NON- DESTRUCTIVE TESTING

B. Tech VI semester (IARE R16)

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UNIT I
NDT
NON- DESTRUCTIVE TESTING

Other terms used in NDT

Non-destructive examination (NDE)

Non-destructive inspection (NDI)

Non-destructive evaluation (NDE)

OBJECTIVE OF NDT

- Material sorting
- Material characterization
- Property monitoring (for process control)
- Thickness measurement
- Defect Detection/ Location and
- Defect characterization.

However the major task of NTD is to detect and identify the range of defects. Defects can include production flaws such as heat treatment cracks, grinding cracks, voids(pores), and fatigue cracks (Generated during service).

NDT(Non-destructive testing **)?**

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

In other words, when the inspection or test is completed the part can still be used.

Non-destructive testing

"NDT is an examination that is performed on an object of any type, size, shape or material to determine the presence or absence of discontinuities, or to evaluate other material characteristics"

DIFFERENCE BETWEEN DESTRUCTIVE AND NON DESTRUCTIVE TEST

NON DESTRUCTIVE TEST	*DESTRUCTIVE TEST*
Used for finding out defects of materials	Used for finding out the properties of the material
Load is not applied on the material	Load is applied on the material
No load applications, so no chance for material damage	Due to load application, material gets damaged
No requirement of special equipments	Special equipments are required
Non expensive	Expensive
Less skill	Skill is required
e.g: dye penetrate test, ultrasonic, radiography, etc	e.g: tensile test, compression test, hardness test, etc

Types of NDT

Visual Examination

Liquid Penetrant Testing

Magnetic Particle Testing

Eddy Current Testing

Radiography

Ultrasonic Testing

Visual Inspection

- Visual inspection is the simplest, fastest and most widely used NDT method.
- Visual inspection is commonly defined as “the examination of a material component, or product for conditions of non conformance using light and eyes, alone or in conjunction with various aids.
- Visual inspection often also involves shaking, listening, feeling , and sometimes even smelling the component being inspected.
- Visual inspection is commonly employed to support/ compliment other NDT methods.
- Digital Detector and computer technology have made it possible to automate some visual inspections. This is known as *machine vision inspection.*

Characteristics Detected(Applicility)

This visual inspection is commonly used:

i. To detect surface characteristics such as finish, Scratches, cracks or colour.
ii. To check stain in transparent materials.
iii. To inspect corrosion.

Principle

- Seeing is believing and the art of seeing is the visual inspection technique.
- Visual testing requires adequate illumination of the test surface and proper eye-sight of the tester.
- The test specimen is illuminated and the test surface is observed and examined. Whenever required, the optical aids such as mirrors, magnifying glasses, microscopes, video cameras and computer- vision system can be employed.

Advantages of VT

- Simple and easy to use.
- Relatively inexpensive.
- Testing speed is high.
- Testing can be performed on components which are in –service.
- Permanent record are available when latest equipment is used.

Limitation

- The test result depend on skill and knowledge of tester.
- Limited to detection of surface flaws.
- Eye resolution is weak.
- Eye fatigue.

Applications

- Checking of the surface condition of the component.
- Checking of alignment of surfaces.
- Checking of shape of the component.
- Checking for evidence of leaking.
- Checking for internal side defects.

Types of visual testing

Unaided or direct visual testing, and

Aided visual testing.

Unaided or direct visual testing

- As the name suggest, the unaided visual testing is carried out with naked eye(and without using any optical aids)
- The most important instrument is visual testing in the human eye.

Fig: Videoscope

Fig: Advanced Videoscope

Fig: Borescopes

Fig. Microscope

Fig: Magnifying glass

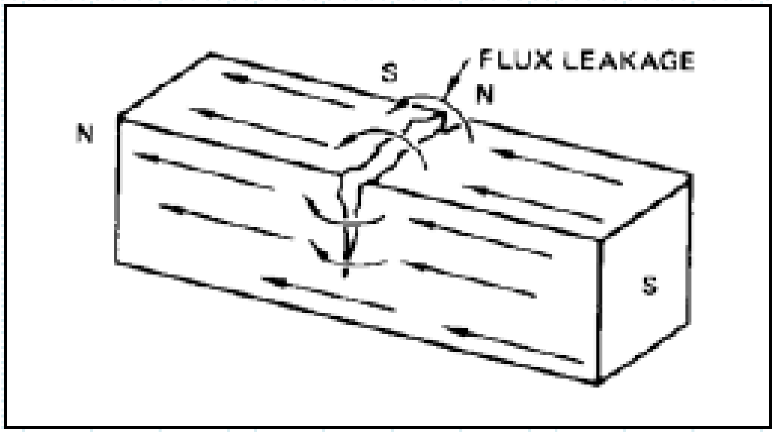
MAGNETIC PARTICL TESTING (MT)

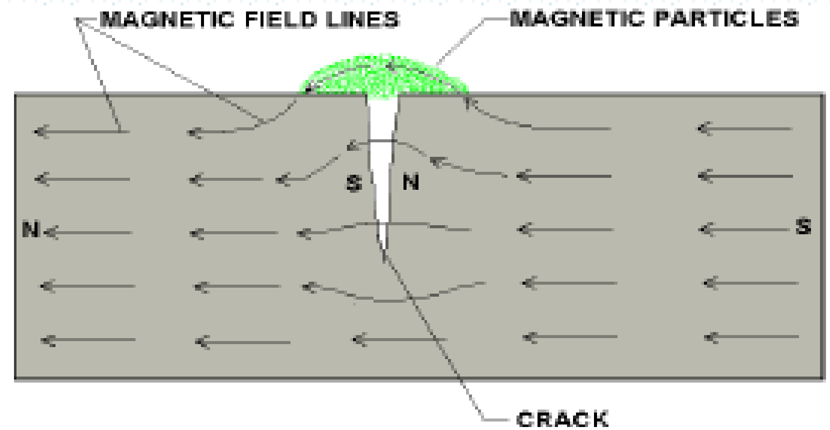
- *MAGNETIC PARTICL TESTING (MT) is an non-destructive testing to locate surface and subsurface discontinuities in parts made by ferromagnetic materials.*

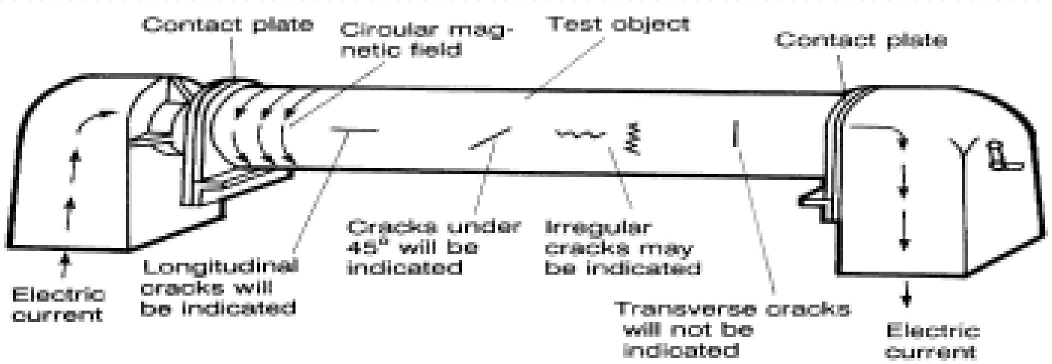
MAGNETIC LINES OF FLUX:

- It is the number of magnetic field lines passing through a surface (such as a loop of wire). The magnetic flux through a closed surface is always zero. ...
- The SI unit of magnetic flux is the Weber (Wb)
- The magnetic lines of forces existing in a magnetic field is called magnetic flux.
- The lines of flux ran through the magnets from south to
- north, exiting the north pole and re entering the south pole.
- The lines of flux formed closed loops that never crossed.

Methodology







Stationary bench unit. The importance of the orientation of a defect in relation to the magnetic field lines is shown.

DIRECT MAGNETIZATION

- With direct magnetization, current is passed directly through the component.
- The flow of current causes a circular magnetic field to form in and around the conductor.
- When using the direct magnetization method, care must be taken to ensure that good electrical contact is established and maintained between the test equipment and the test component to avoid damage of the component (*due to arcing or overheating at high resistance points)*.

Applications

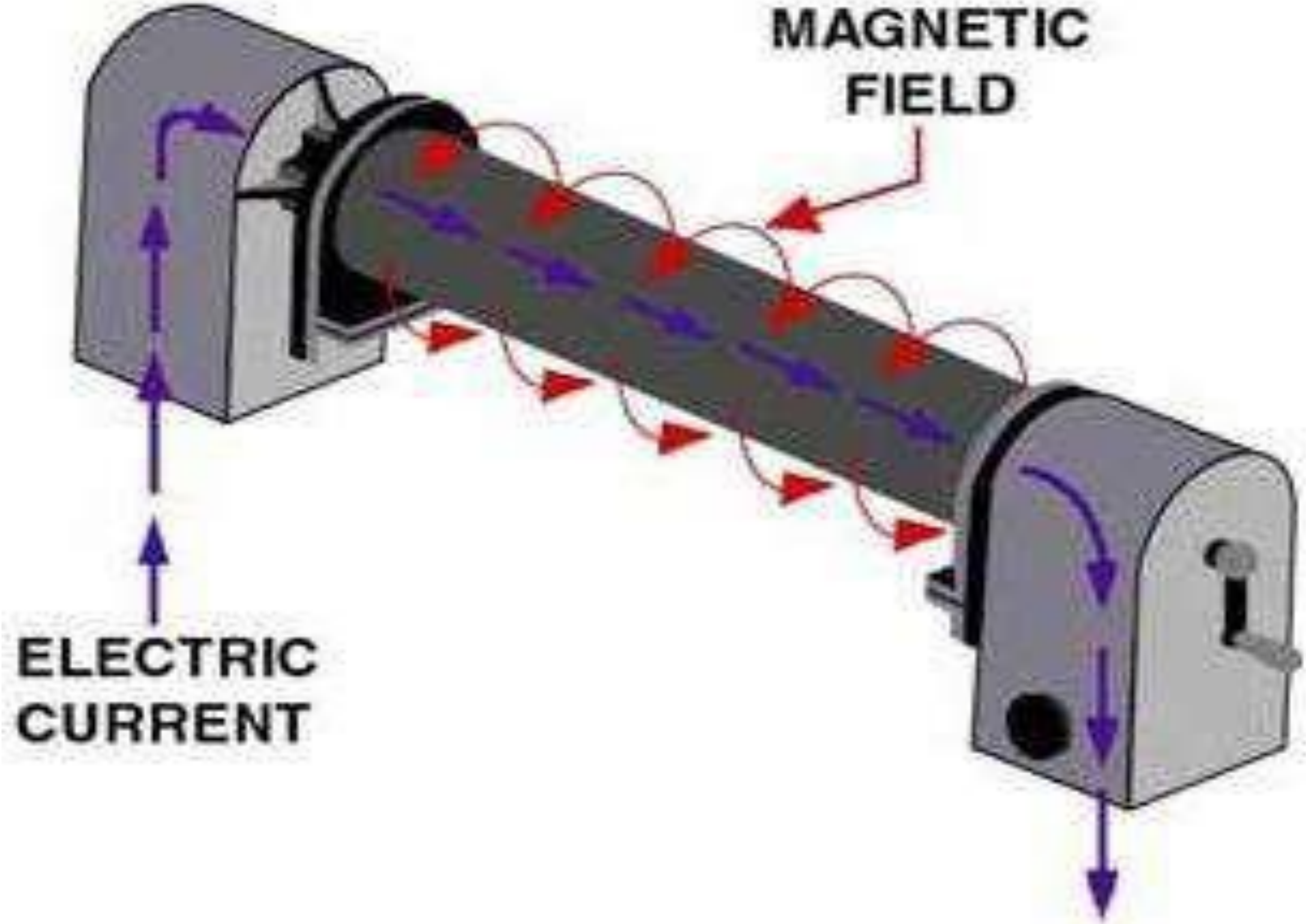
- Detection on Ferromagnetic materials only.
- Cracks oriented perpendicular to the current direction best observed.
- Sensitivity also depends on the type of current used.

Limitations

- Non Magnetic subsatnces cannot be evaluated.
- Avoid local heating and burning of substances.
- Demagnetization is important after performing the test.

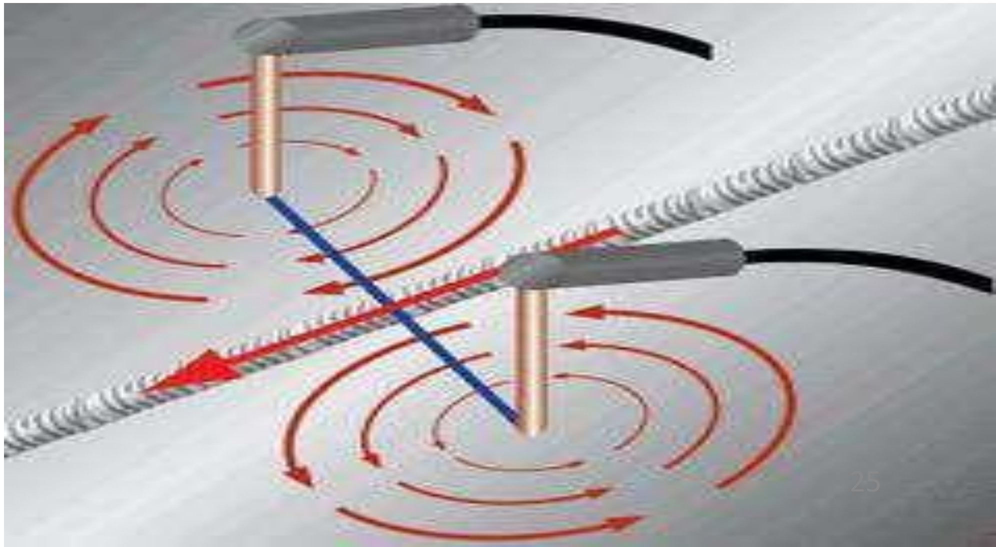
Clamping The Component Between Two Electrical Contacts

- One way involves clamping the component between two electrical contacts in a special piece of equipment.
- Current is passed through the component and a circular magnetic field is established in and around the component.


MAGNETIC
FIELD
ELECTRIC
CURRENT

CLAMPS OR PRODS

- A second technique involves using clamps or prods, which are attached or placed in contact with the component.
- Electrical current flows through the component from contact to contact.
- The current sets up a c path of the current.



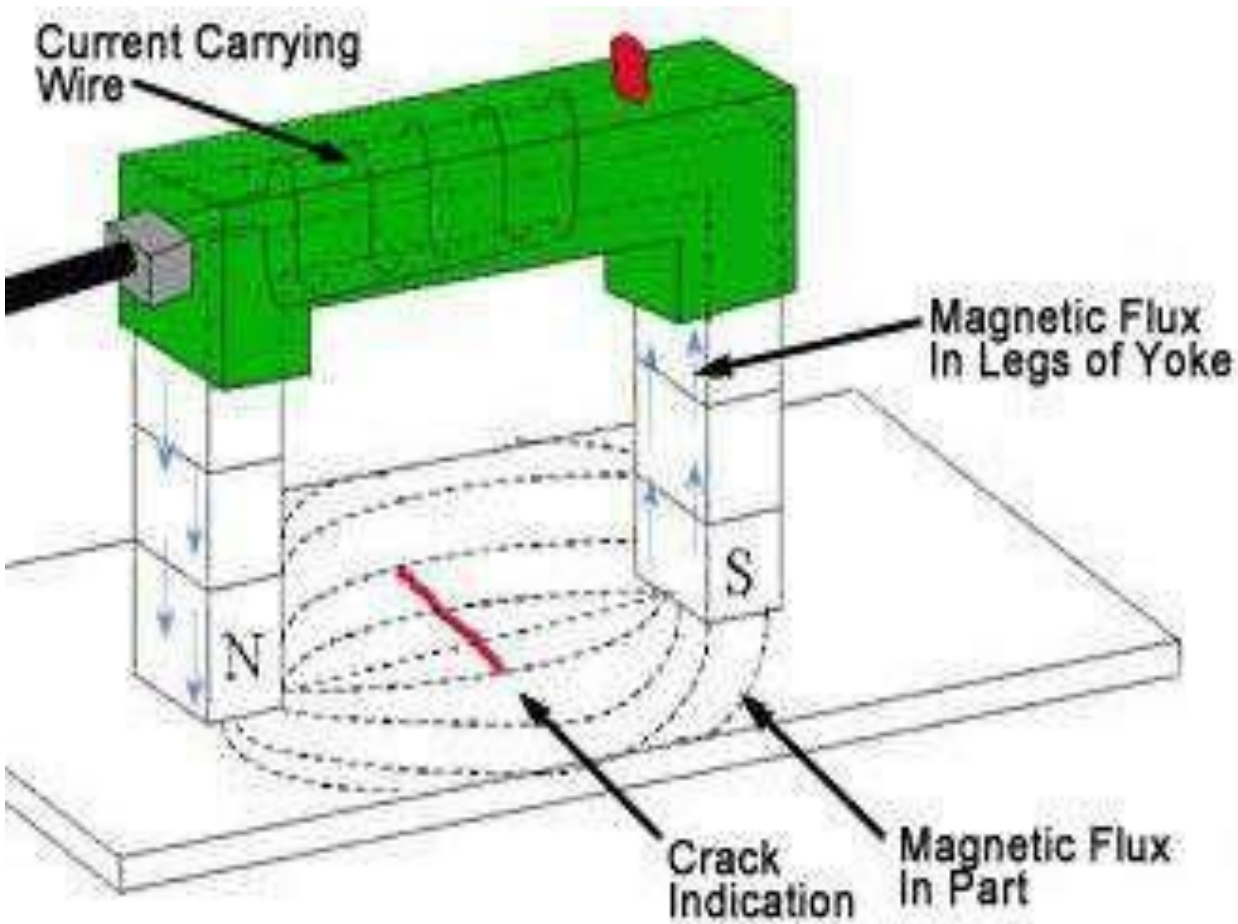
INDIRECT MAGNETIZATION

•Indirect magnetization is accomplished by using a strong external magnetic field to establish a magnetic field within the component. As with direct magnetization, there are several ways that indirect magnetization can be accomplished.

- 1.PERMANENT MAGNETS:-

- The use of *permanent magnets is a low cost method of* establishing a magnetic field.
- However, their use is limited due to lack of control of the field strength and the difficulty of placing and removing strong permanent magnets from the

PERMANENT MAGNET



ELECTRO MAGNET

ELECTROMAGNET

- *Electromagnets in the form of an adjustable* horseshoe magnet (*called a yoke) eliminate* the problems associated with permanent magnets and are used extensively in industry.

