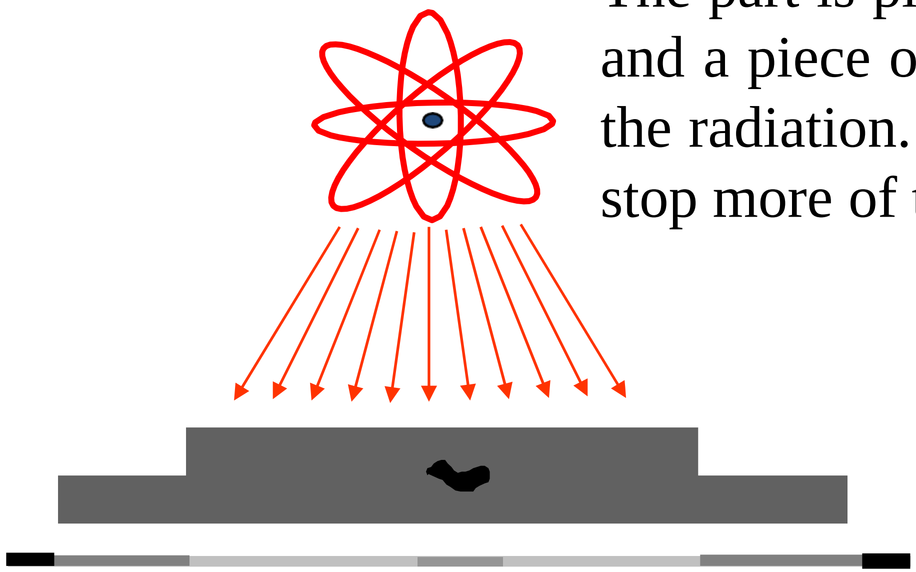
Radiography

The radiation used in radiography testing is a higher energy (shorter wavelength) version of the electromagnetic waves that we see as visible light. The radiation can come from an X-ray generator or a radioactive source.





General Principles of Radiography



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

X-ray film

Top view of developed film

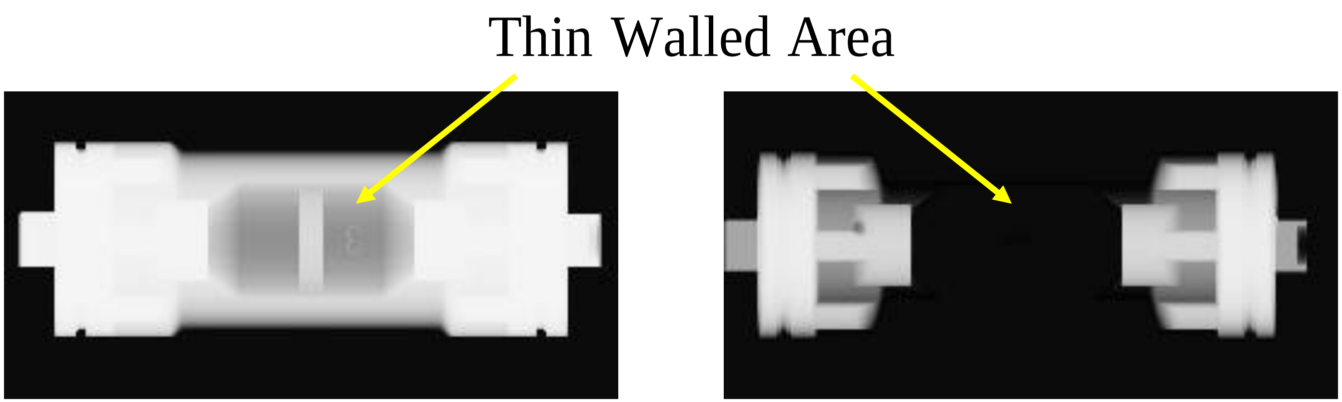
The film darkness (density) will vary with the amount of radiation reaching the film through the test object.

= less exposure

= more exposure

General Principles of Radiography

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

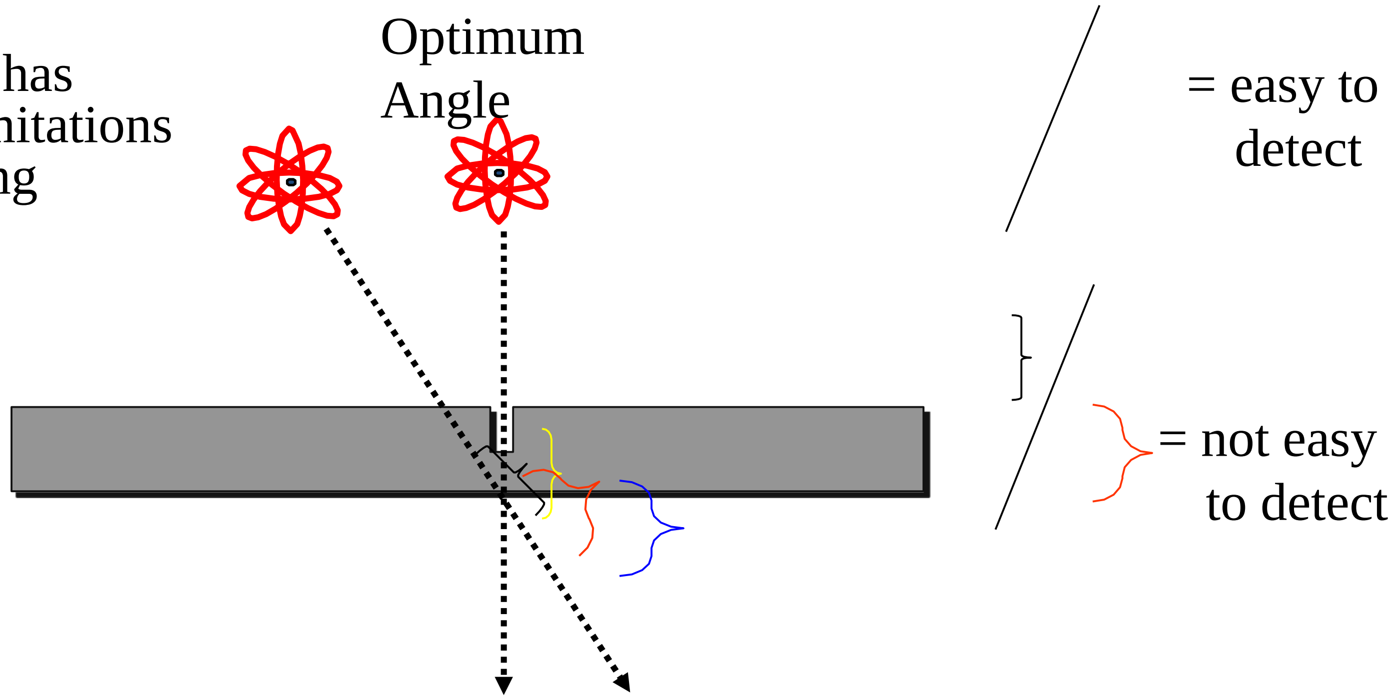


Low Energy Radiation

High energy Radiation

Flaw Orientation

Radiography has sensitivity limitations when detecting cracks.

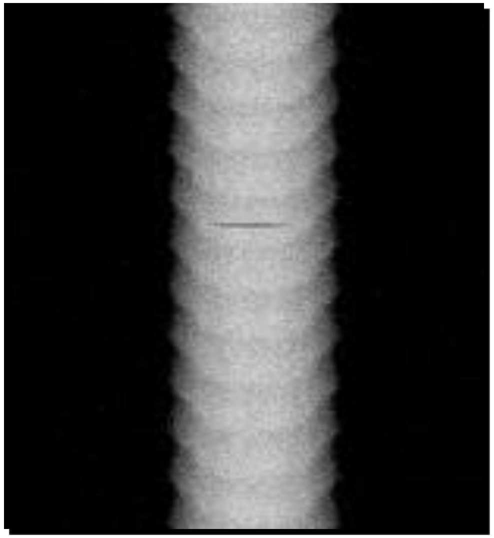


X-rays "see" a crack as a thickness variation and the larger the variation, the easier the crack is to detect.

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

Flaw Orientation (cont.)

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



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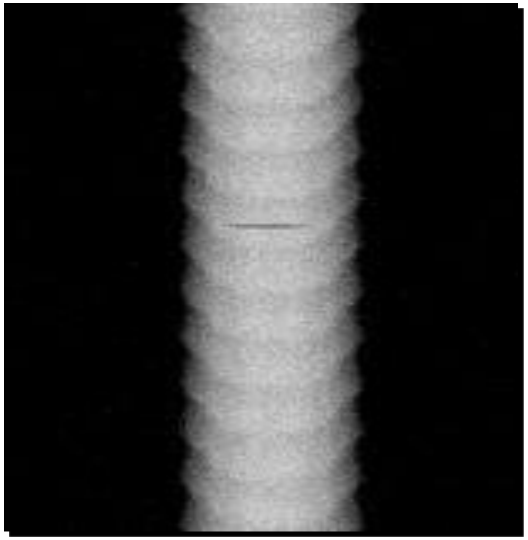
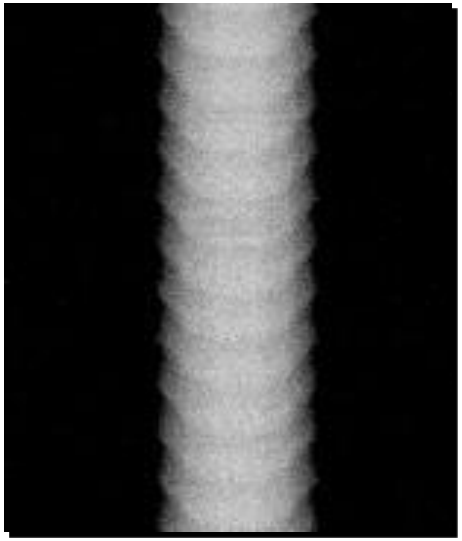