- Electromagnets only exhibit a magnetic flux when electric current is flowing around the soft iron core.

- When the magnet is placed on the component, a magnetic field is established between the north and south poles of the magnet.

UNIT-II

ULTRASONIC TESTING

INTRODUCTION

- Ultrasonic testing(UT) is the one of the popular flaw detection non-destructive testing methods.

- In ultrasonic testing high frequency sound energy is used to identify surface an sub- surface discontinuities.

- Ultrasonic testing is completely safe method of NDT and it is extensively used in many basic manufacturing and service industries. Especially in applications of inspecting welds and structural metals.

- Because of its high penetration capacity, inspection of extremely thick sections are possible using Ultrasonic testing.

Spectrum of sound

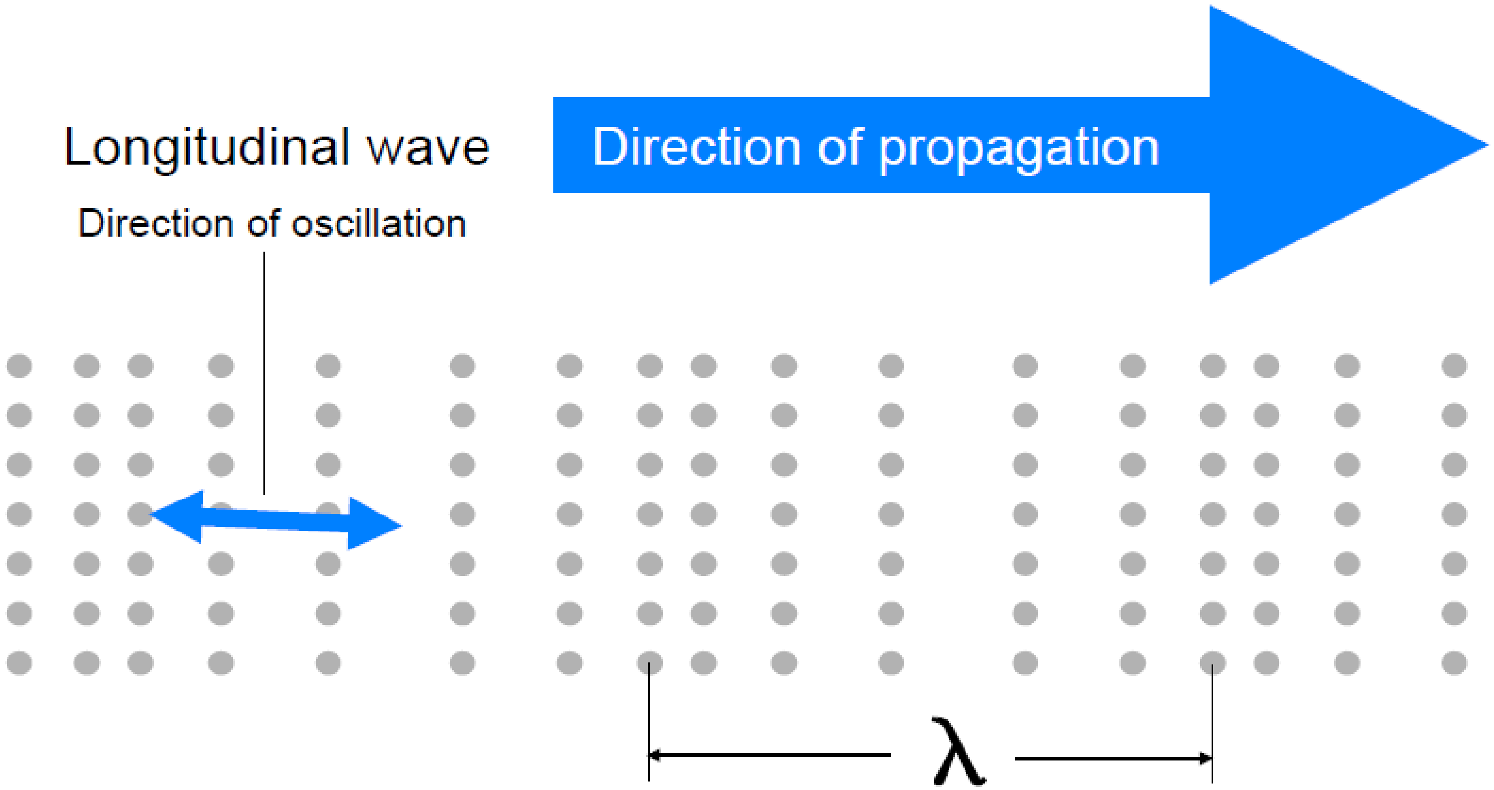
Frequency range Hz	Description	Example
0 - 20	Infrasound	Earth quake
20 - 20.000	Audible sound	Speech, music
> 20.000	Ultrasound	Bat, Quartz crystal

Modes of Propagation

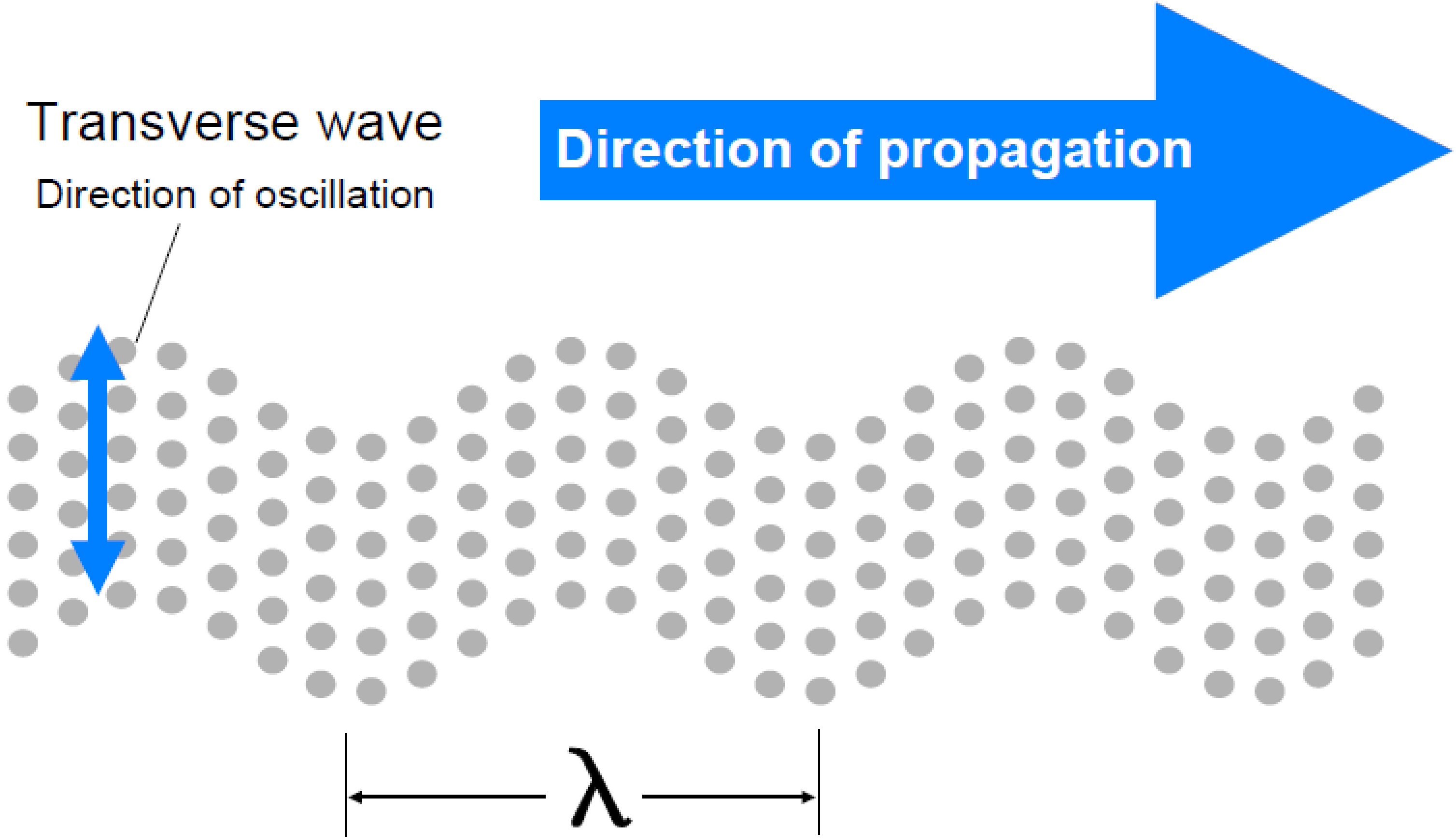
- **Longitudinal waves**
- **Shear waves**
- **Surface waves (Rayleigh), and**
- **Lamb waves (plate)**

longitudinal waves

- In a longitudinal waves, Particle motion in the medium is parallel to the direction of the wave front



Transverse wave



Transverse wave

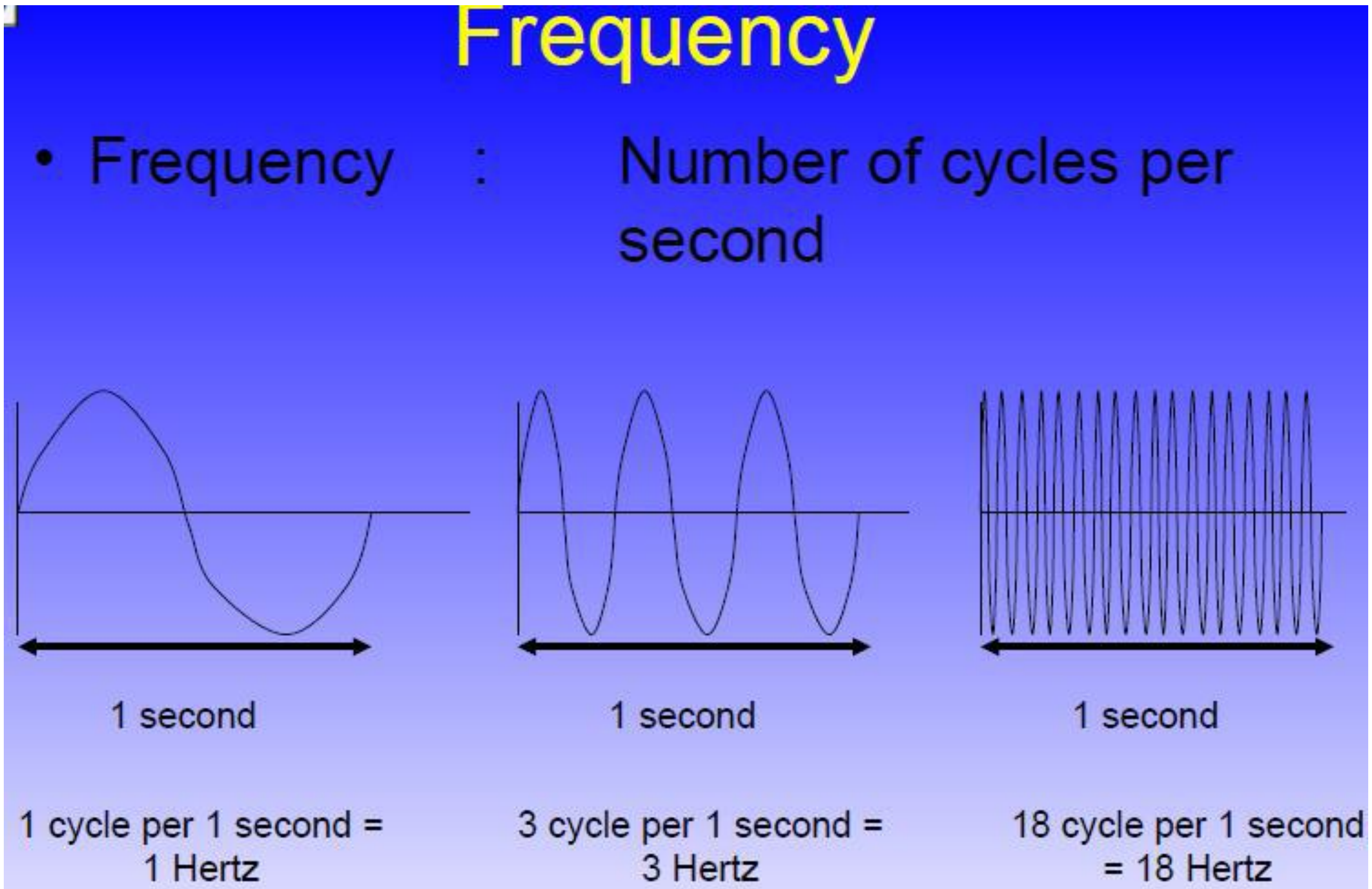
- A transverse wave is a moving wave that consists of oscillations occurring perpendicular (right angled) to the direction of energy transfer (or the propagation of the wave).

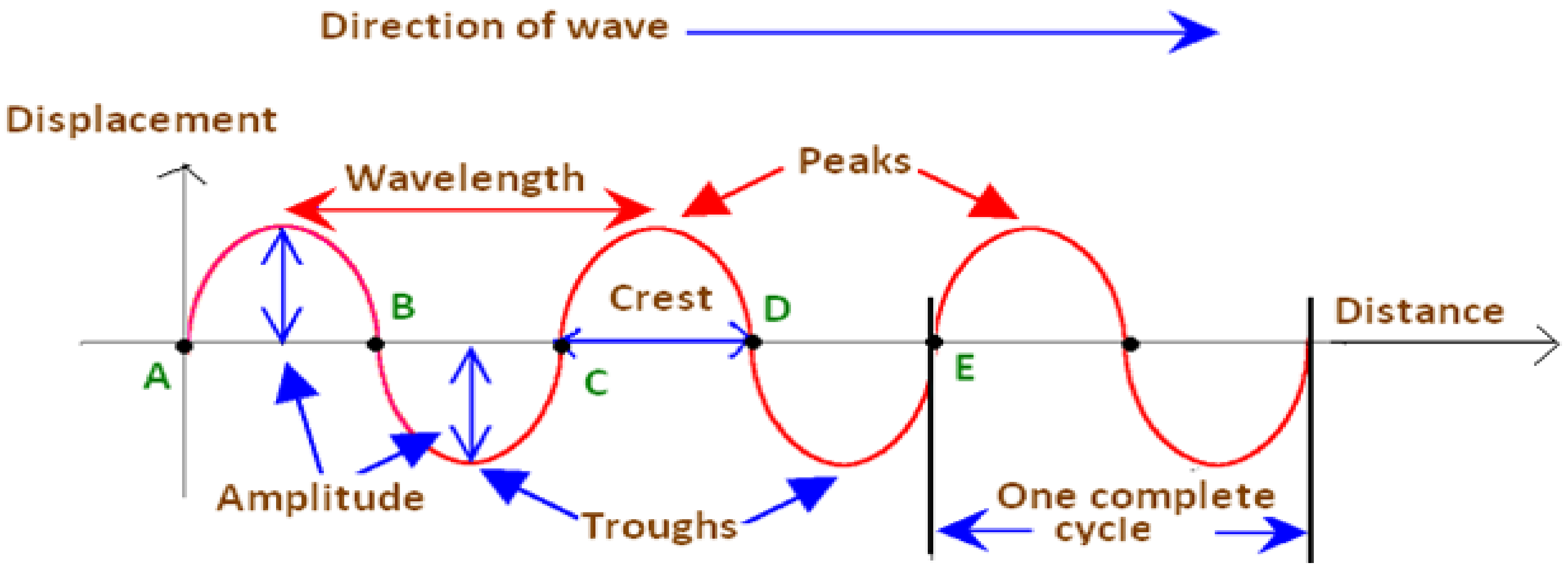
Surface waves

- Surface waves represent an oscillating motion that travels along the surface of a test piece to a depth of one wavelength.

- Surface waves can be used to detect surface breaking cracks in a test piece.

Terminologies used in UT




Direction of wave
Displacement
Wavelength
Peaks
B
Crest
D
Distance
A
C
E
Amplitude
Troughs
One complete
cycle

FREQUENCY

- Generally the choice of test frequency depends upon two factors : the minimum size of defect, which is to be detected and the medium in which such a defect is situated.

$F \uparrow \quad \lambda \downarrow \quad F \downarrow \quad \lambda \uparrow$

- **Penetration Depth:**

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

- **Scattering:**

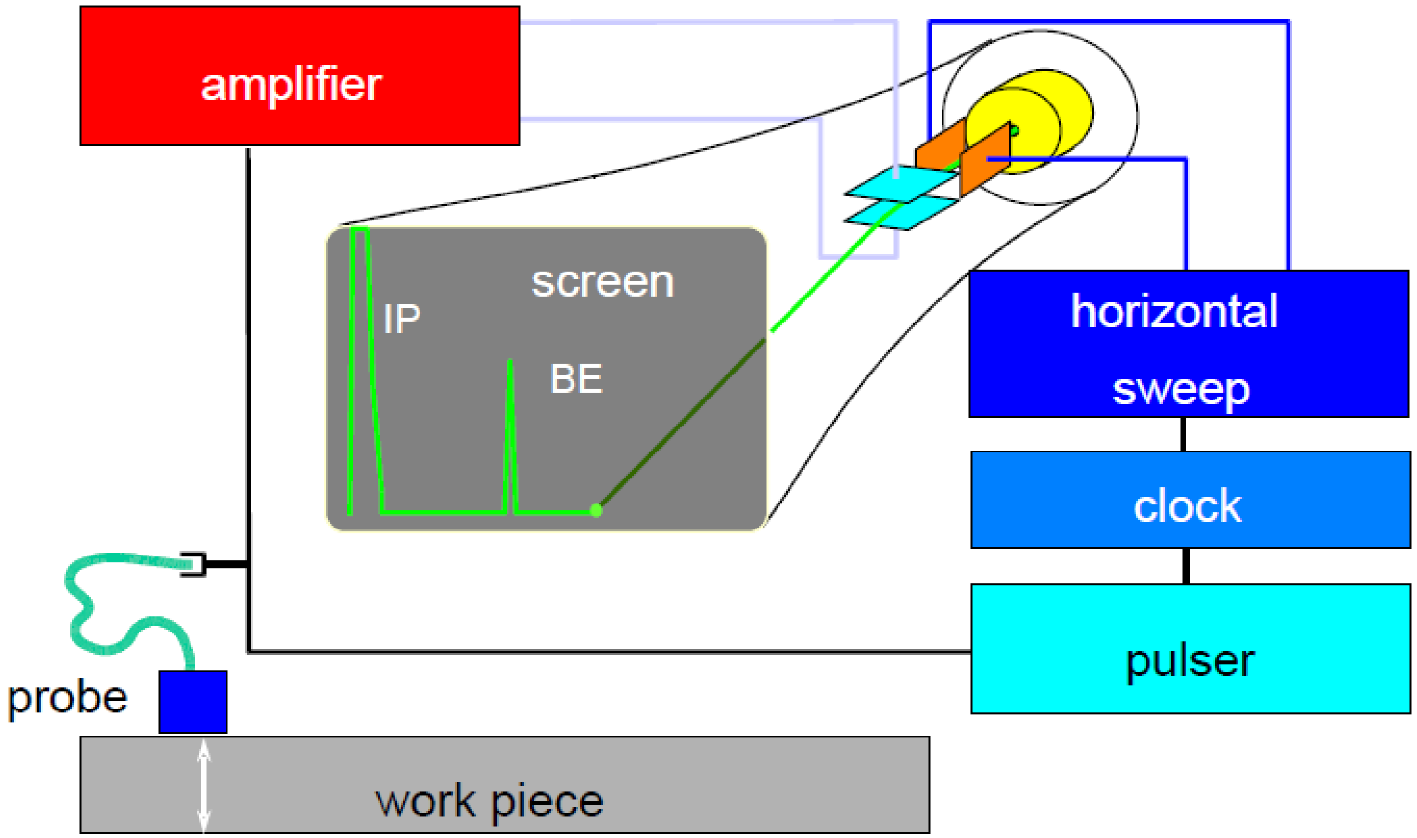
  Scattering is the reflection of sound beam its original direction of propagation.