10^{o}



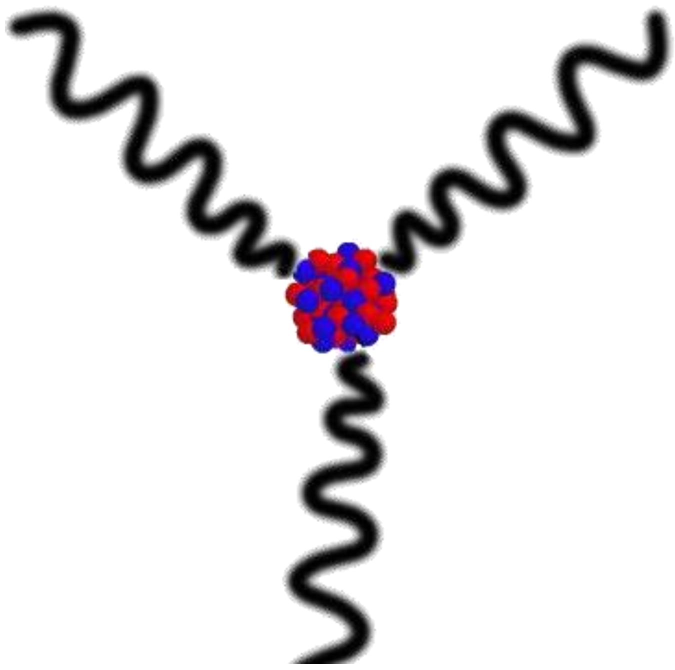
20^{o}

Radiation Sources

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

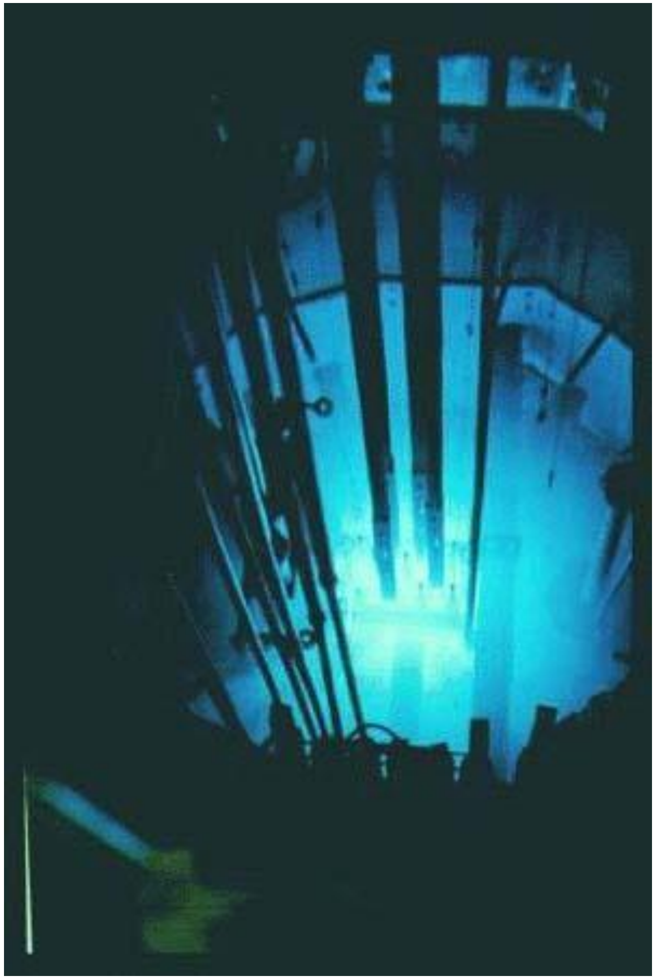
Gamma Radiography

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



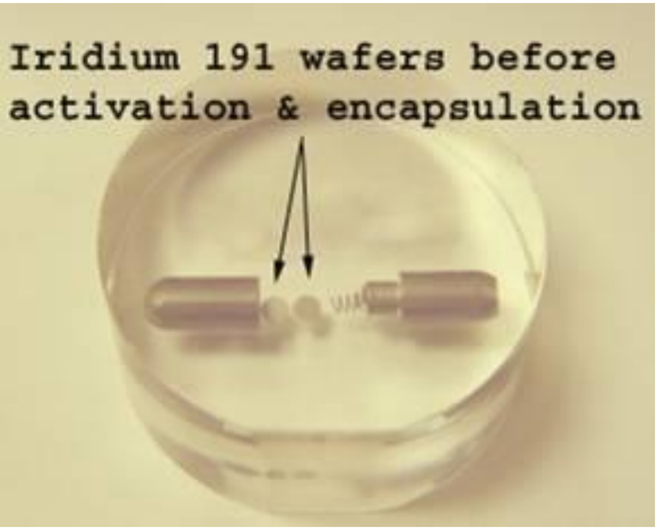
Gamma Radiography (cont.)

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



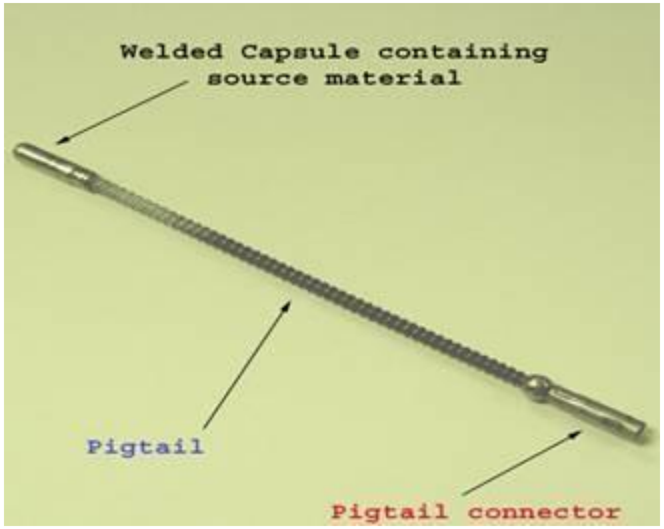
Gamma Radiography (cont.)

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



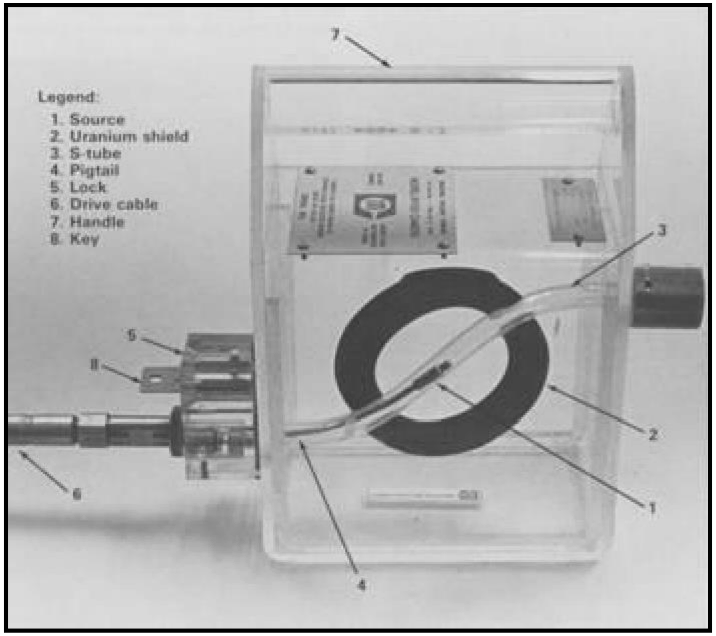
The radioactive "capsule" is attached to a cable to form what is often called a "pigtail."

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



Gamma Radiography (cont.)

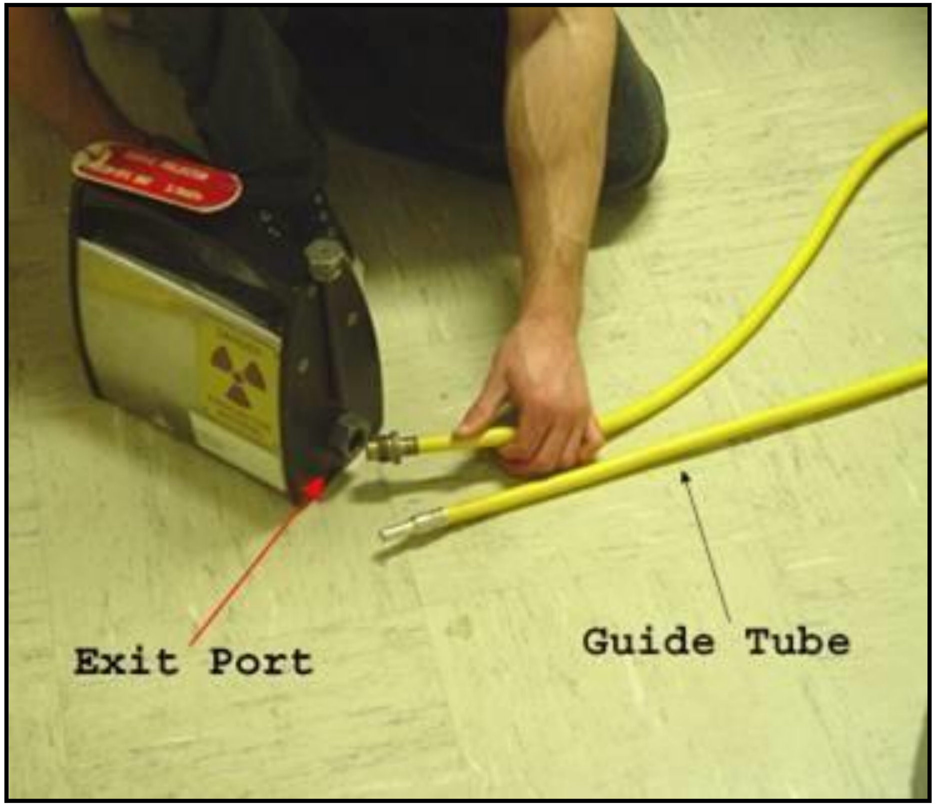
A device called a "camera" is used to store, transport and expose the pigtail containing the radioactive material. The camera contains shielding material which reduces the radiographer's exposure to radiation during use.



Gamma Radiography (cont.)

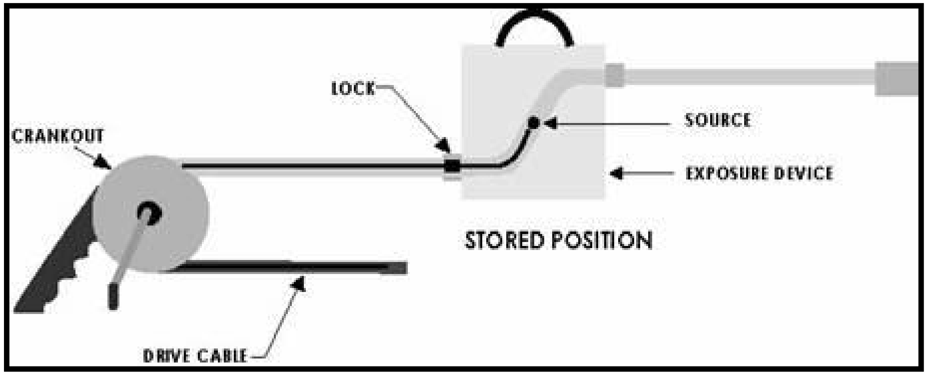
A hose-like device called a guide tube is connected to a threaded hole called an "exit port" in the camera.

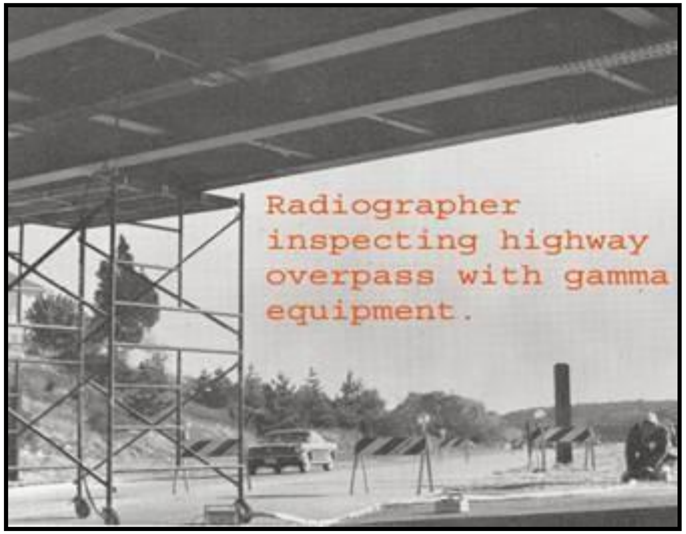
The radioactive material will leave and return to the camera through this opening when performing an exposure!



Gamma Radiography (cont.)

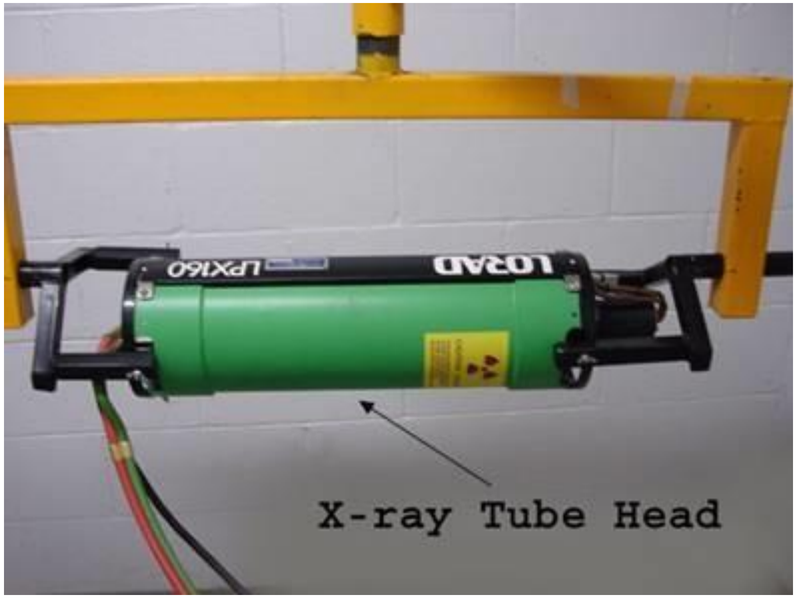
A "drive cable" is connected to the other end of the camera. This cable, controlled by the radiographer, is used to force the radioactive material out into the guide tube where the gamma rays will pass through the specimen and expose the recording device.





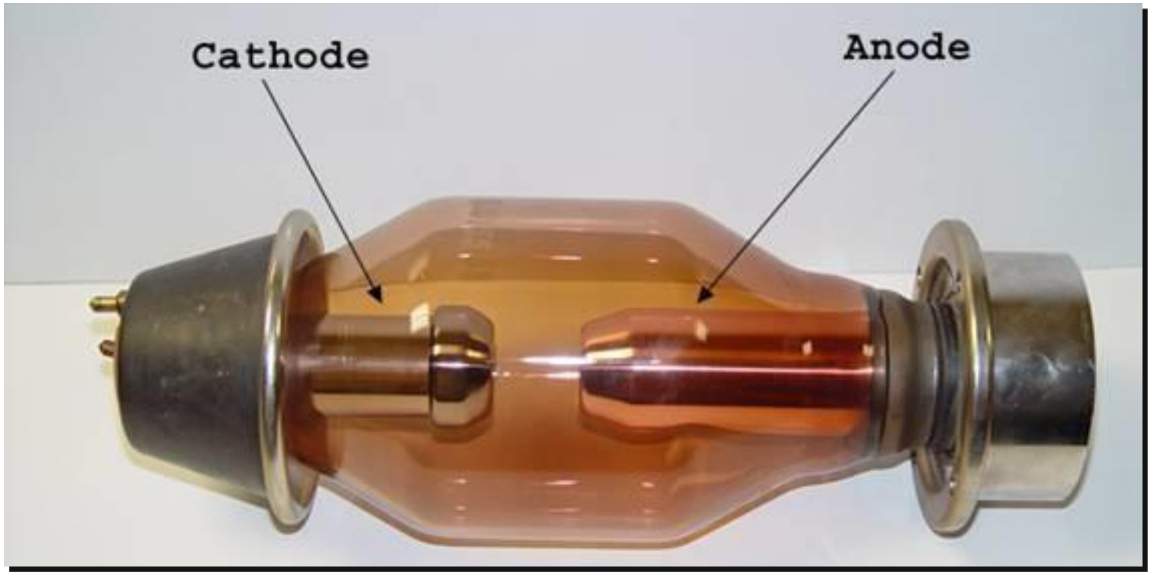
X-ray Radiography

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



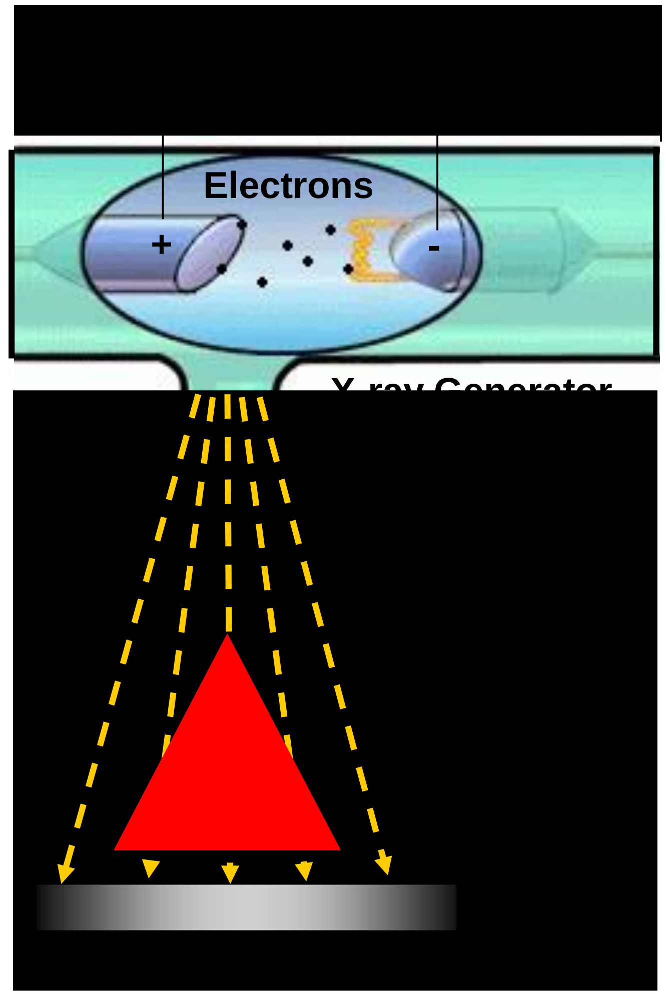
X-ray Radiography (cont.)

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



X-ray Radiography (cont.)