- **Absorption:**

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

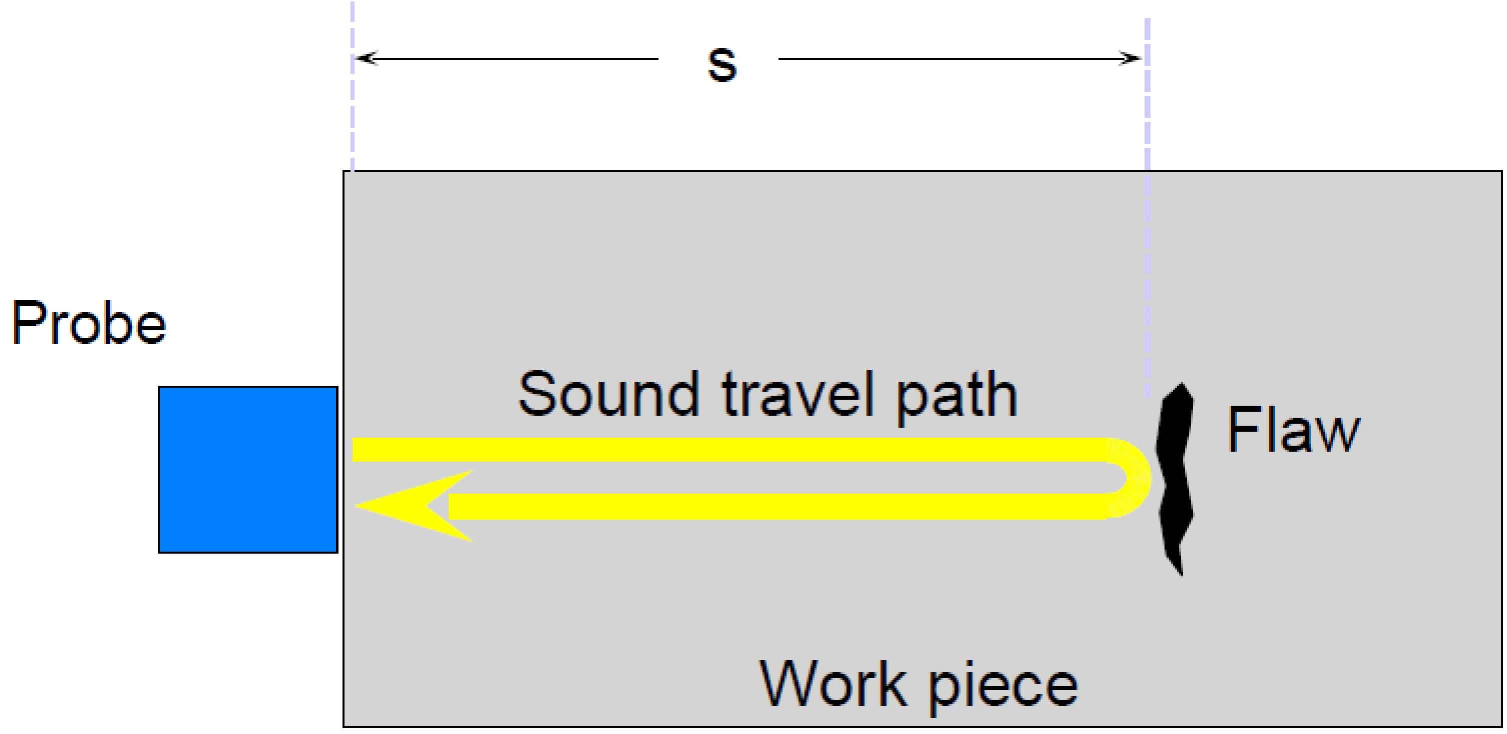
Basic Principles of Ultrasonic Testing

Block diagram: Ultrasonic Instrument



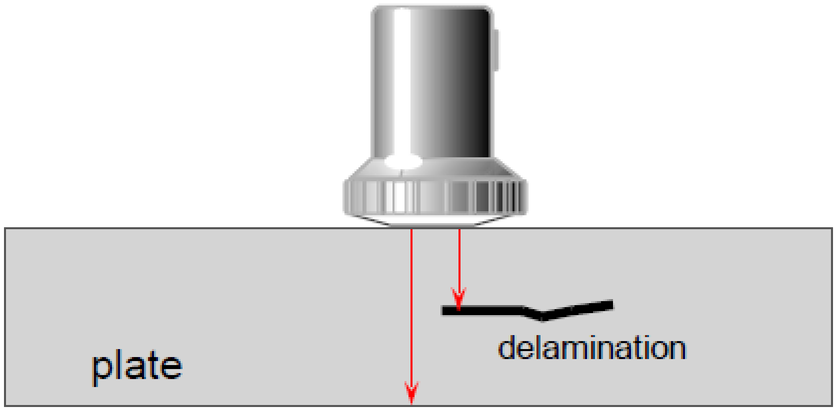
Basic Principles of Ultrasonic Testing

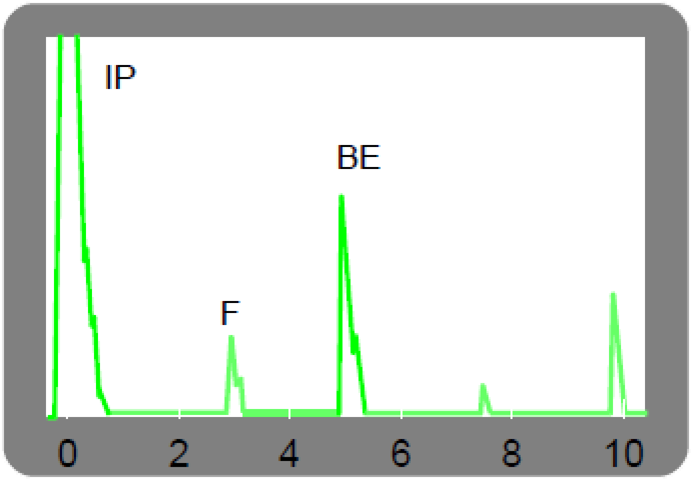
Sound reflection at a flaw



Basic Principles of Ultrasonic Testing

Plate testing





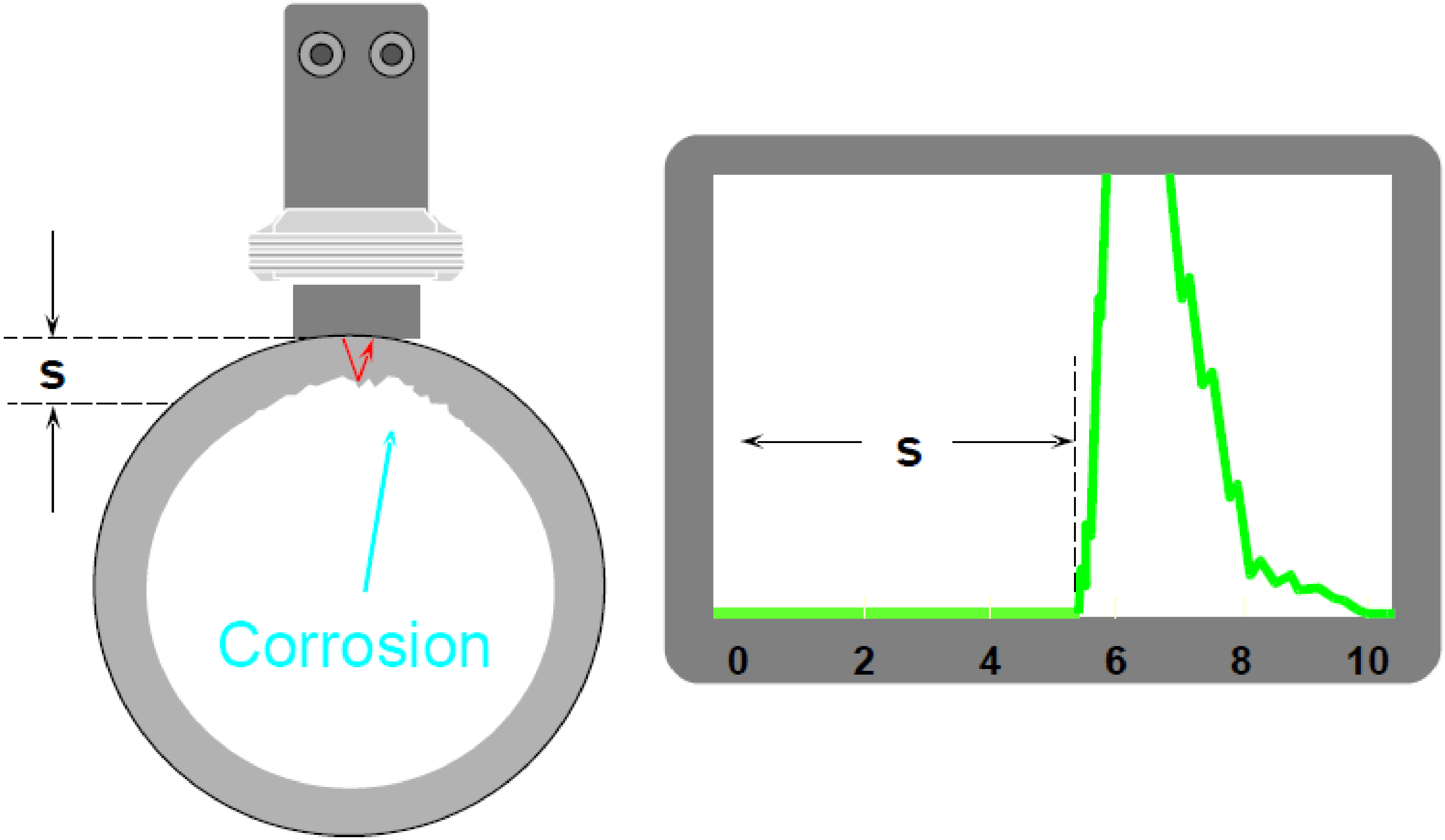
IP = Initial pulse

F = Flaw

BE = Backwall echo

Basic Principles of Ultrasonic Testing

Wall thickness measurement



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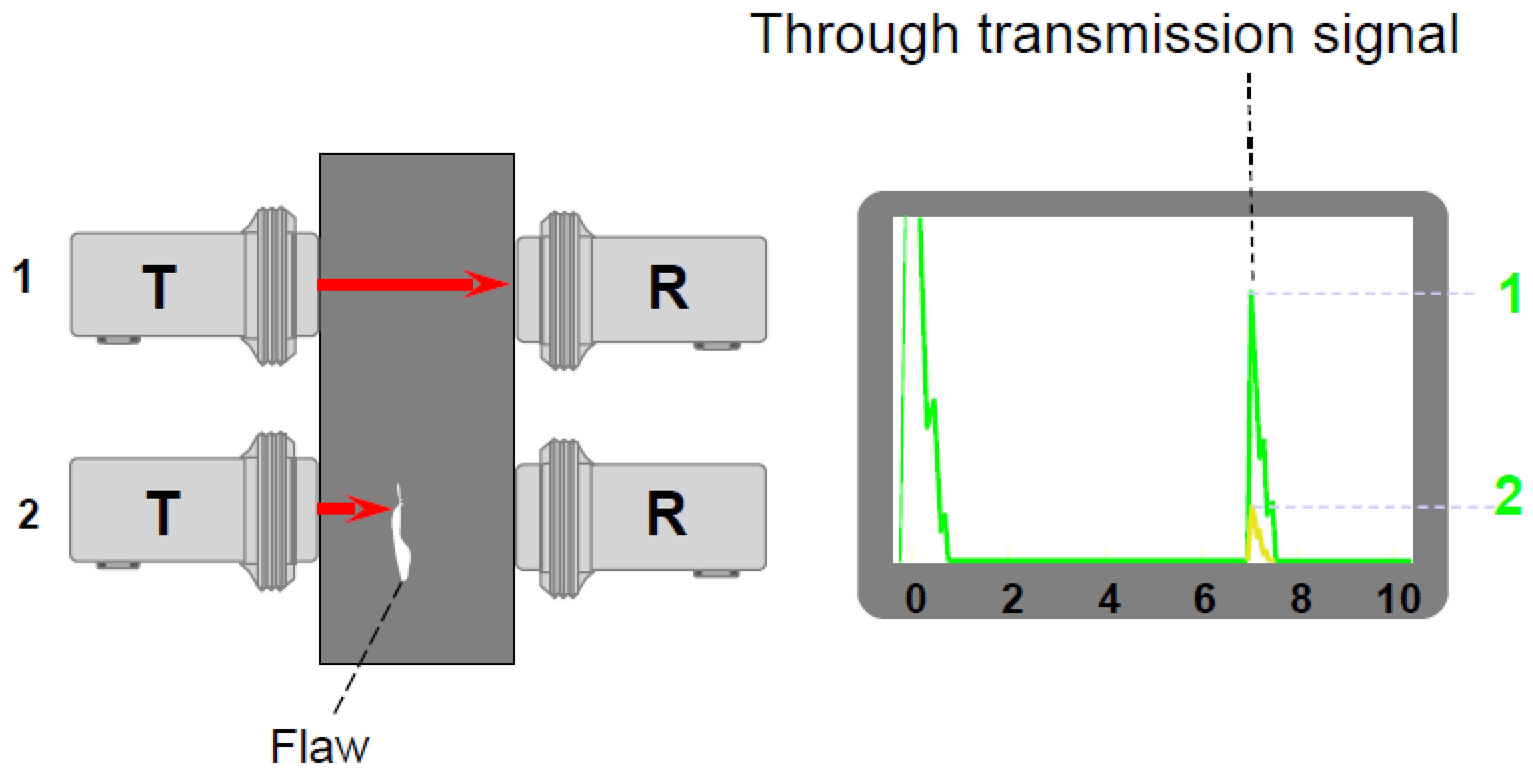
Basic Principles of Ultrasonic Testing