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



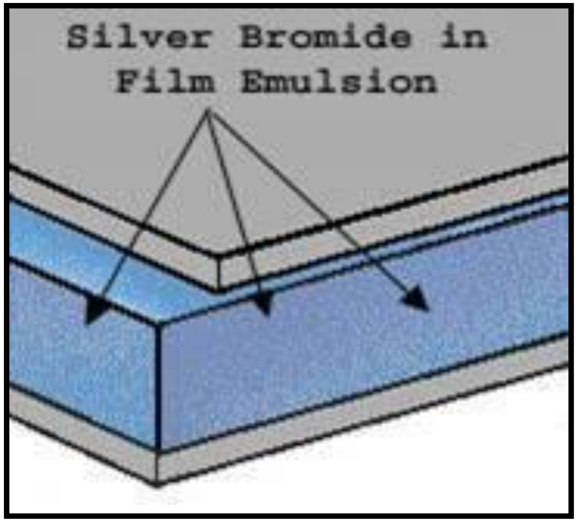
Imaging Modalities

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

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

Film Radiography

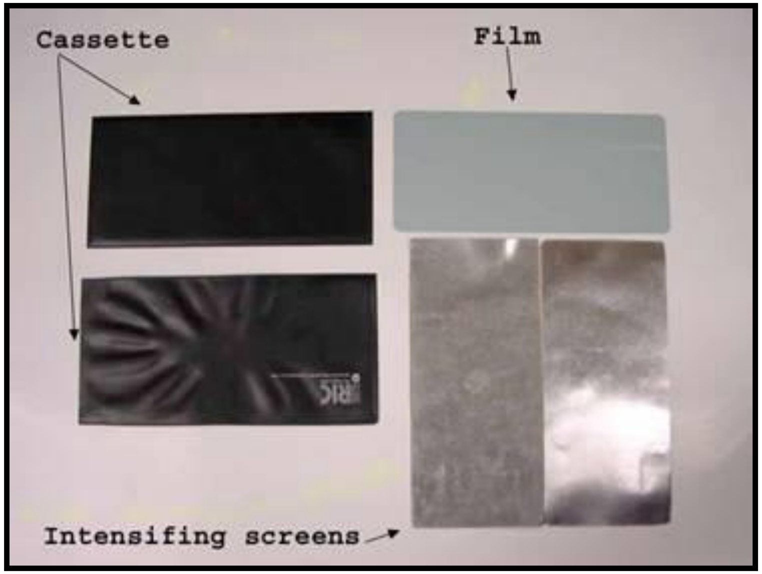

Photo Coutesy of AGFA-Gevaert Group

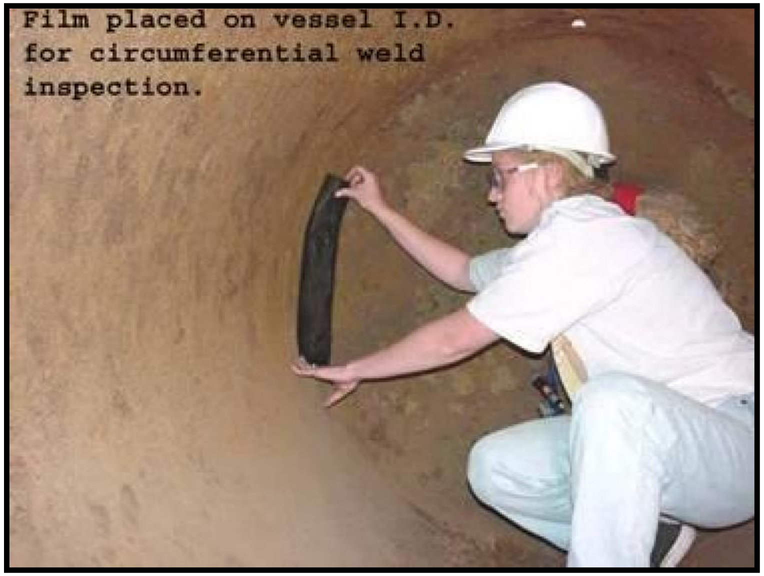


- One of the most widely used and oldest imaging mediums in industrial radiography is radiographic film.
- Film contains microscopic material called silver bromide.
- Once exposed to radiation and developed in a darkroom, silver bromide turns to black metallic silver which forms the image.

Film Radiography (cont.)

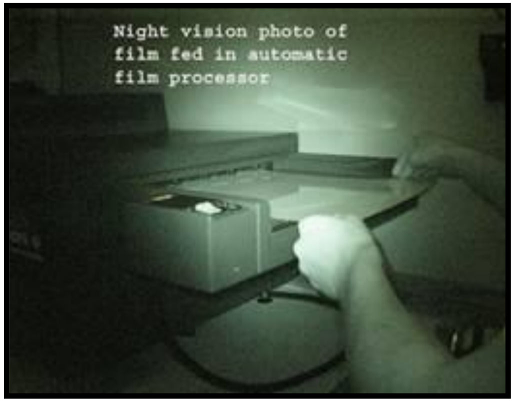
- Film must be protected from visible light. Light, just like x-rays and gamma rays, can expose film. Film is loaded in a “light proof” cassette in a darkroom.
- This cassette is then placed on the specimen opposite the source of radiation. Film is often placed between screens to intensify radiation.





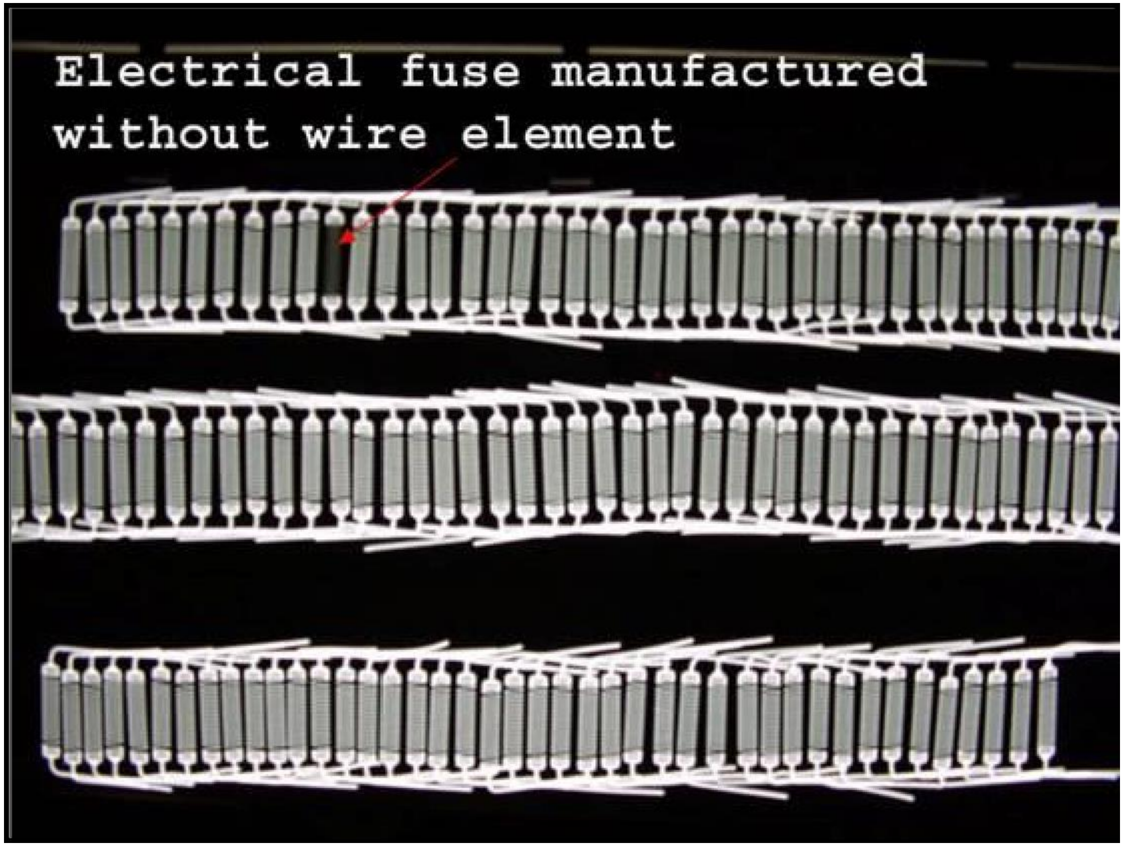
Film Radiography (cont.)

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



Film Radiography (cont.)

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



Digital Radiography

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

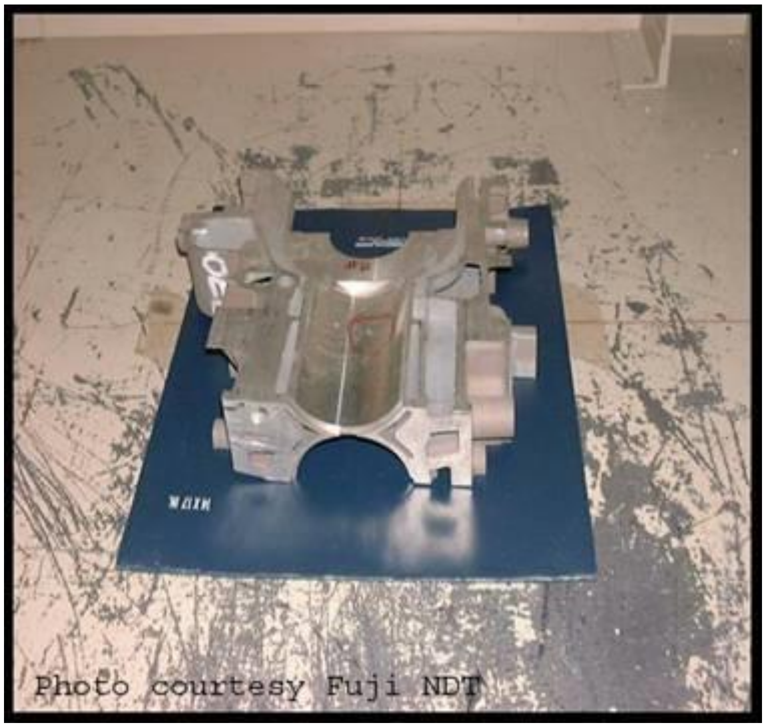
Digital Radiography (cont.)

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

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

Computed Radiography

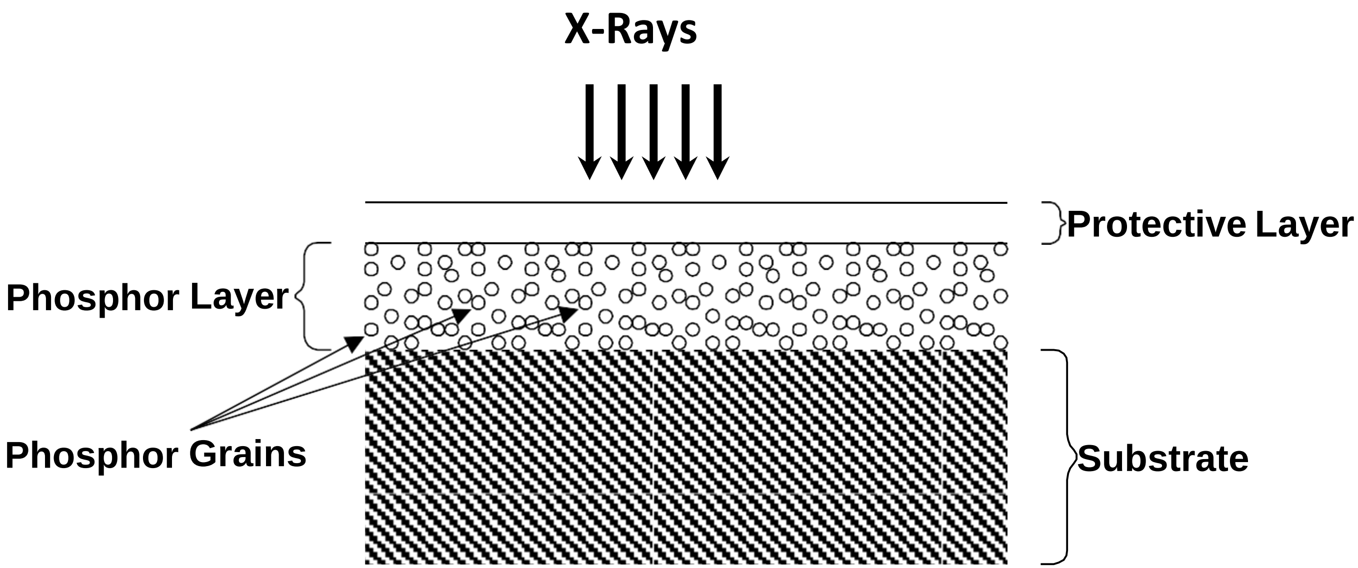
Computed Radiography (CR) is a digital imaging process that uses a special imaging plate which employs storage phosphors.



Computed Radiography (cont.)

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

CR Phosphor Screen Structure



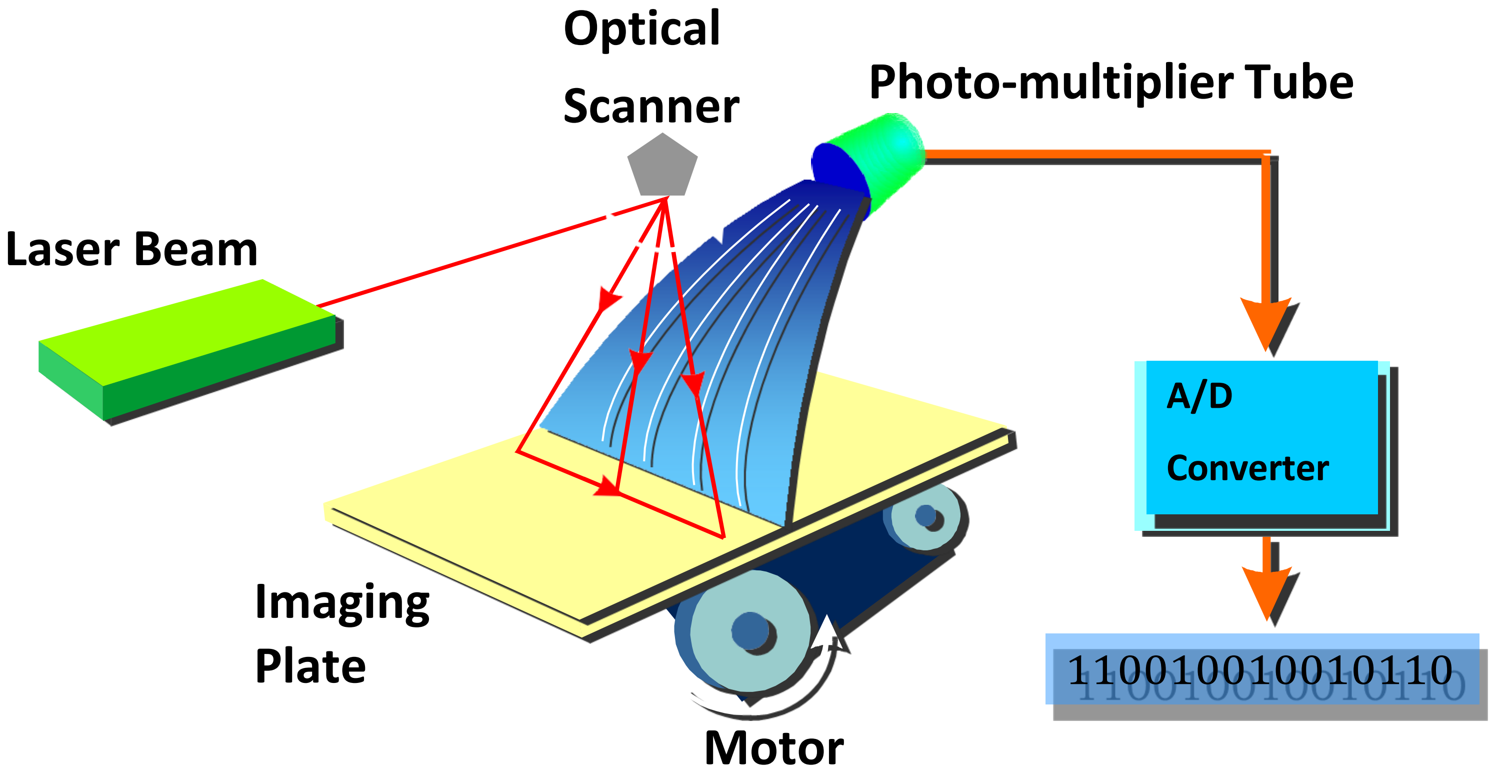
Computed Radiography (cont.)

After exposure:

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

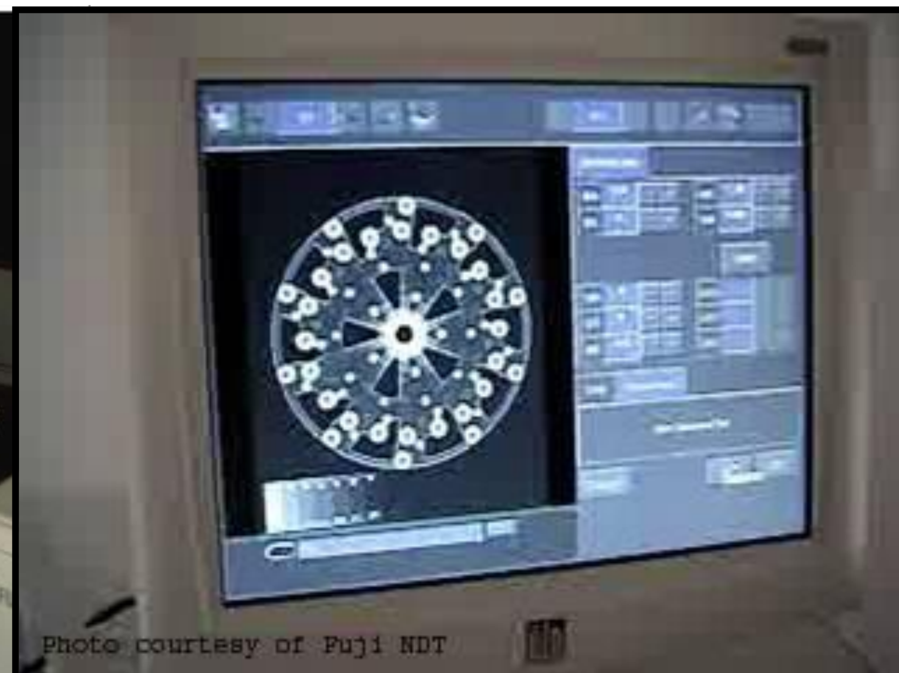
Computed Radiography (cont.)

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



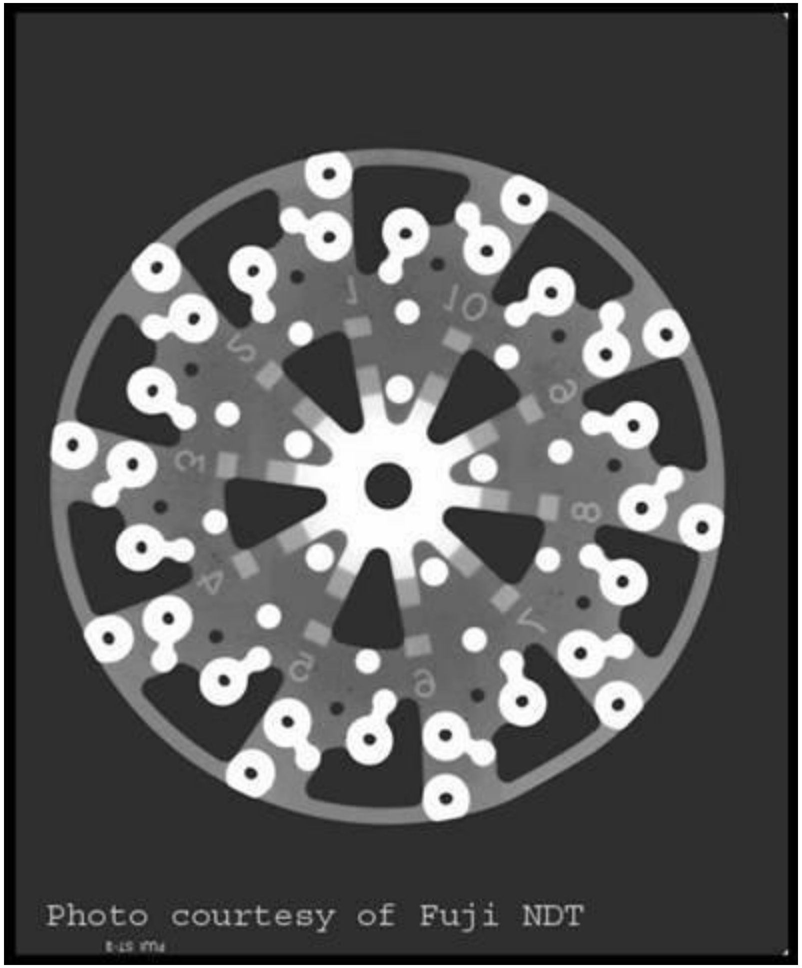
Computed Radiography (cont.)

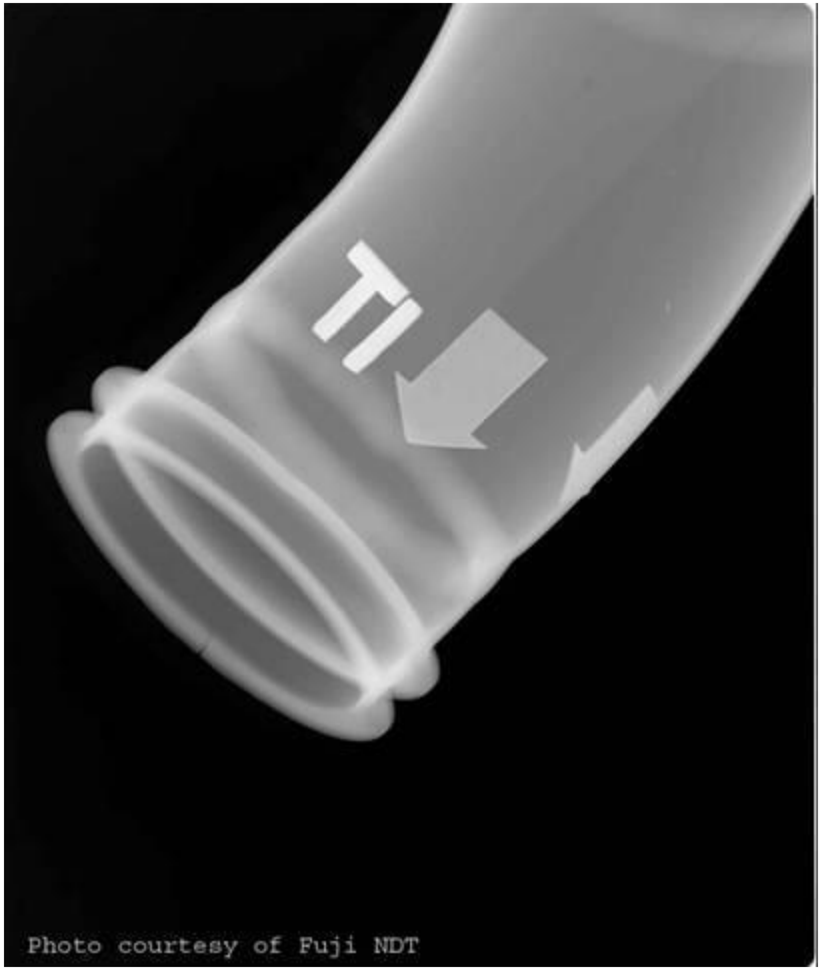
Digital images are typically sent to a computer workstation where specialized software allows manipulation and enhancement.