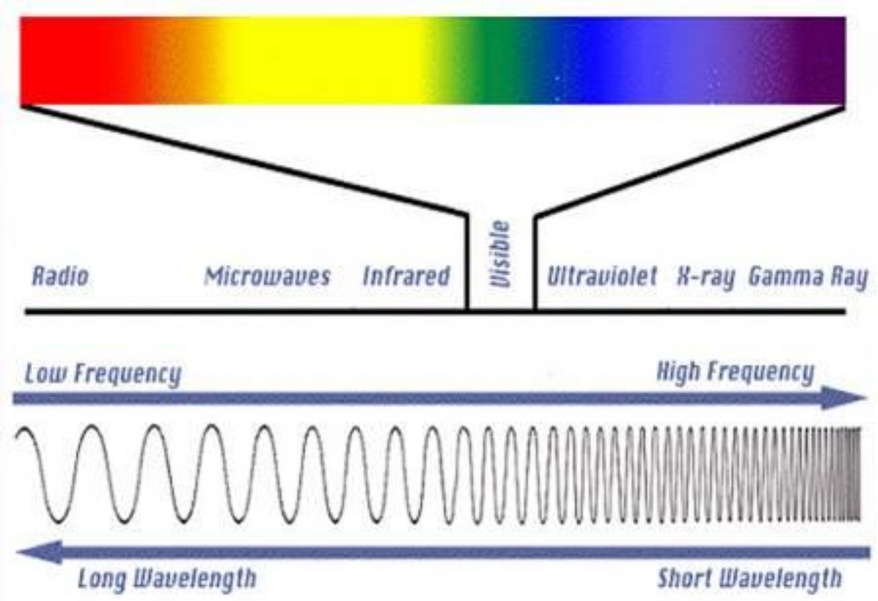
Through transmission testing

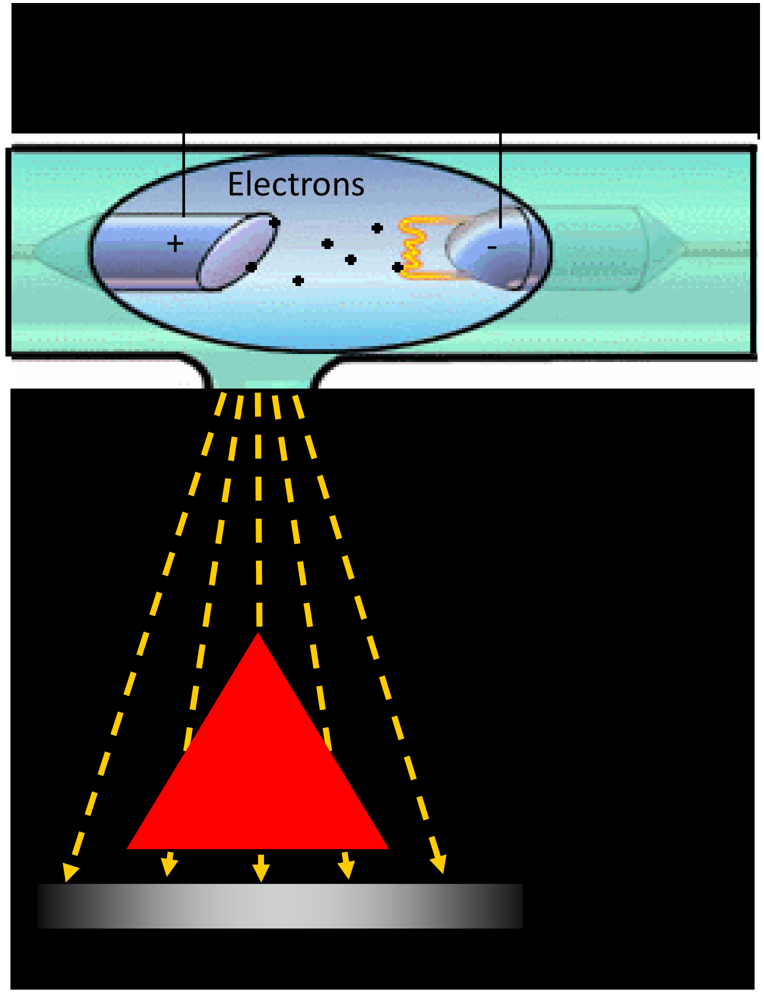


UNIT III
RADIOGRAPHY TESTING

RADIOGRAPHY TESTING

- **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.**





X-ray Generator or Radioactive Source Creates Radiation

Introduction

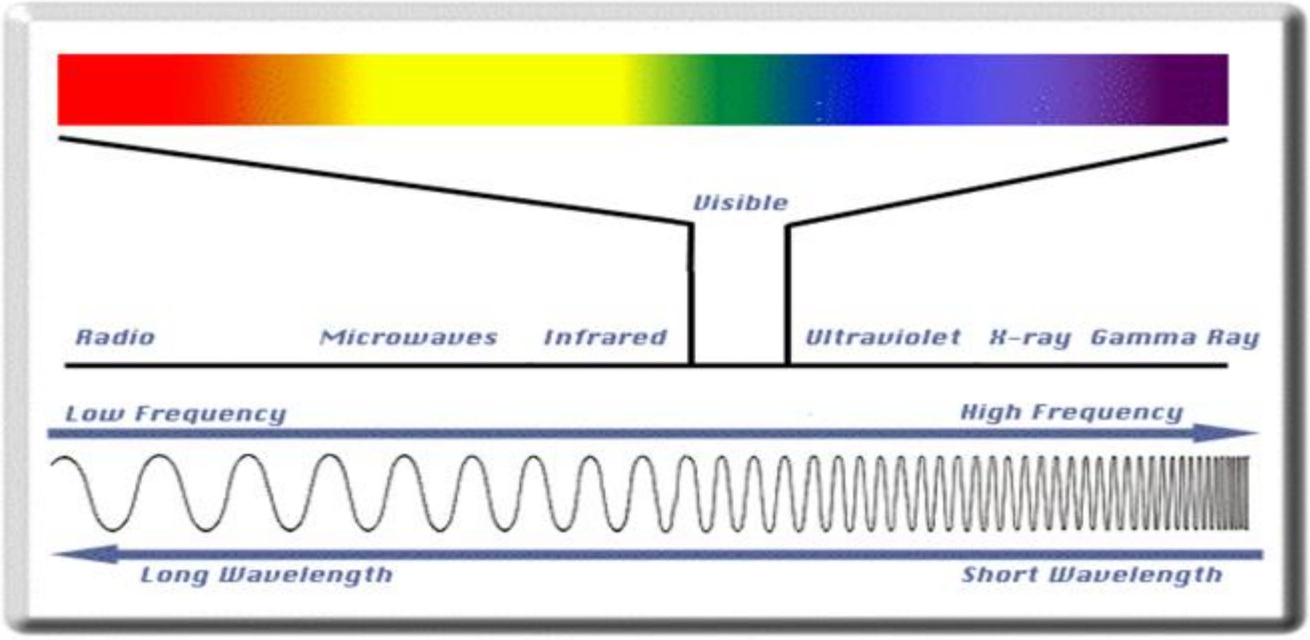
- This module presents information on the NDT method of radiographic inspection or radiography.
- Radiography uses penetrating radiation that is directed towards a component.
- The component stops some of the radiation. The amount that is stopped or absorbed is affected by material density and thickness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

outline

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

Electromagnetic Radiation

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

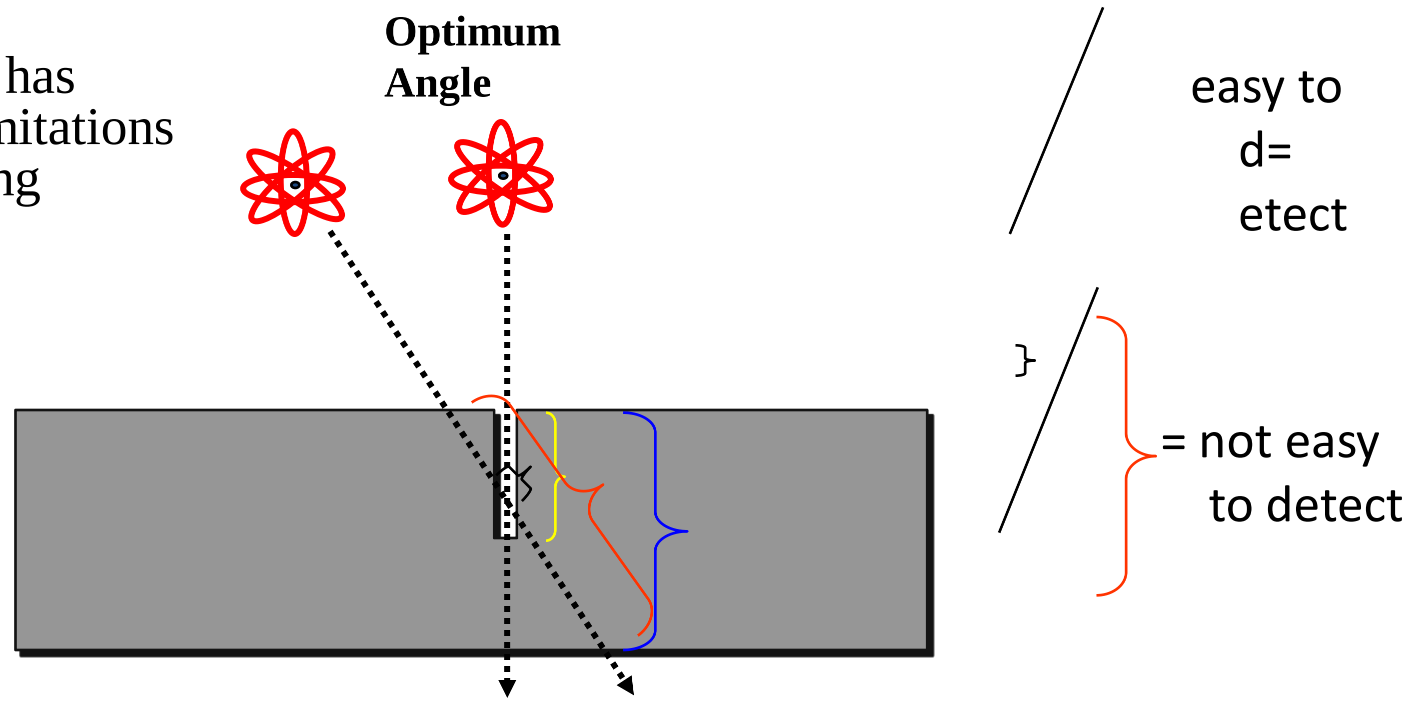


General Principles of Radiography

- The part is placed between the radiation source and a piece of film. The part will stop some of the radiation. Thicker and more dense area will stop more of the. Radiation.
- The film darkness (density) will vary with the amount of radiation reaching the film through the test object.

Flaw Orientation

Radiography has sensitivity limitations when detecting cracks.

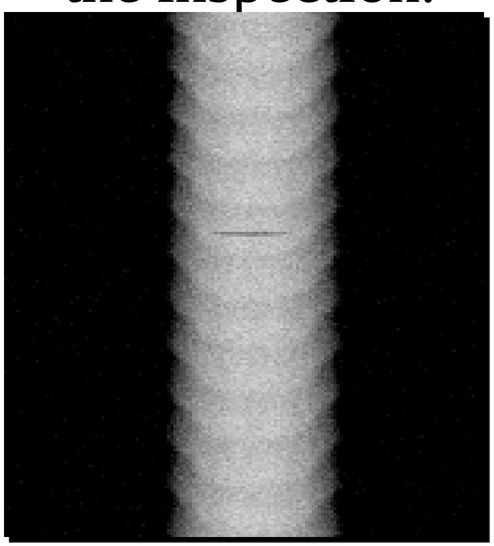


X-rays “see” a crack as a thickness variation and the larger the variation, the easier the crack is to detect.

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

- 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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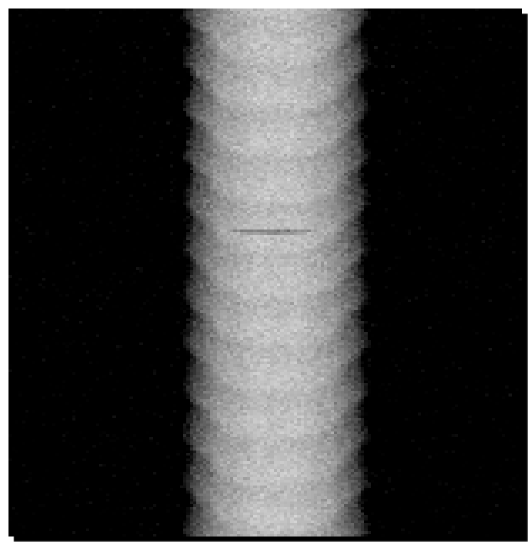
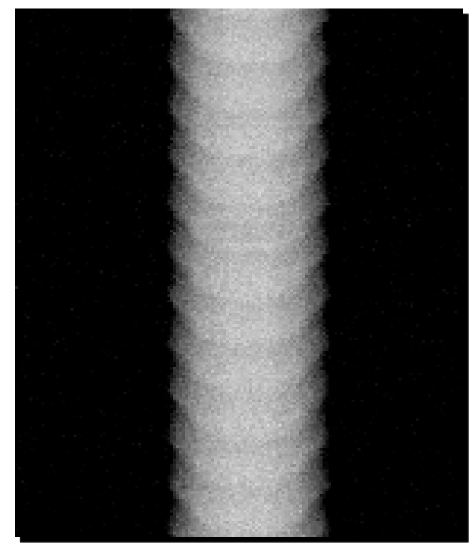


10º



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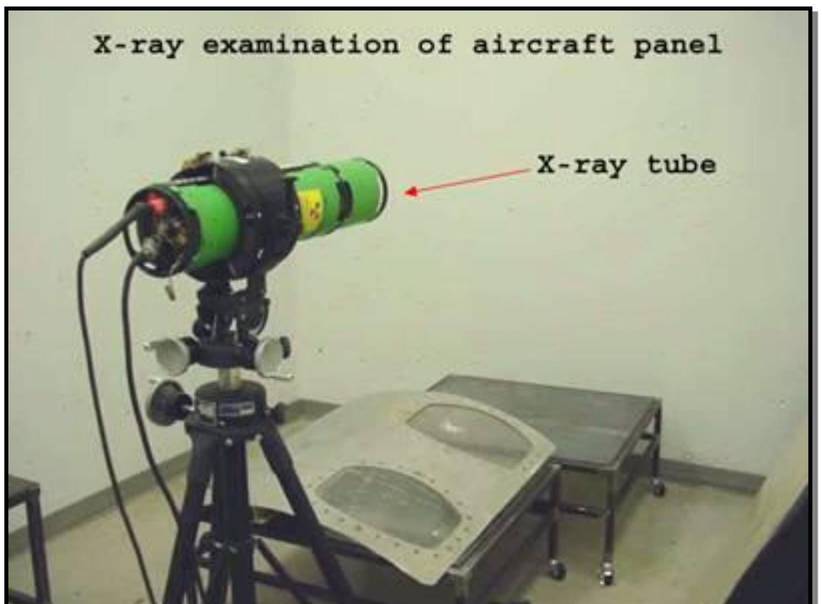
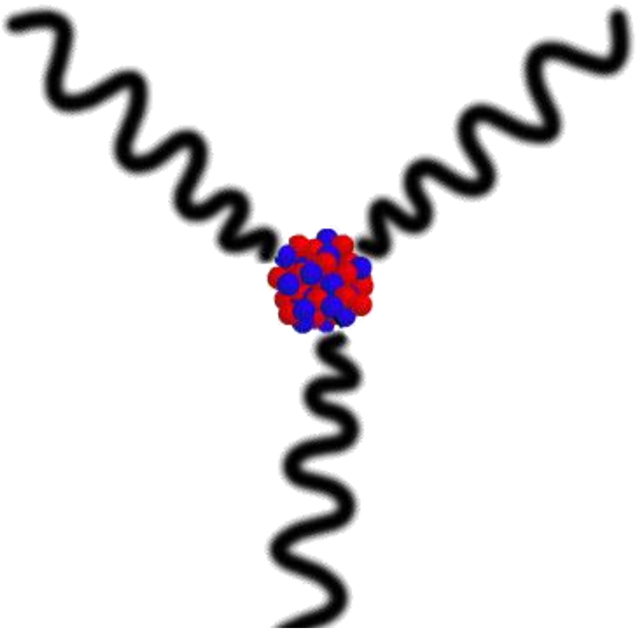
Radiation Sources

- Two of the amost 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.)

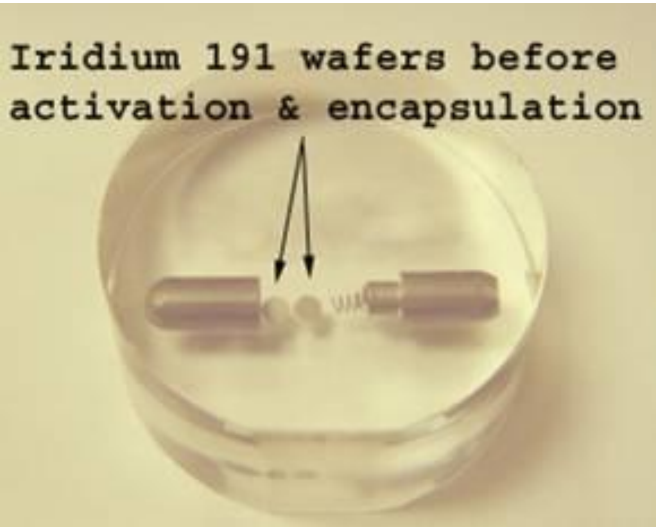
- Most of the radioactive material used in industrial radiography is artificially produced.
- This is done by subjecting stable material to a source of neutrons in a special nuclear reactor.
- This process is called activation.

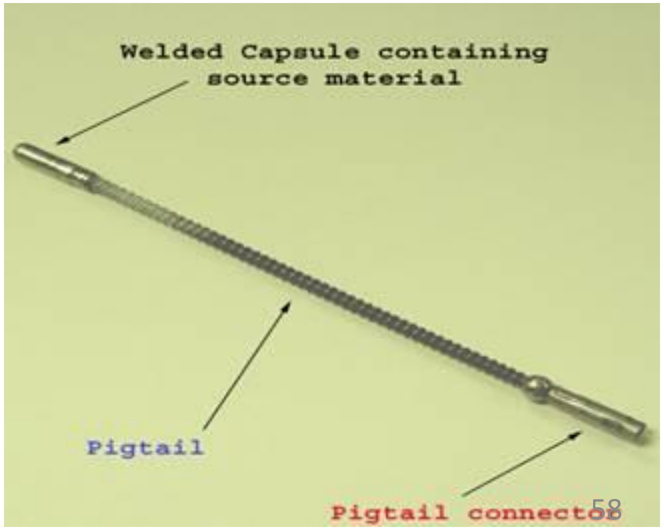
Gamma Radiography (cont.)

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."

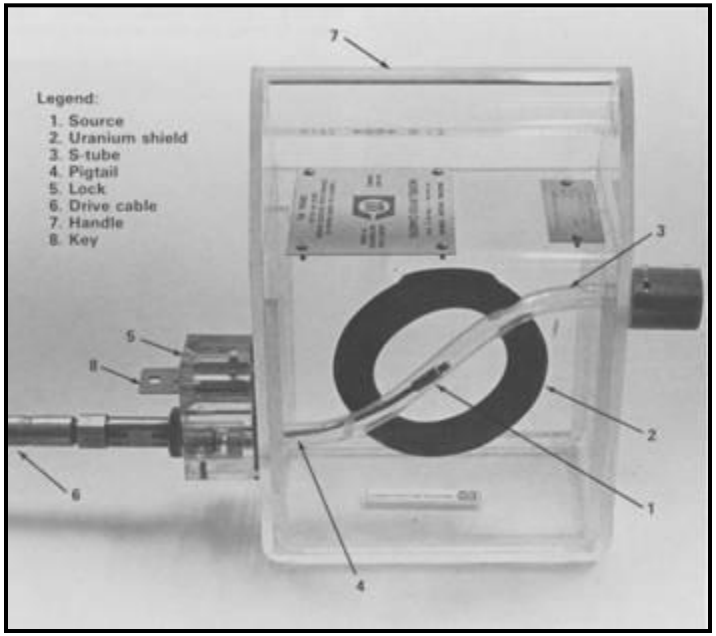
The pigtail has a special connector at the other end that attaches to a drive cable.





Gamma Radiography (cont.)