Computed Radiography (cont.)

Examples of computed radiographs:





Real-Time Radiography

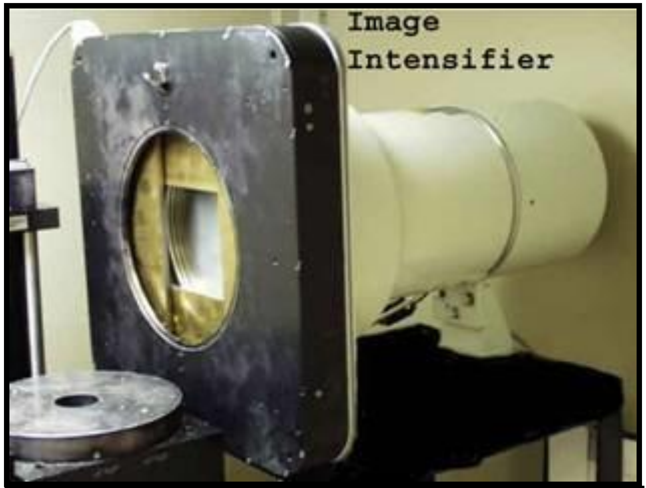
- Real-Time Radiography (RTR) is a term used to describe a form of radiography that allows electronic images to be captured and viewed in real time.
- Because image acquisition is almost instantaneous, X-ray images can be viewed as the part is moved and rotated.
- Manipulating the part can be advantageous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

Real-Time Radiography (cont.)

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

Real-Time Radiography (cont.)

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

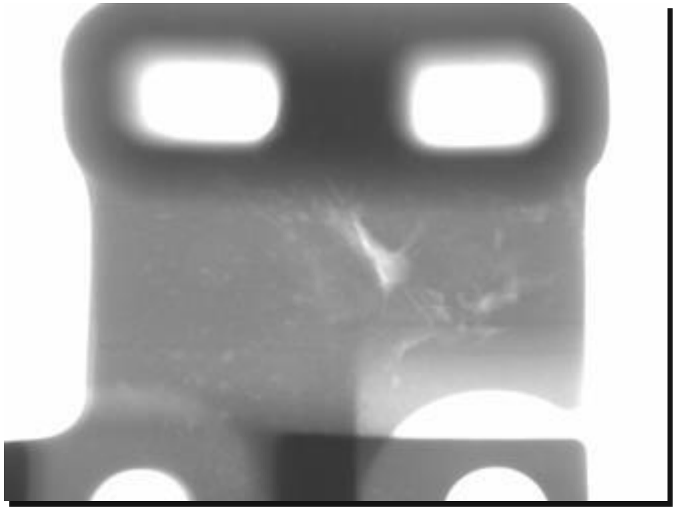


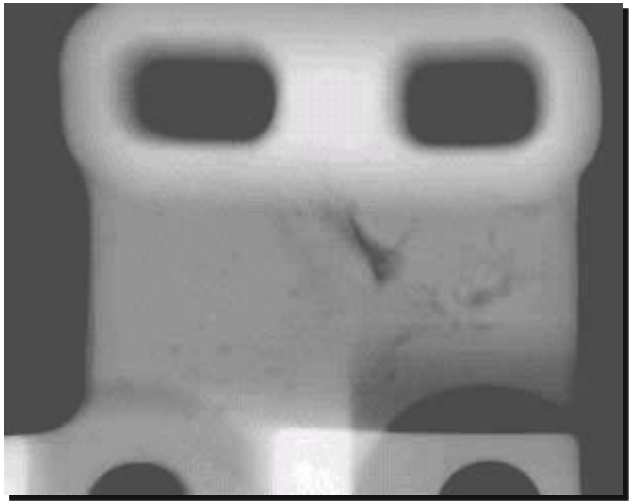
Real-Time Radiography (cont.)

- A special camera which captures the light output of the screen is located near the image intensifying screen.
- The camera is very sensitive to a variety of different light intensities.
- A monitor is then connected to the camera to provide a viewable image.
- If a sample positioning system is employed, the part can be moved around and rotated to image different internal features of the part.

Real-Time Radiography (cont.)

Comparing Film and Real-Time Radiography





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

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

Direct Radiography

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

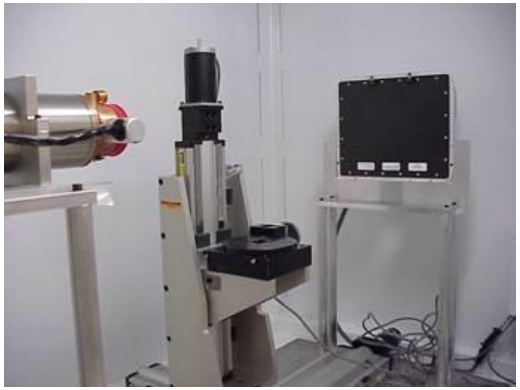
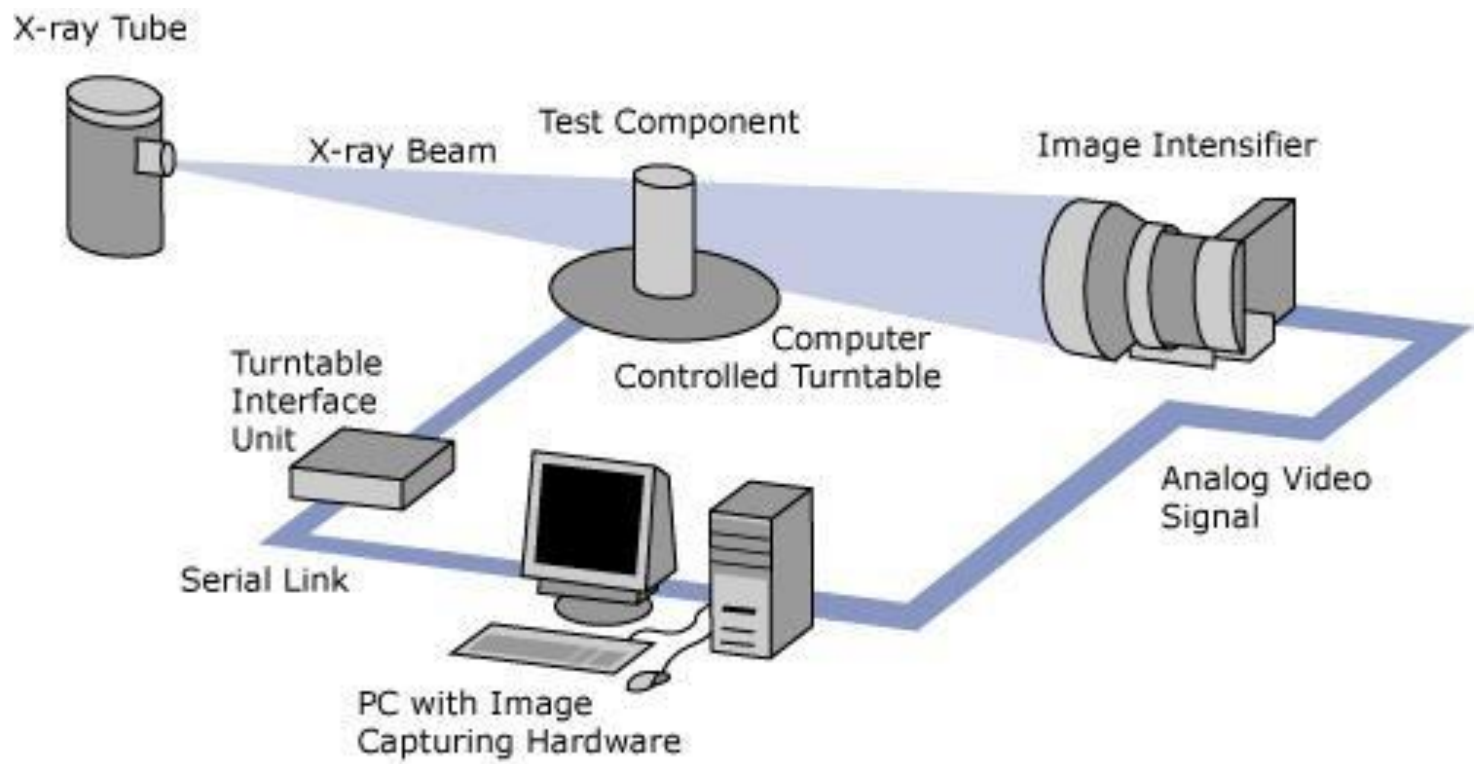


Image courtesy AFGA NDT

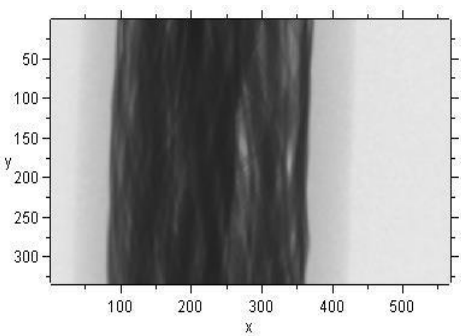
Computed Tomography

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

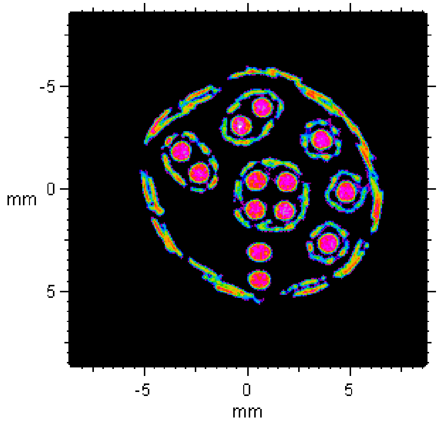


Computed Tomography (cont.)