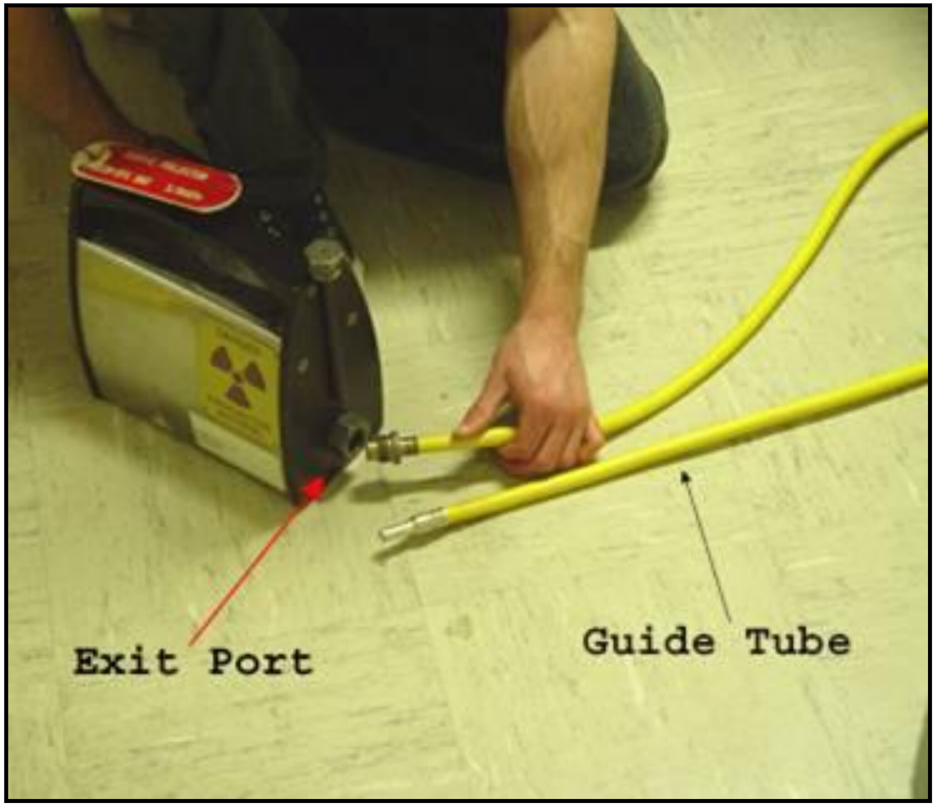
A device called a “camera” is used to store, transport and expose the pigtail containing the radioactive material. The camera contains shielding material which reduces the radiographer’s exposure to radiation during use.



Gamma Radiography (cont.)

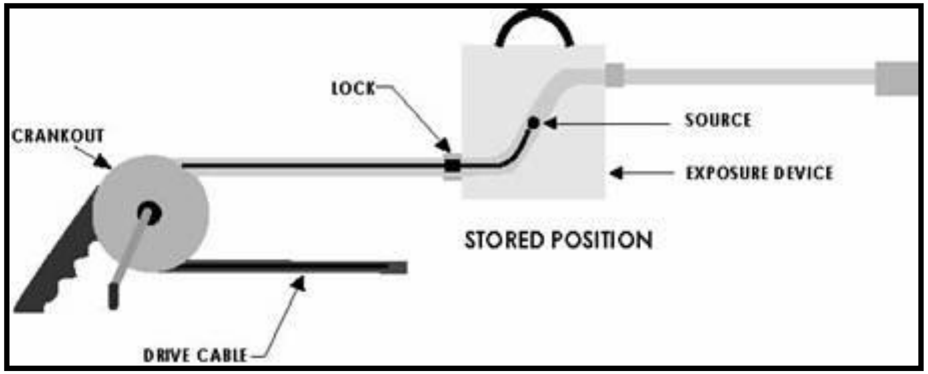
A hose-like device called a guide tube is connected to a threaded hole called an “exit port” in the camera.

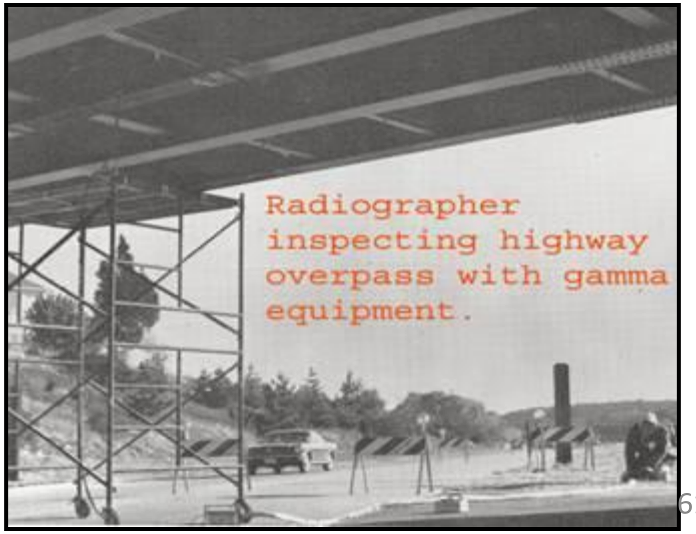
The radioactive material will leave and return to the camera through this opening when performing an exposure!



Gamma Radiography (cont.)

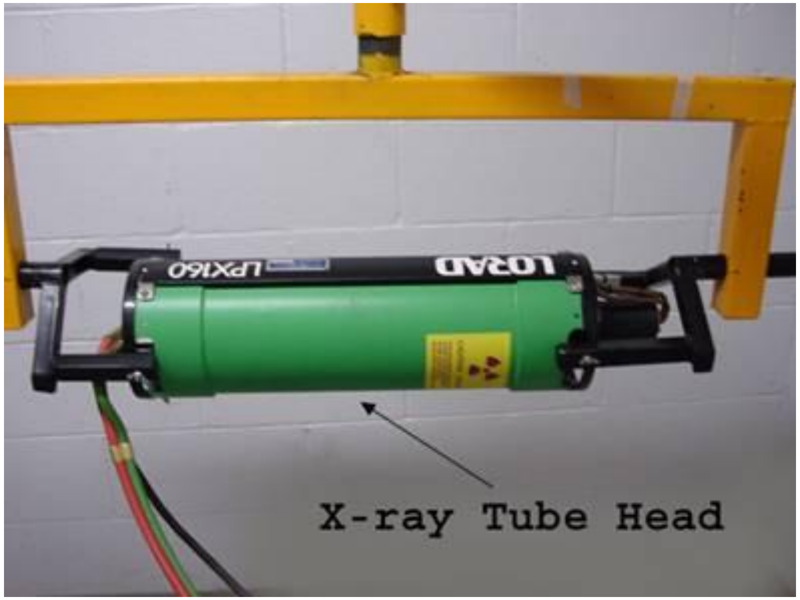
A "drive cable" is connected to the other end of the camera. This cable, controlled by the radiographer, is used to force the radioactive material out into the guide tube where the gamma rays will pass through the specimen and expose the recording device.





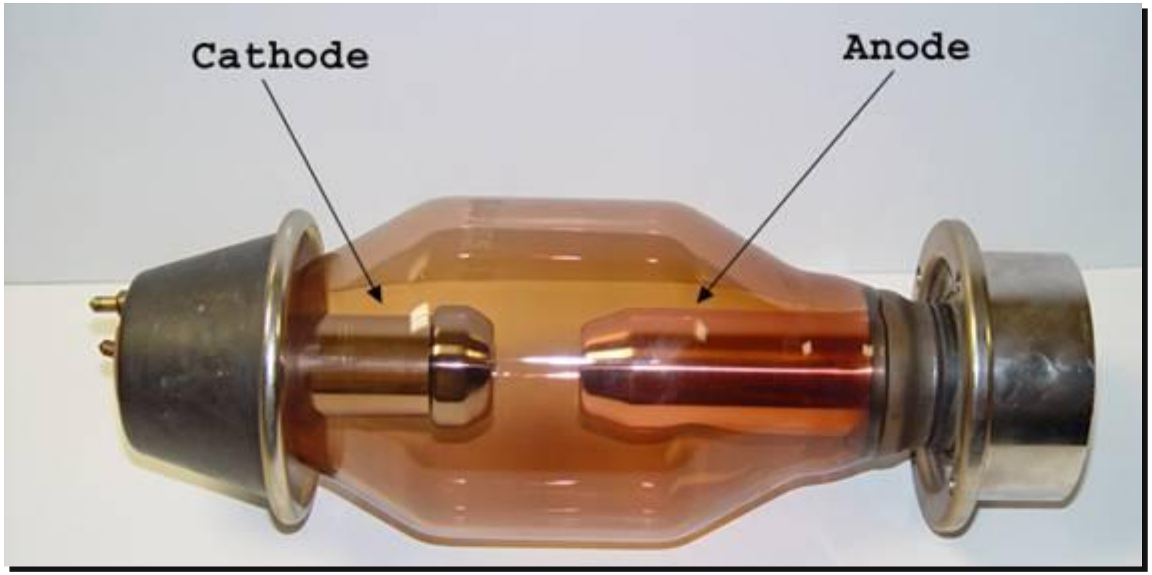
X-ray Radiography

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.



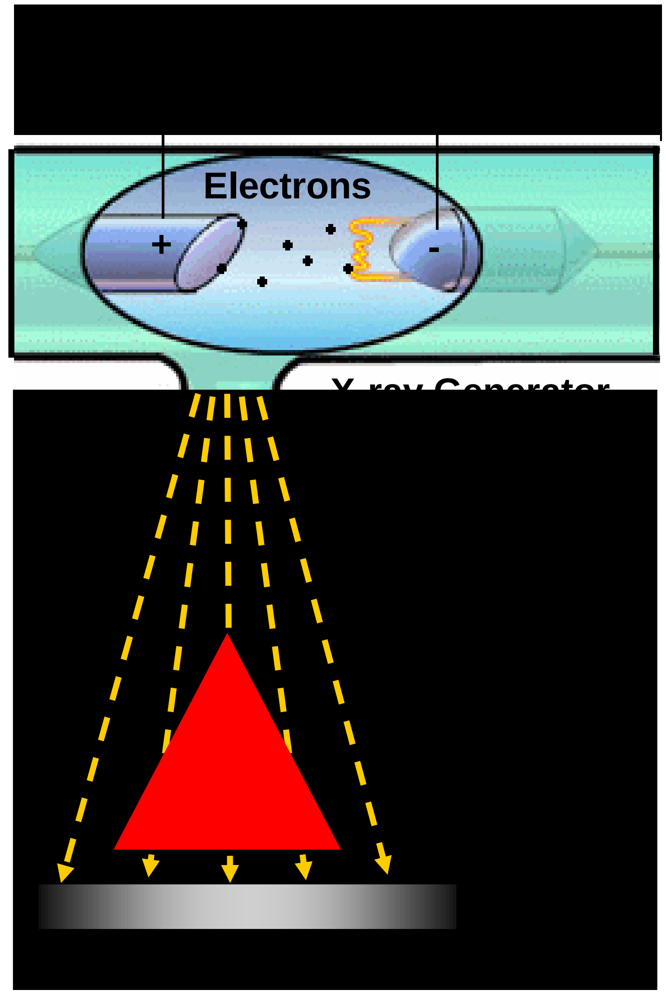
X-ray Radiography (cont.)

- 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.



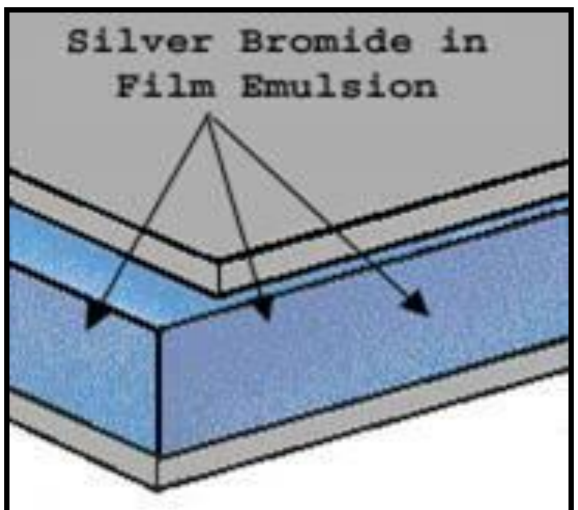
Imaging Modalities

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

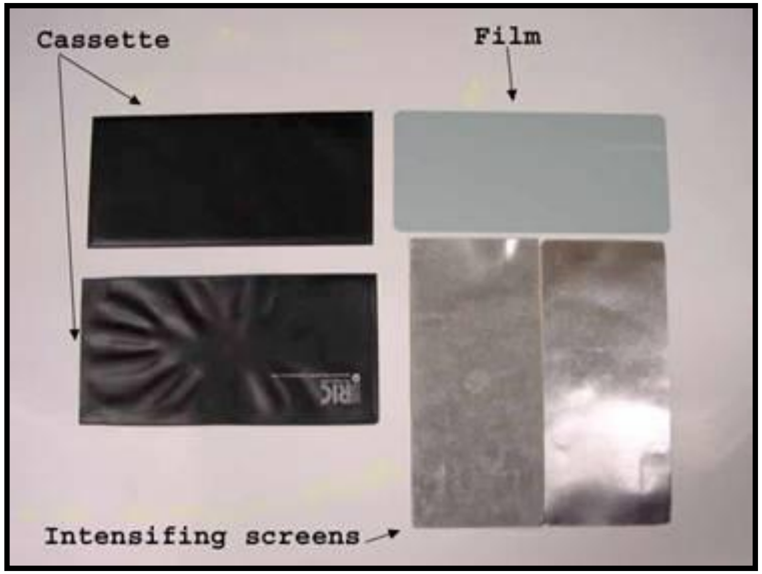


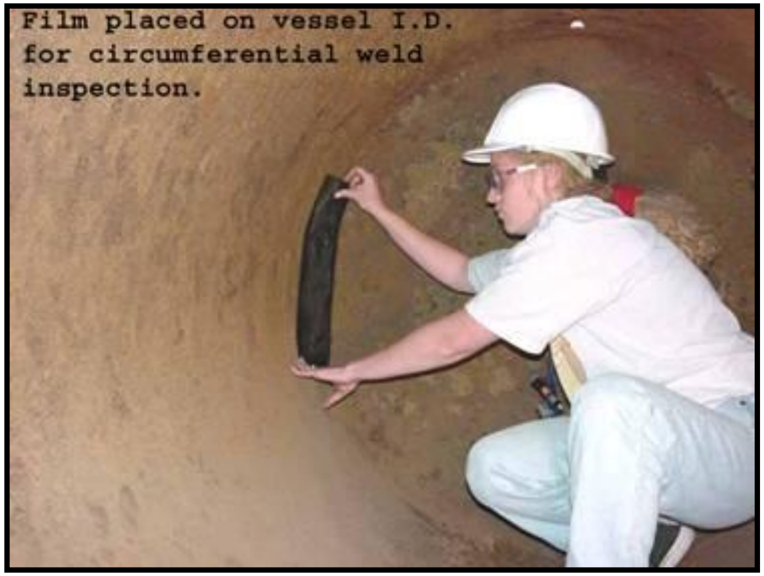
- One of the most widely used and oldest imaging mediums in industrial radiography is radiographic film.

- 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.



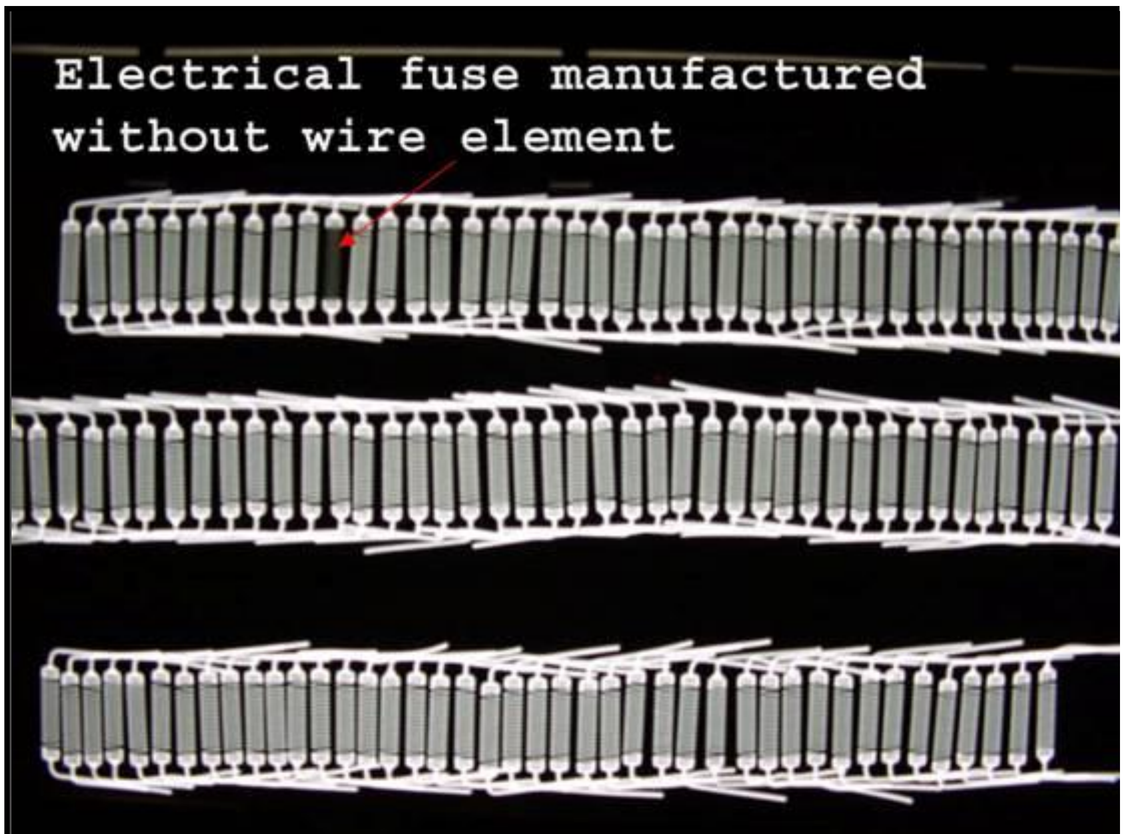


Film Radiography (cont.)

- In order for the image to be viewed, the film must be “developed” in a darkroom. The process is very similar to phaaotographic 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.

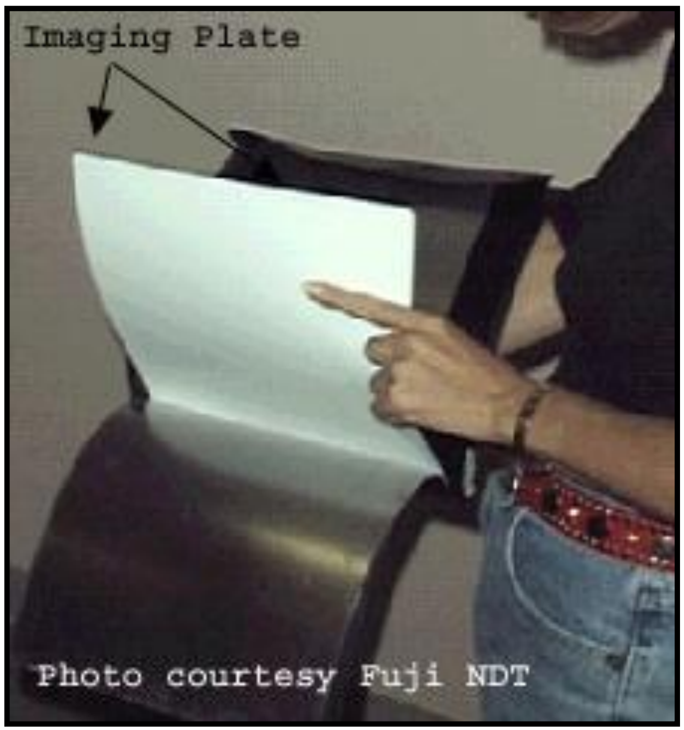
Digital Radiography (cont.)

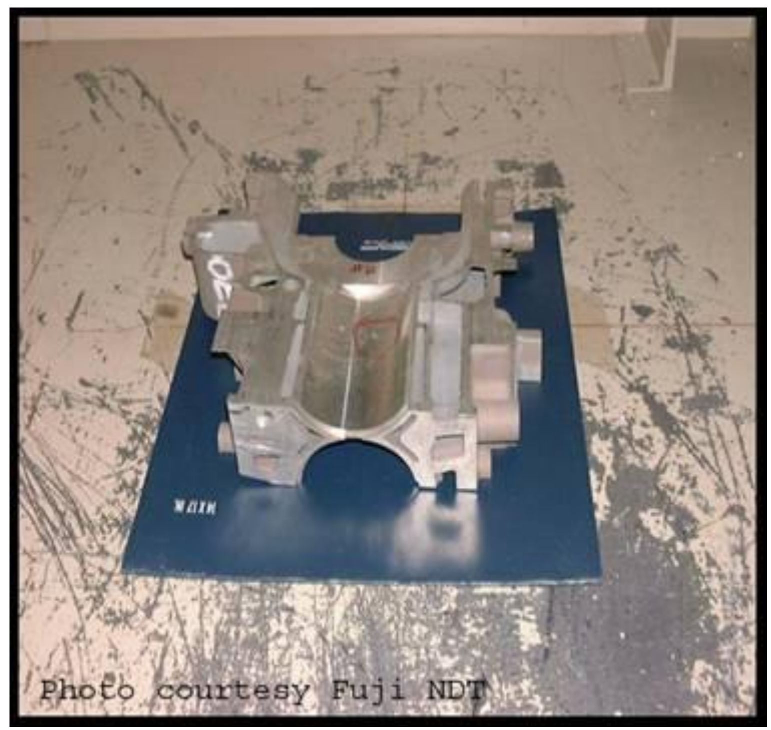
There are a number of forms of digital radiographic imaging including:

- 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.

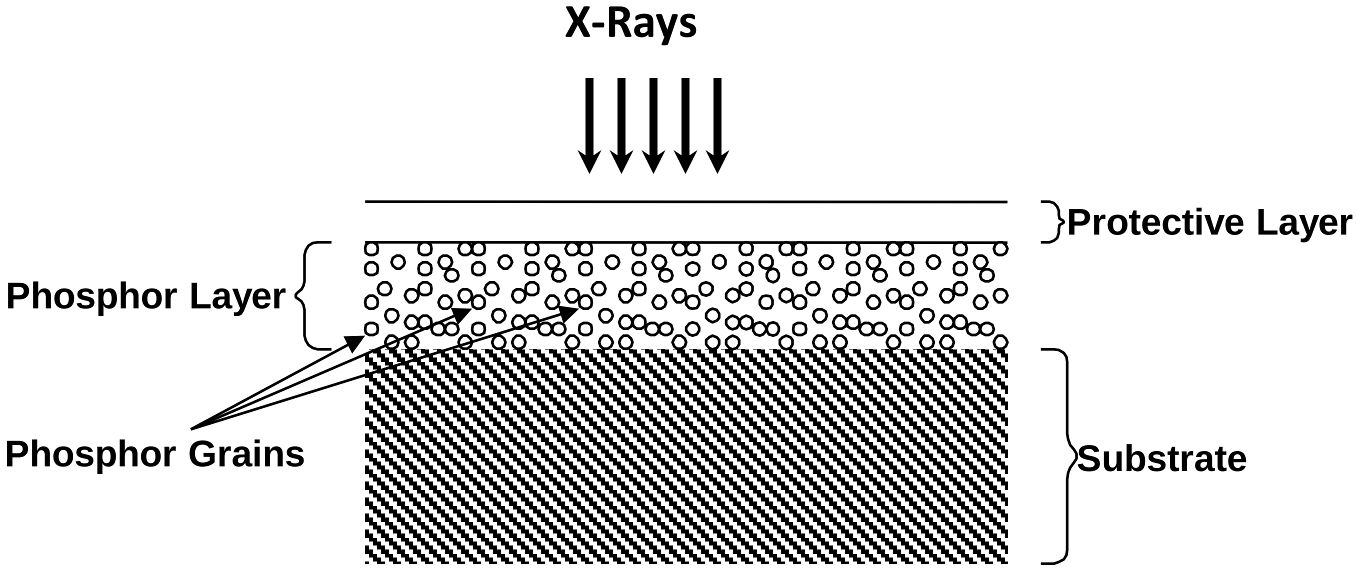




Computed Radiography (cont.)

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

CR Phosphor Screen Structure



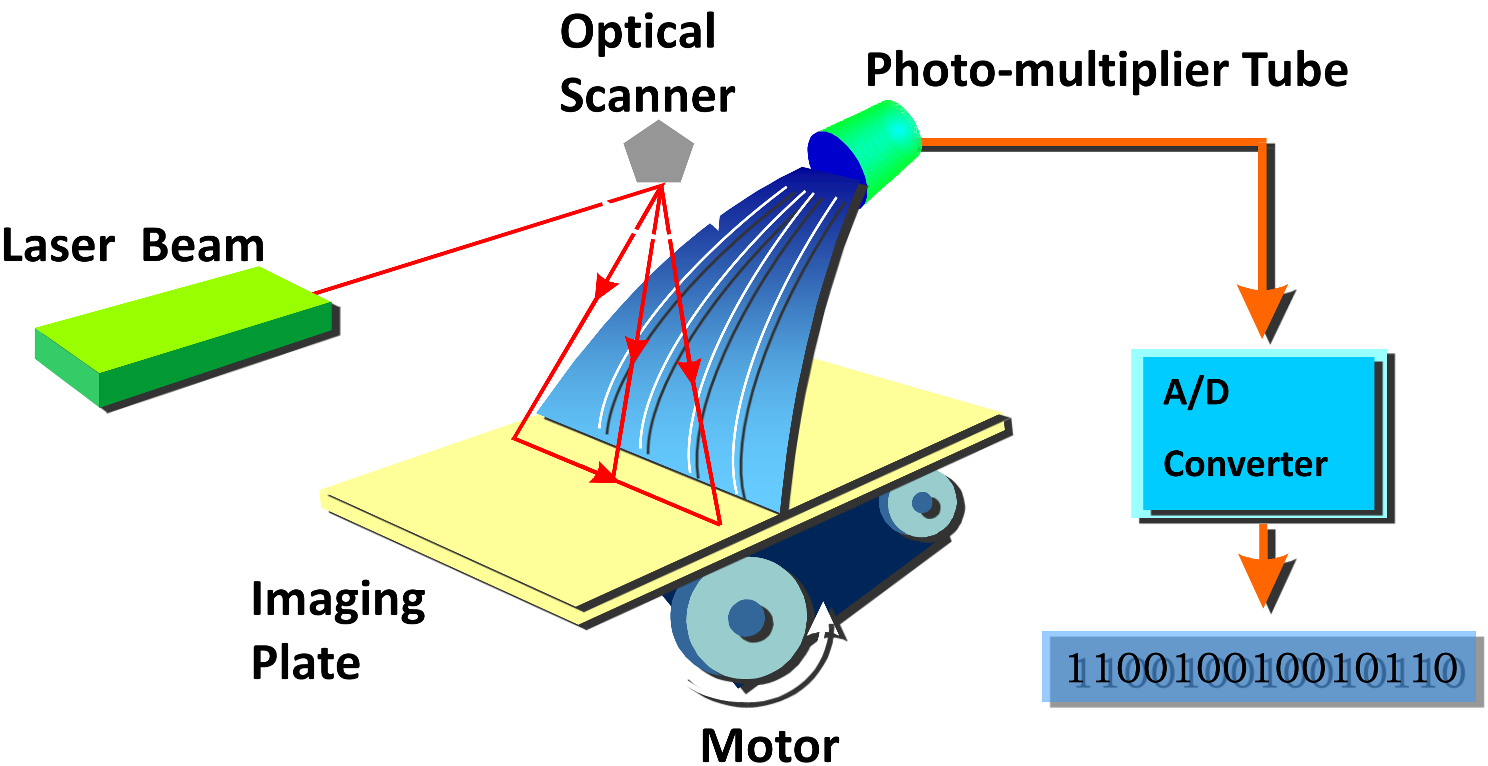
Computed Radiography (cont.)

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:

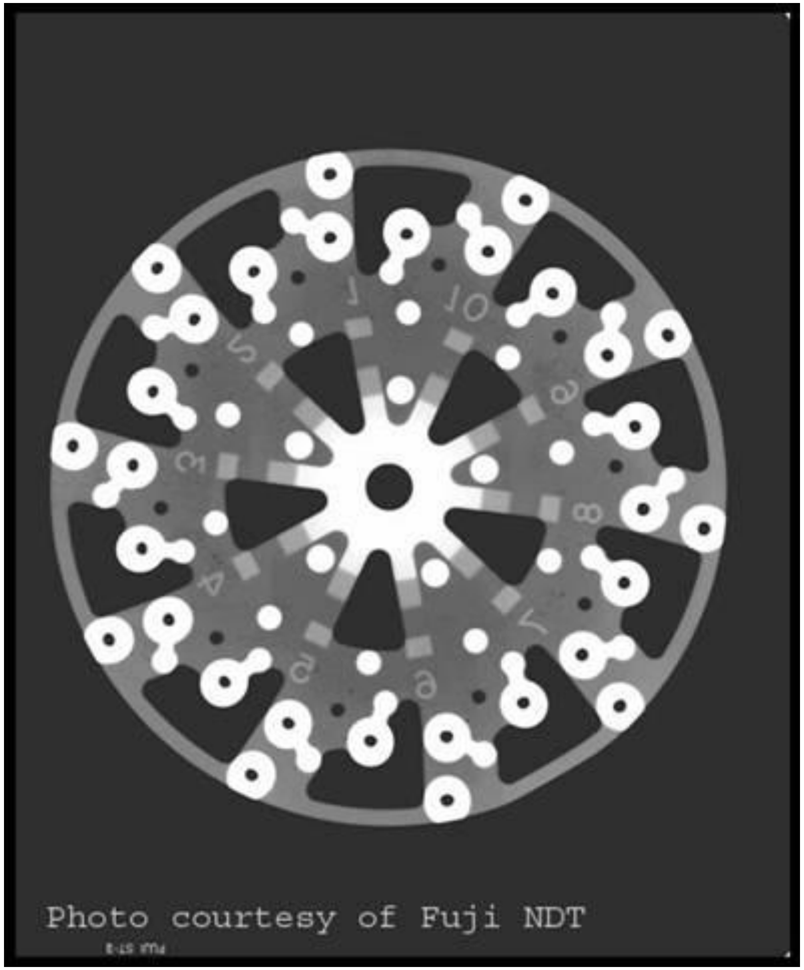


Photo courtesy of Fuji NDT

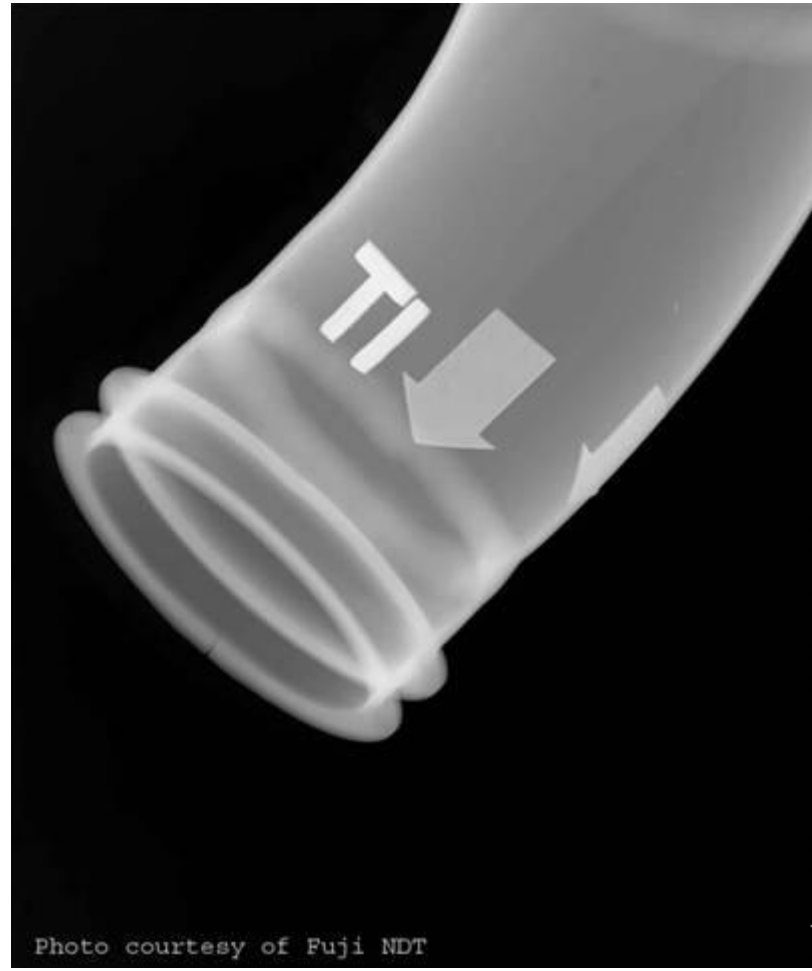


Photo courtesy of Fuji NDT

Real-Time Radiography

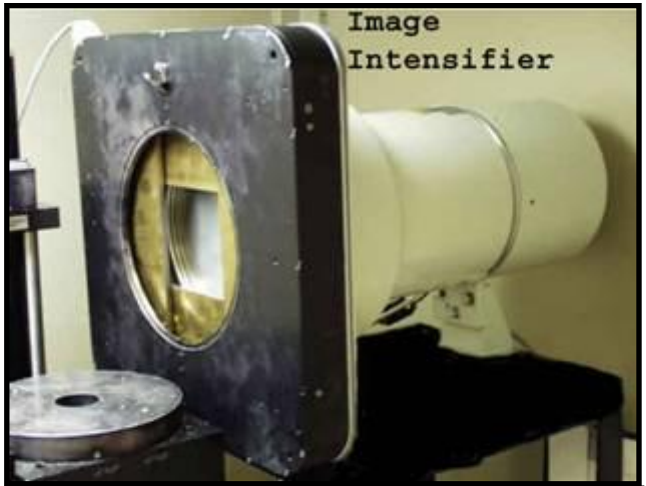
- Real-Time Radiography (RTR) is a term used to describe a form of radiography that allows electronic images to be captured and viewed in real time.
- Because image acquisition is almost instantaneous, X-ray images can be viewed as the part is moved and rotated.
- Manipulating the part can be advantageous 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.

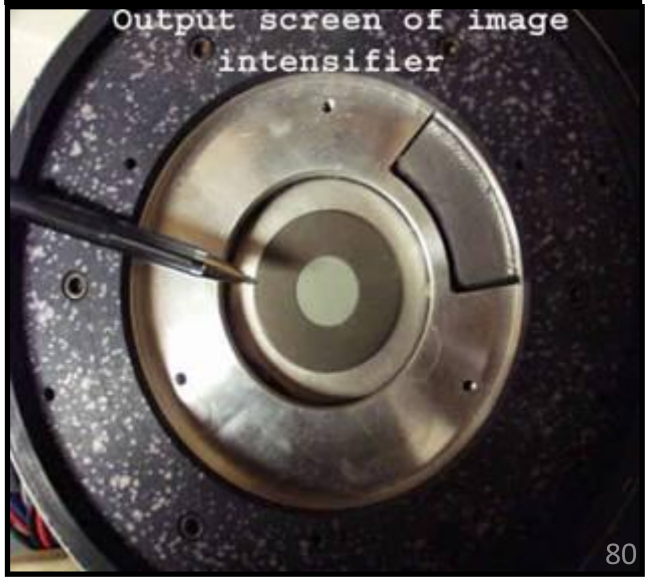
Real-Time Radiography (cont.)

- 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.



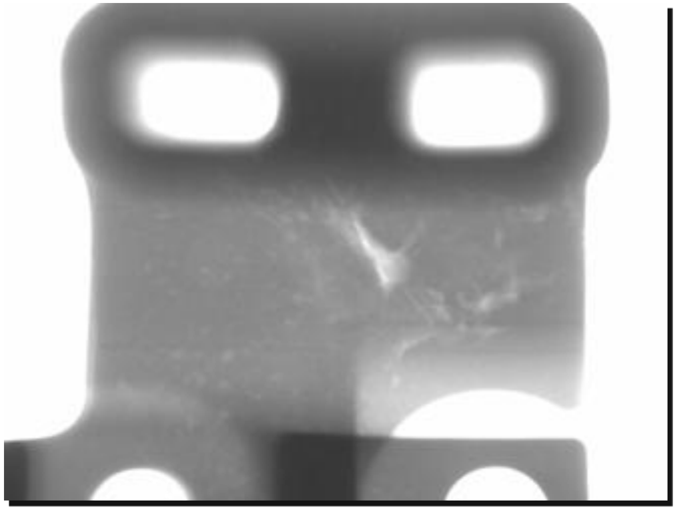


Real-Time Radiography (cont.)