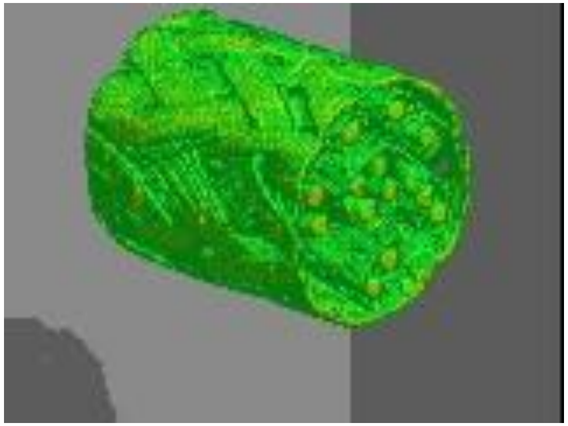
- Many separate images are saved (grabbed) and complied into 2-dimensional sections as the sample is rotated.
- 2-D images are them combined into 3-dimensional images.



Real-Time Captures



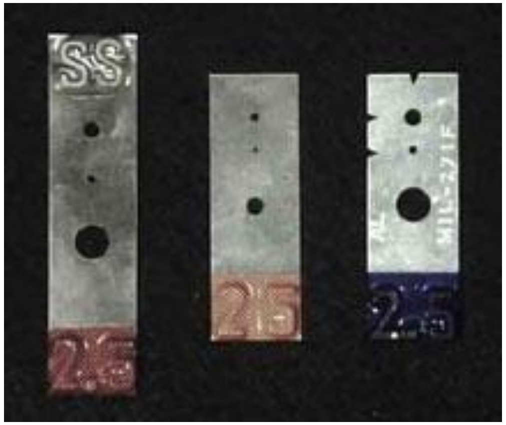
Compiled 2-D Images



Compiled 3-D Structure

Image Quality

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



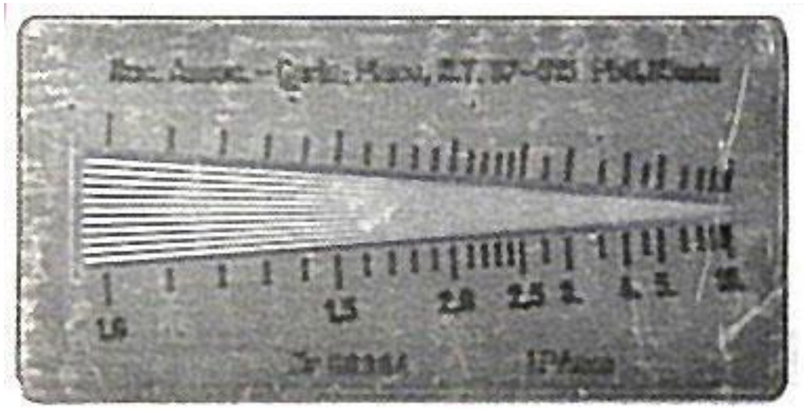
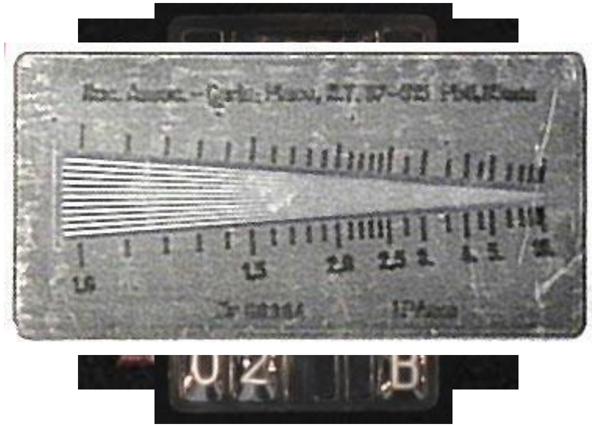
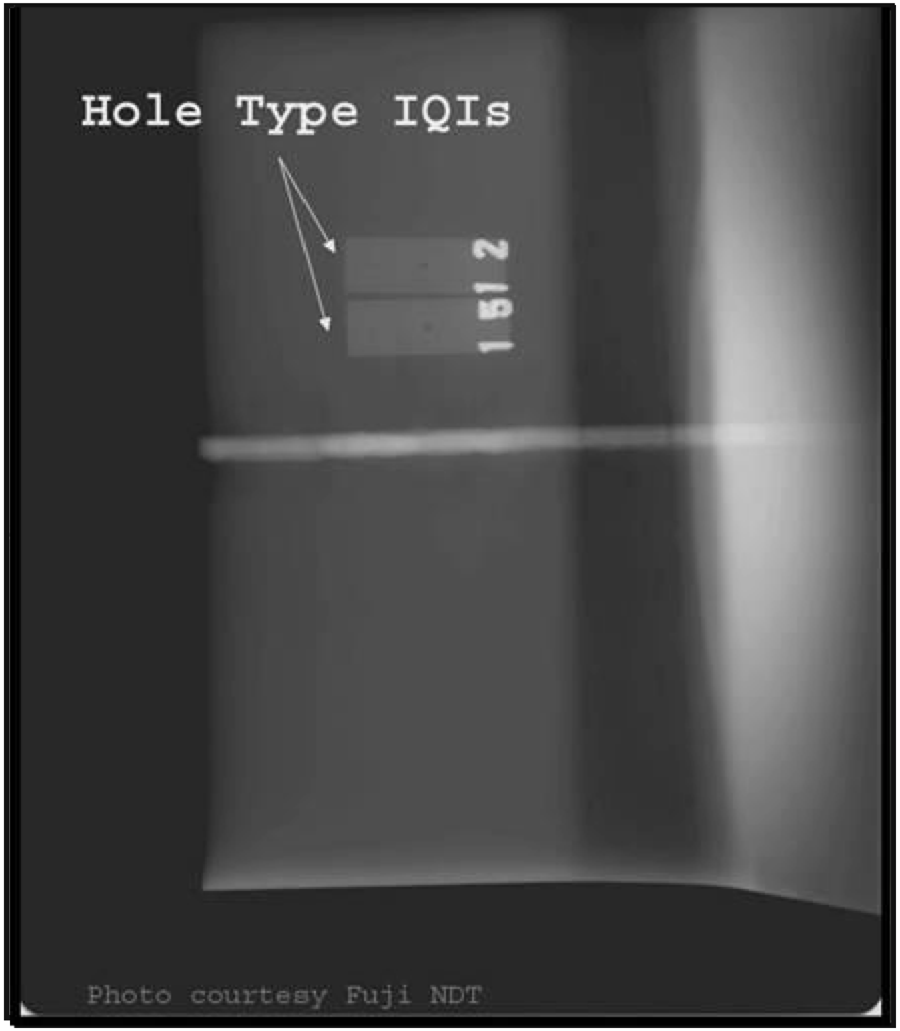


Image Quality (cont.)

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



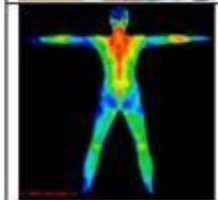


Radiation Safety

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

Radiation Safety (cont.)

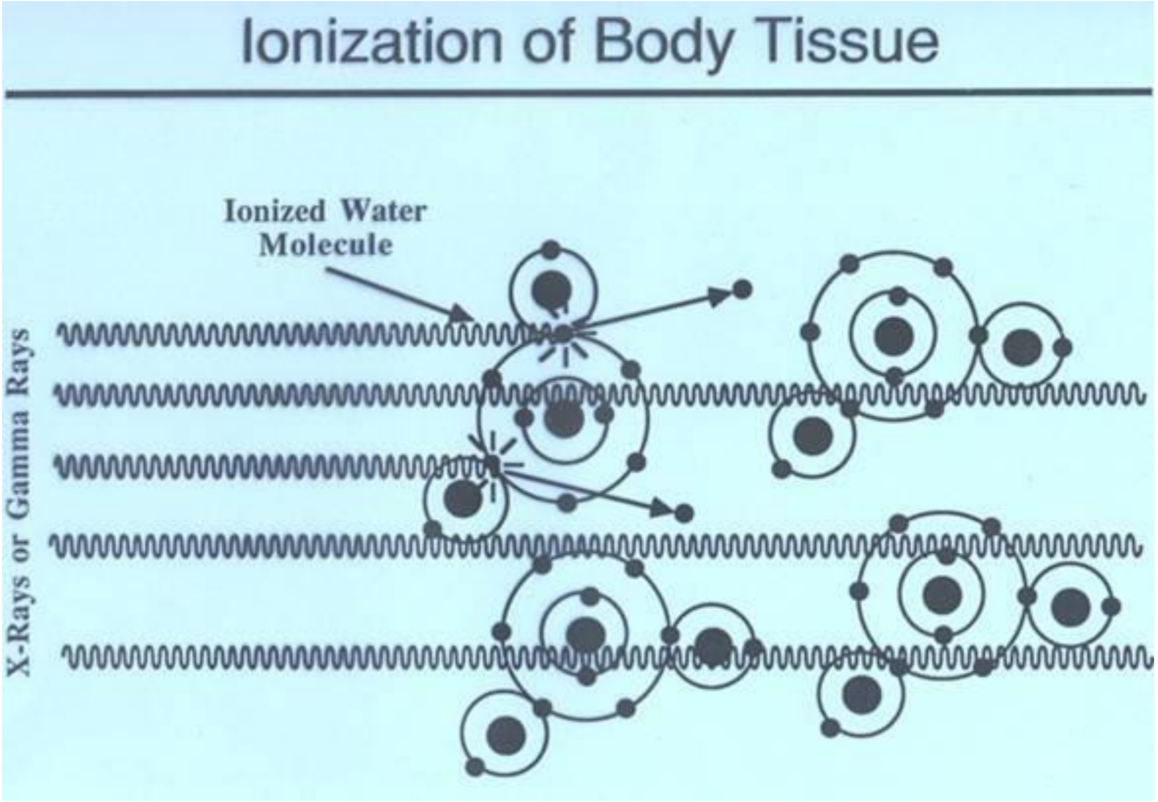
There are many sources of radiation. In general, a person receives roughly 100 mrem/year from natural sources and roughly 100 mrem/year from manmade sources.

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

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

Radiation Safety (cont.)

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



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

This can cause radiation burns or cancer.

Radiation Safety (cont.)

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

Survey Meter

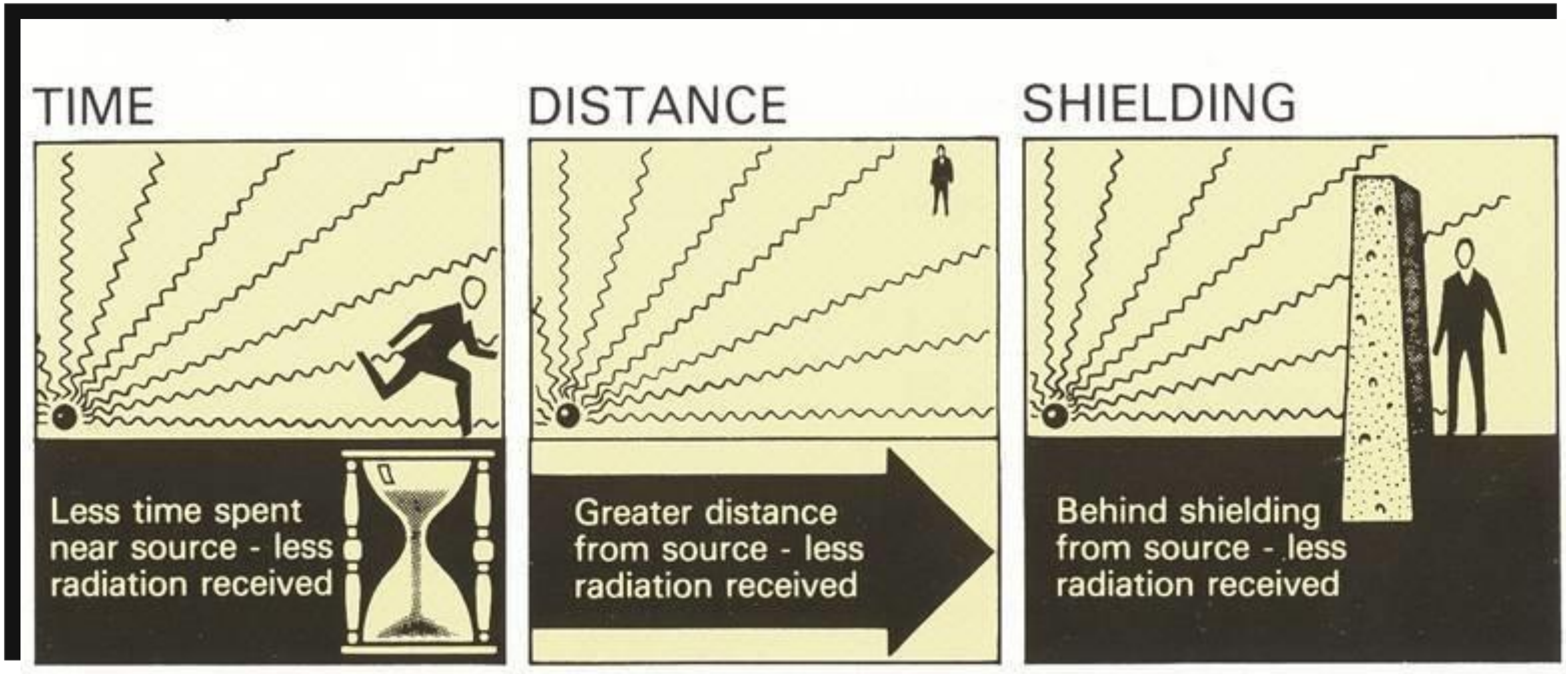
Pocket Dosimeter

Radiation Alarm

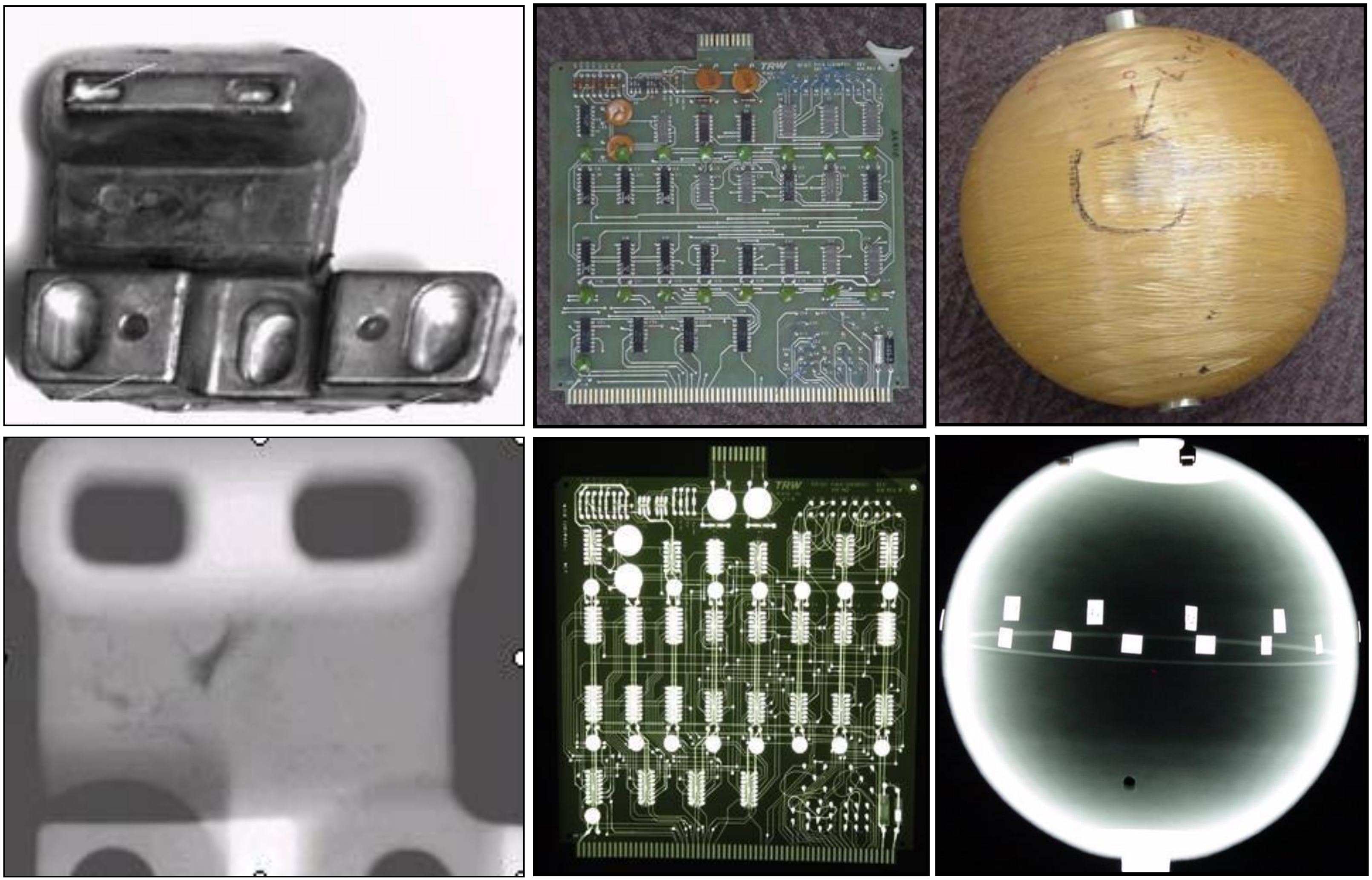
Radiation Badge

Radiation Safety (cont.)

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

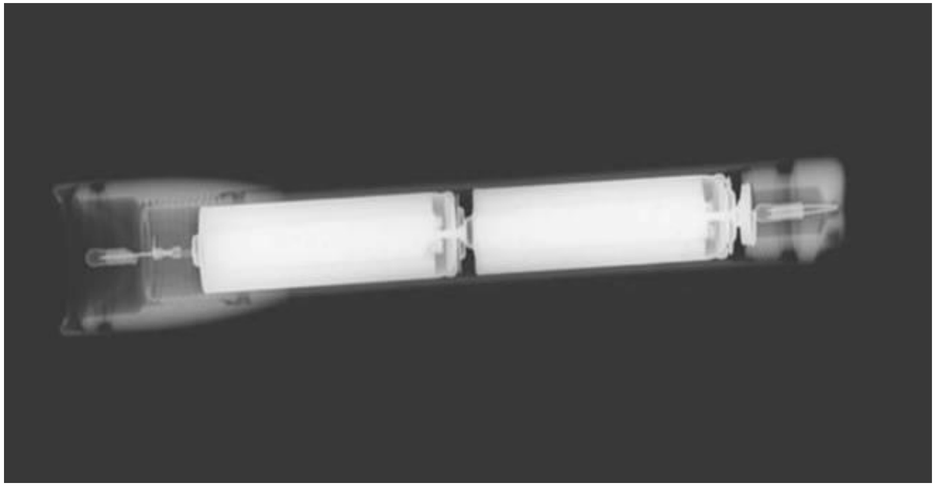


Radiographic Images

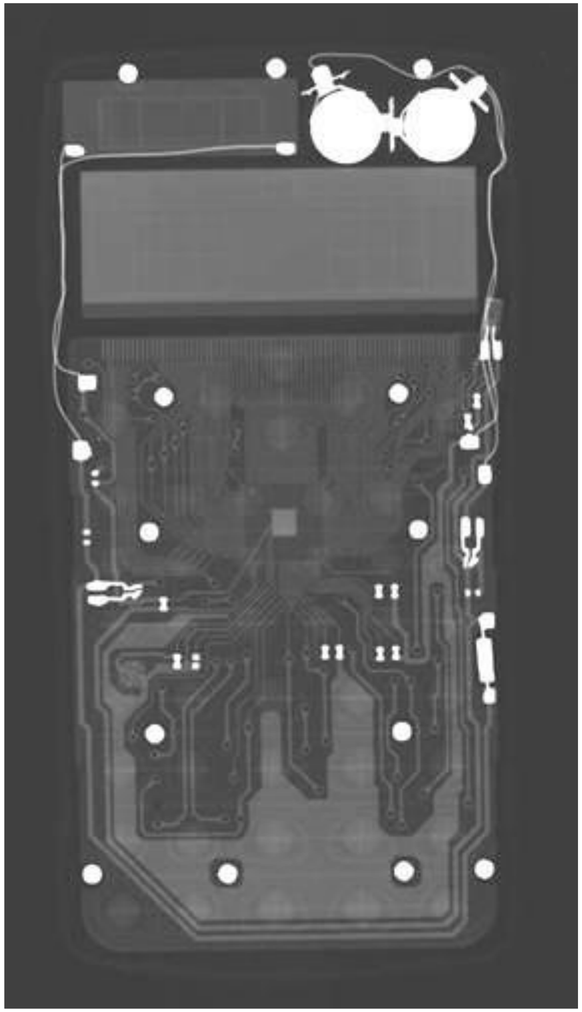


Radiographic Images

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



Radiographic Images



Advantages of Radiography

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

Disadvantages of Radiography

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

Glossary of Terms

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

Glossary of Terms

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

Glossary of Terms

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

Glossary of Terms

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

Thank you