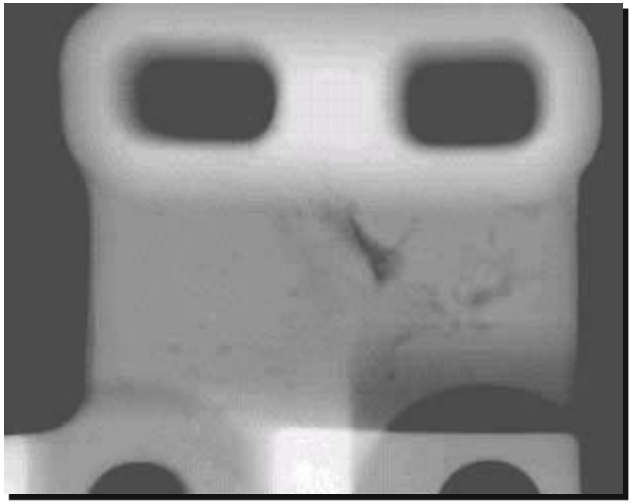
- A special camera which captures the light output of the screen is located near the image intensifying screen.
- The camera is very sensitive to a variety of different light intensities.
- A monitor is then connected to the camera to provide a viewable image.
- If a sample positioning system is employed,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

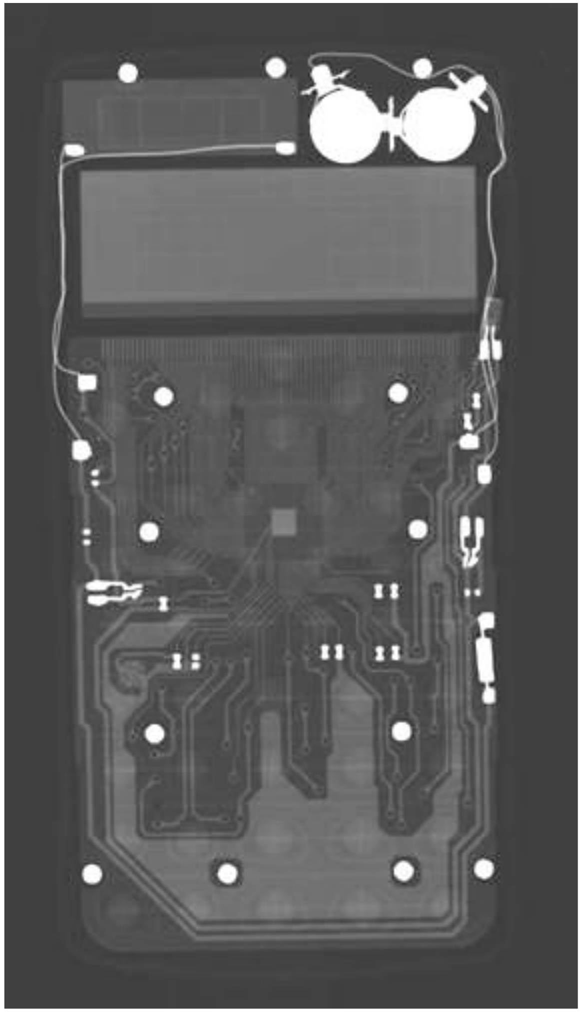


Real-time images are lighter in areas where more X-ray photons reach and excite the fluorescent screen.

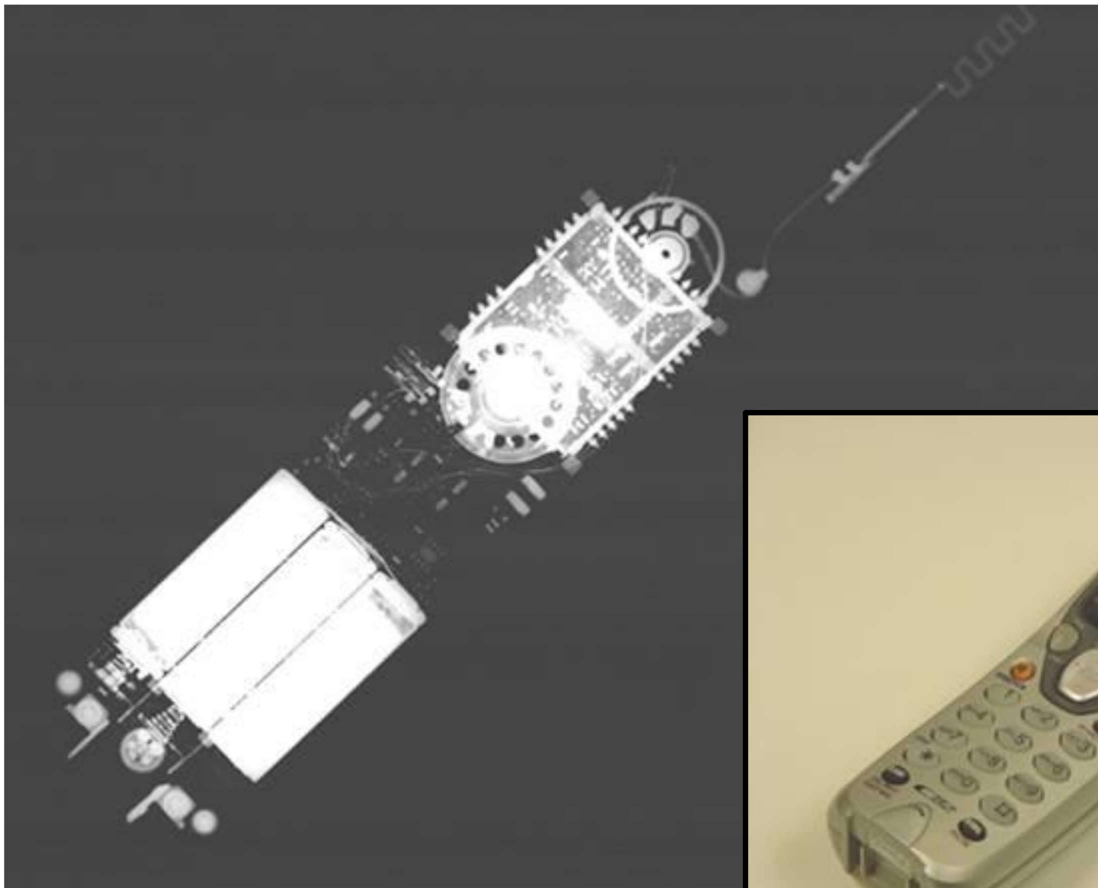


Film images are darker in areas where more X-ray photons reach and ionize the silver molecules in the film.

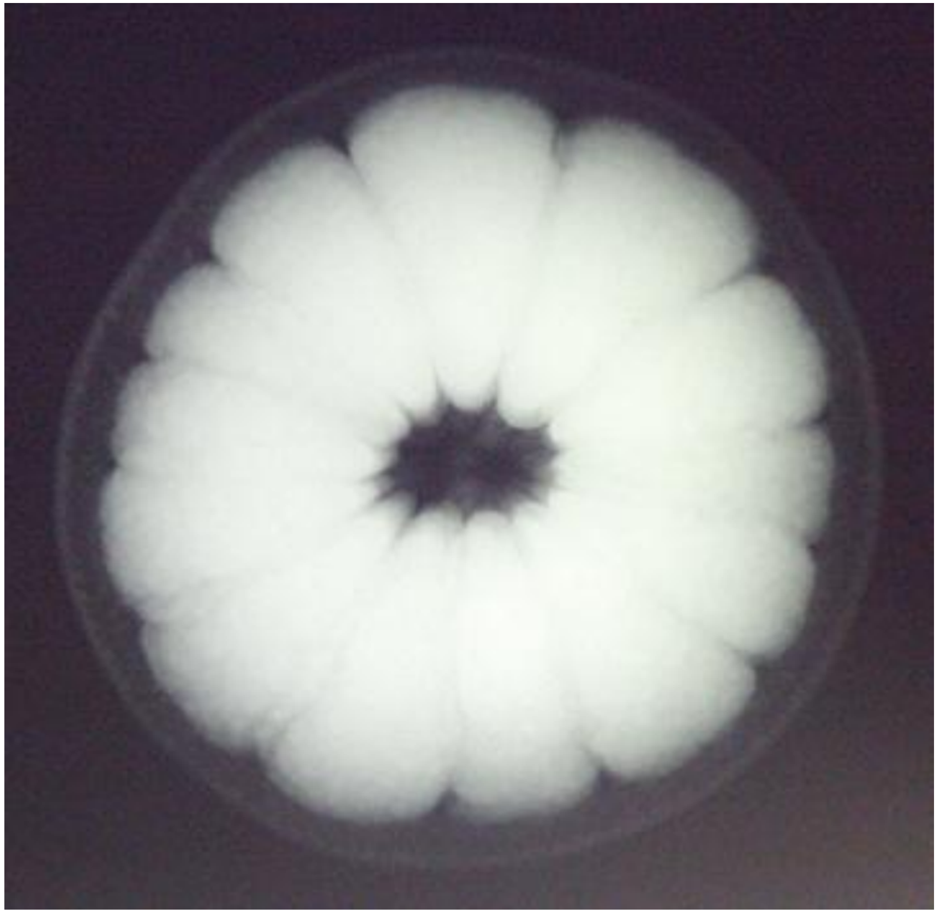
Radiographic Images

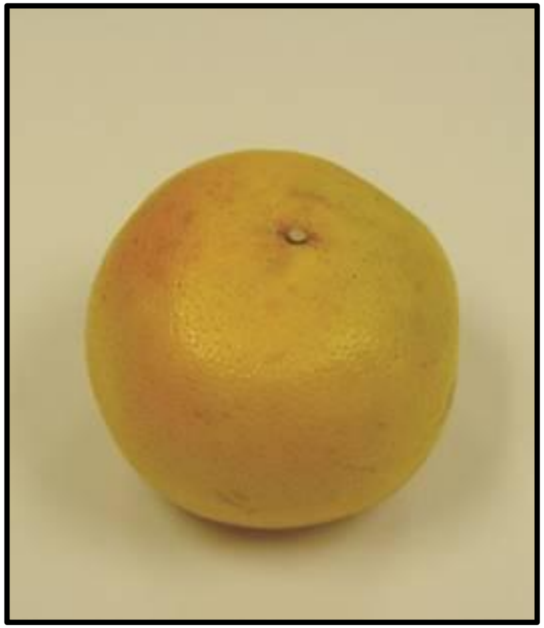


Radiographic Images



Radiographic Images





Advantages of Radiography

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

Disadvantages of Radiography

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

UNIT IV

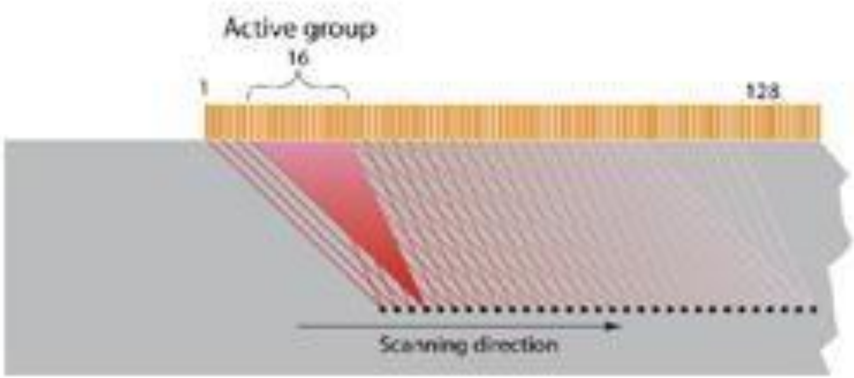
ADVANCED NDE TECHNIQUES -I

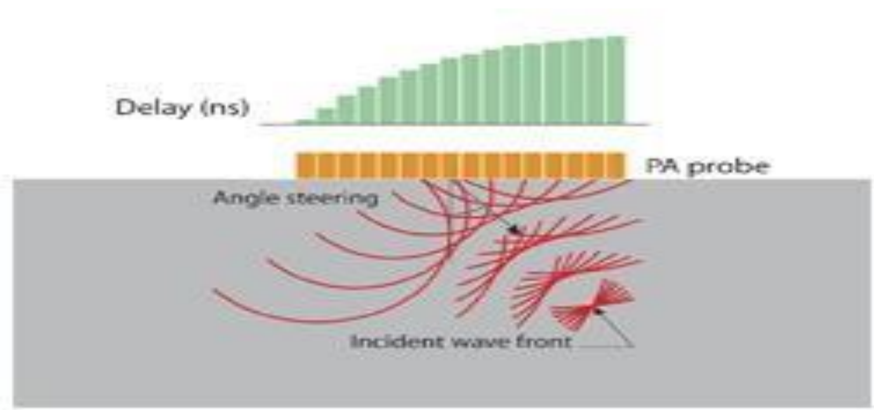
What is PAUT?

- Phased Array Ultrasonic Testing is an advanced ultrasonic technique used for flaw detection, sizing, and imaging
- Uses multi-element (array) probes for increased beam steering and focusing compared to conventional UT
- Like having many small conventional UT probes in one pulsed at predetermined intervals

How Phased Array Works

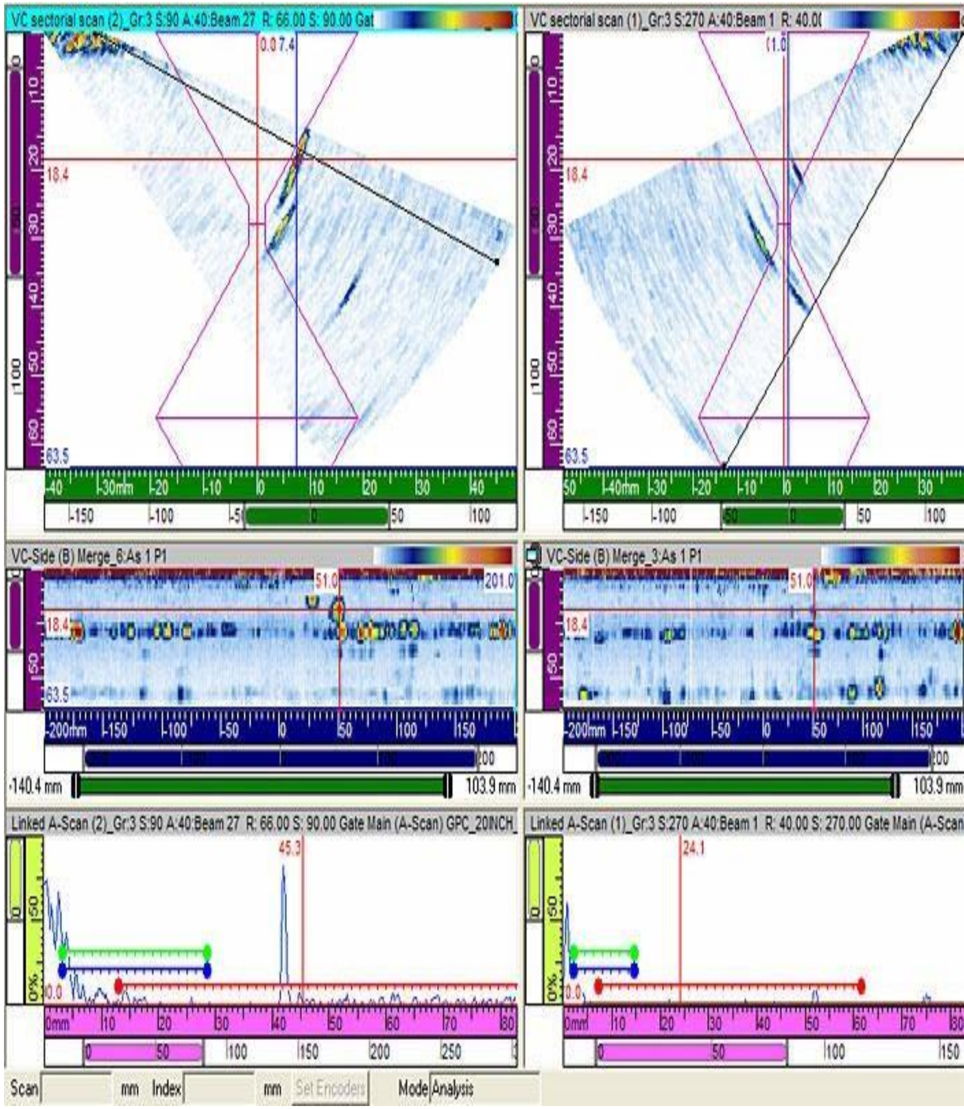
- Each individual wave generated within the scan goes through the pulse/receive cycle as shown below





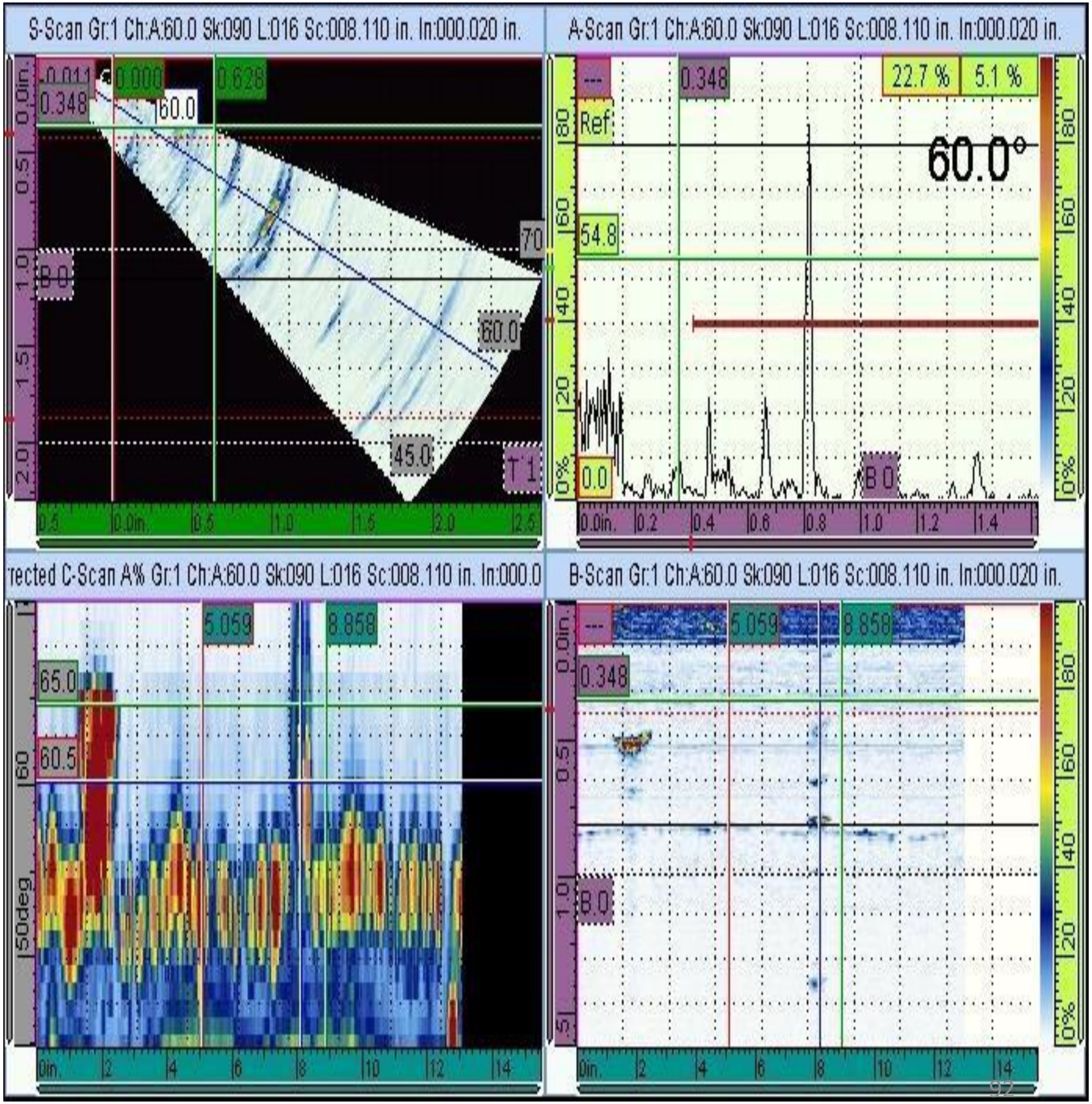
How Phased Array Works

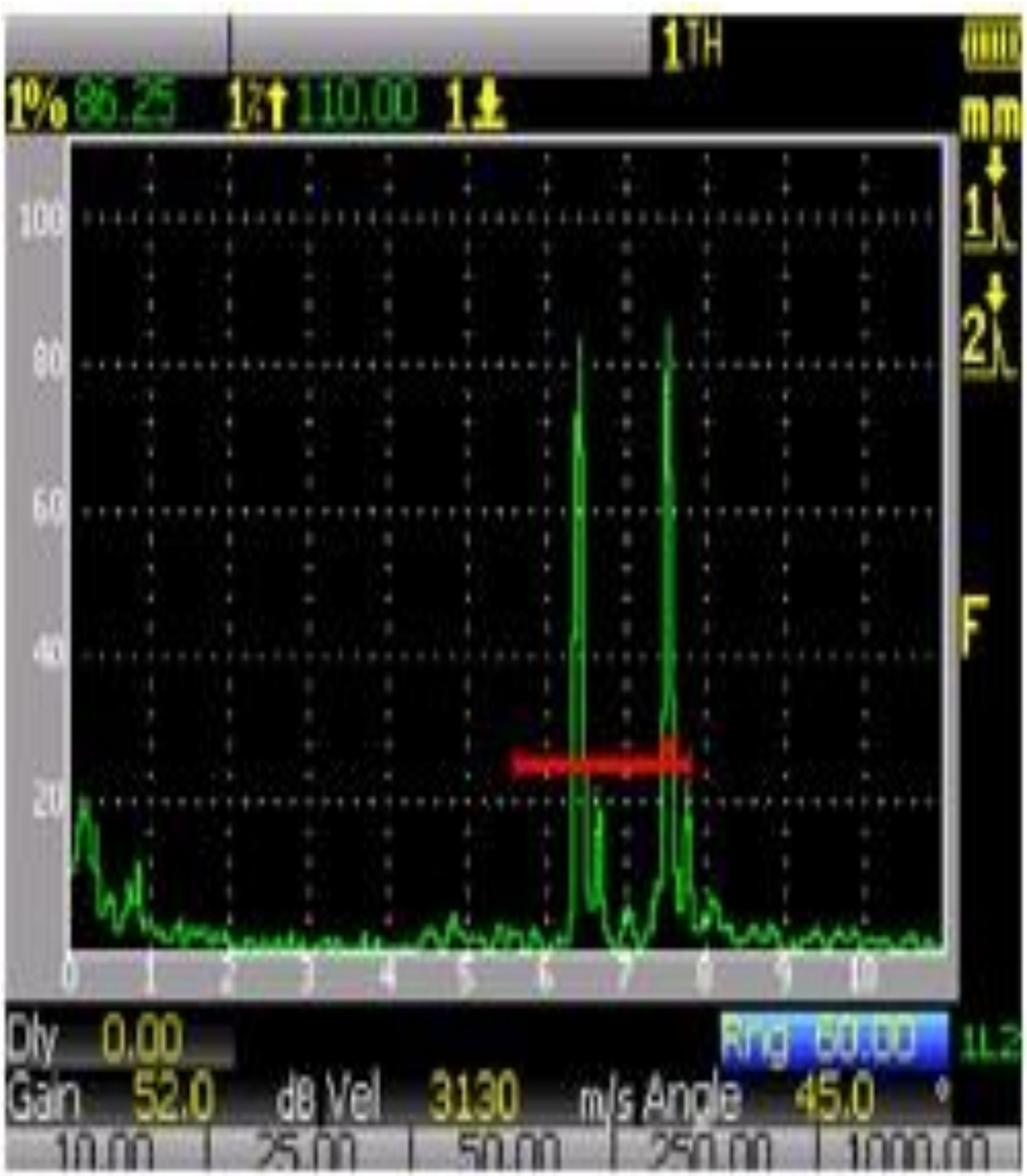
- Each received analog
A-Scan is digitized and
rendered into
2D display formats
- Signals from the entire
equence are compiled into
various image formats for
evaluation



PAUT Views

- A data view is a 2D graphic rendering of the ultrasonic data
- Data views
  - A-Scan
  - B-Scan
  - C-Scan
  - S-Scan
  - ToFD
  - Ray Tracing
  - Strip Charts



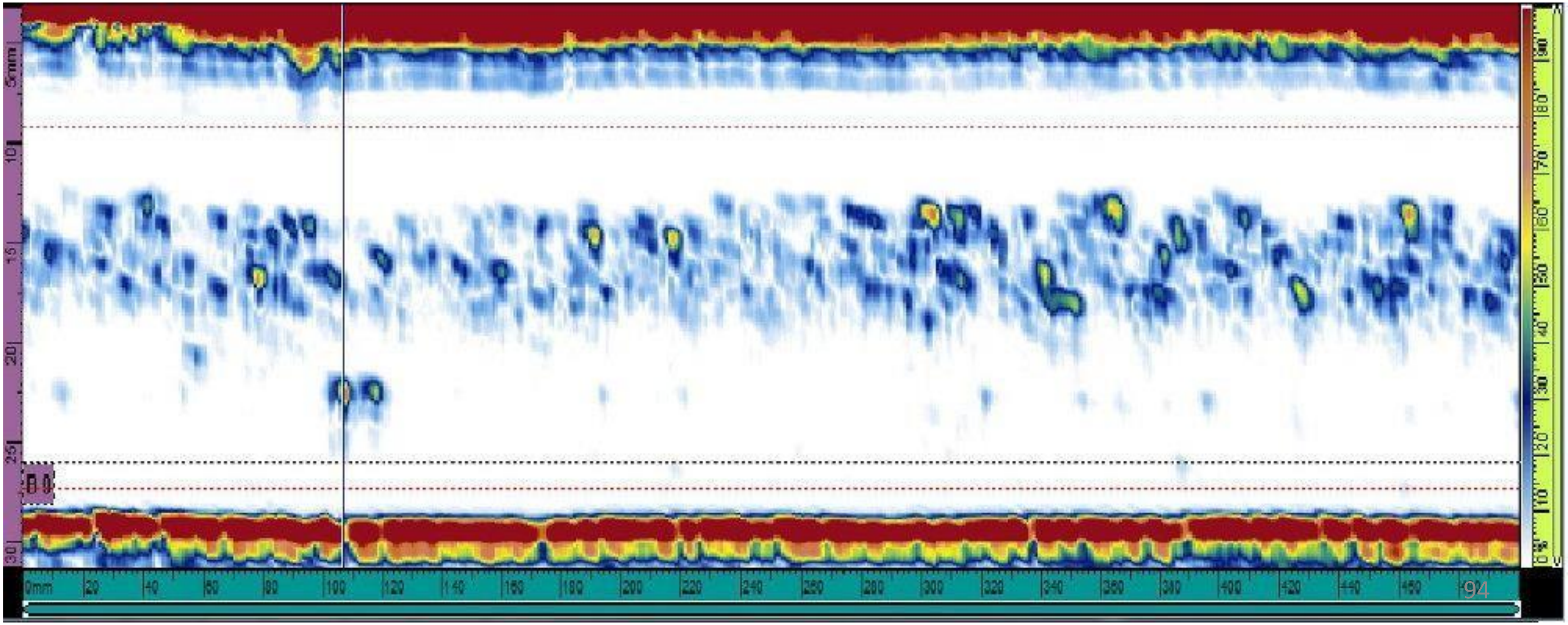


A-Scan View

- Source by which all other views are created
- Amplitude vs time
- An A-Scan exists for every sound beam
  - One for each segment of a linear scan
  - One for each angle of an S-Scan
- Rulers allow presentation of information in time, sound path, or true depth
- Amplitude is linked to color pallet

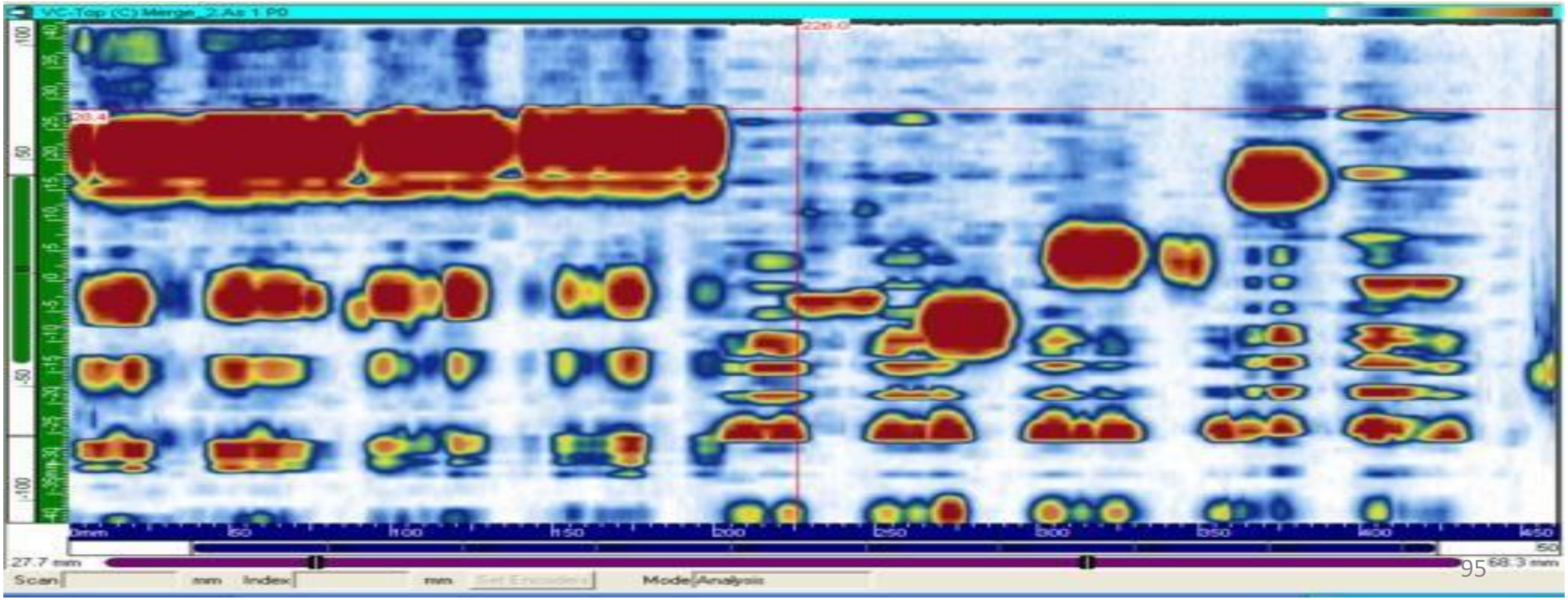
B-Scan View

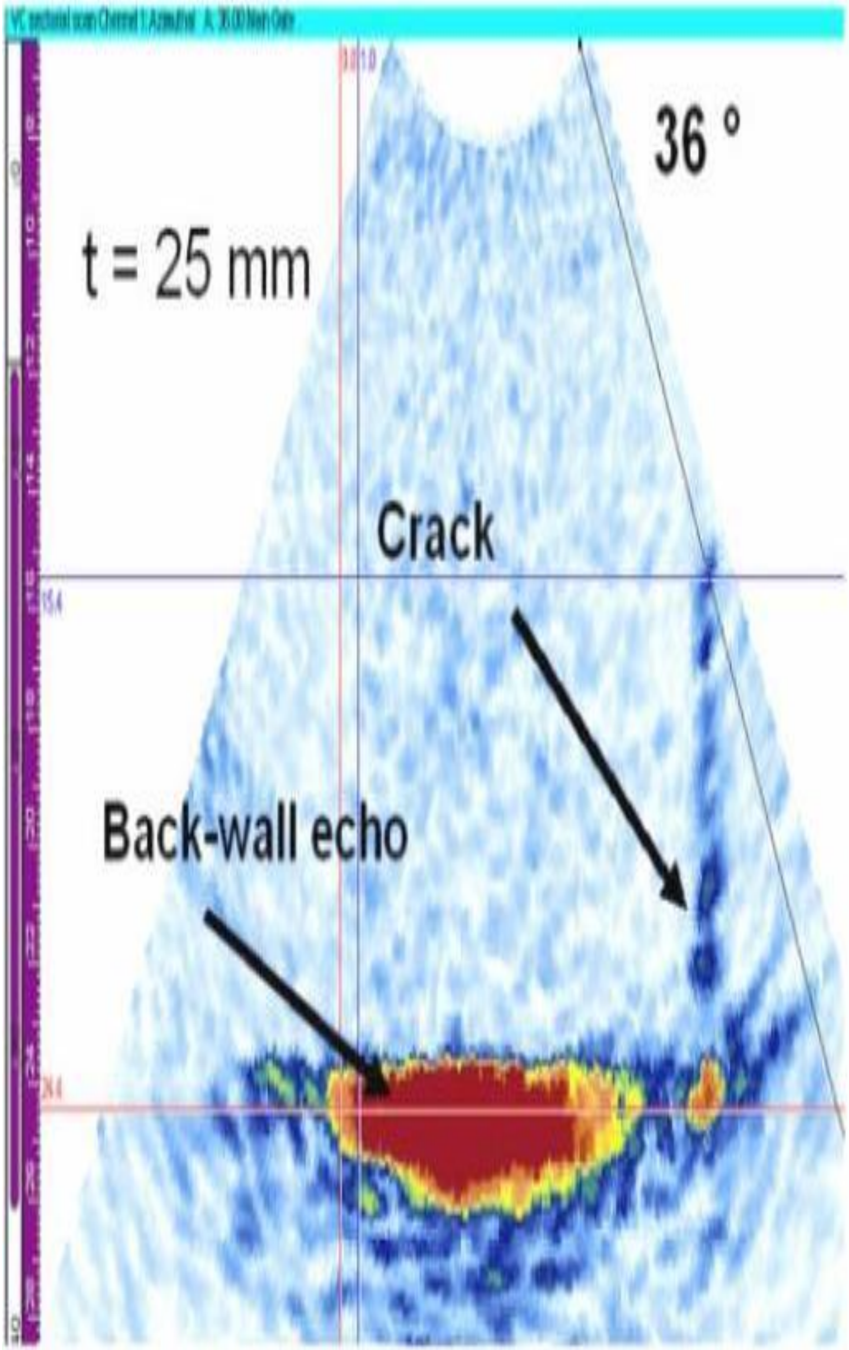
- A side view looking from the back side of the probe
- Represents data collected through the entire scan length for one A-Scan
- View changes dynamically as angle or VPA is scrolled



C-Scan View

- C-Scan is a plan view/top view
- View is generated based on gate positioning and mode (may be configured for gate A and B independently)
- Data can be presented in amplitude or position (thickness) formats



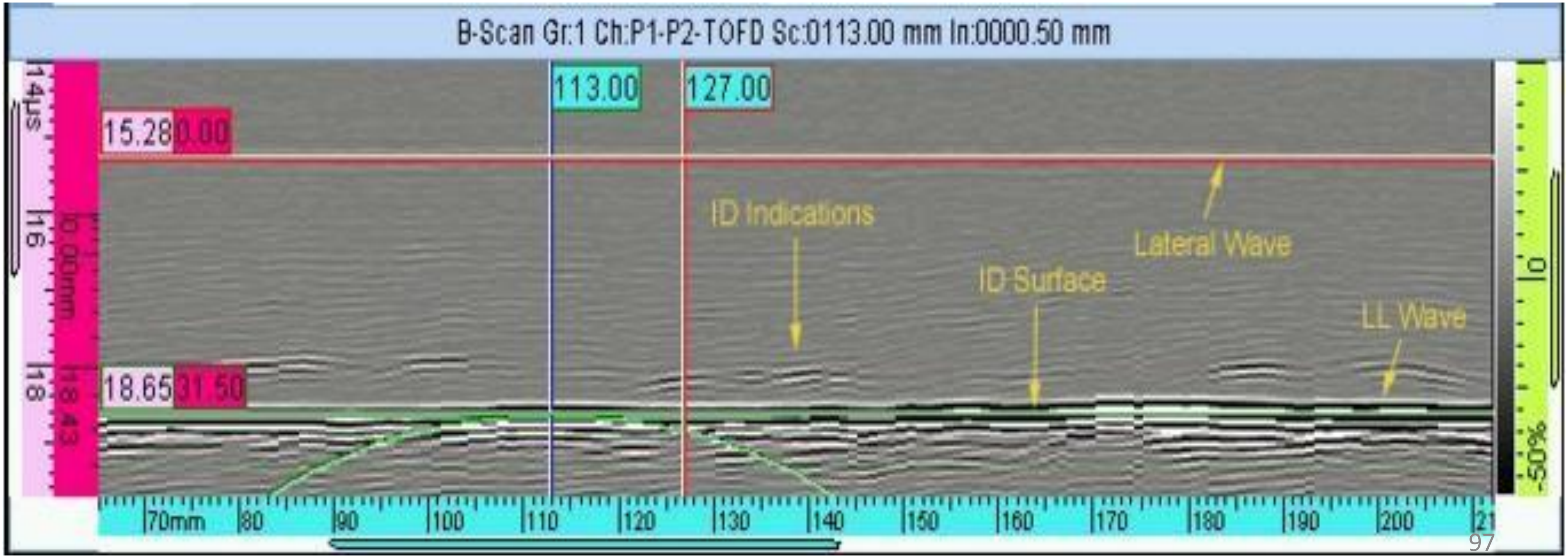


S-Scan View

- Presents all A-Scans within the group in an angular sector or sweep range
- A-Scans are converted to color coded lines representing amplitude
- May be corrected for delay and true depth relative to the ultrasonic axis as shown here

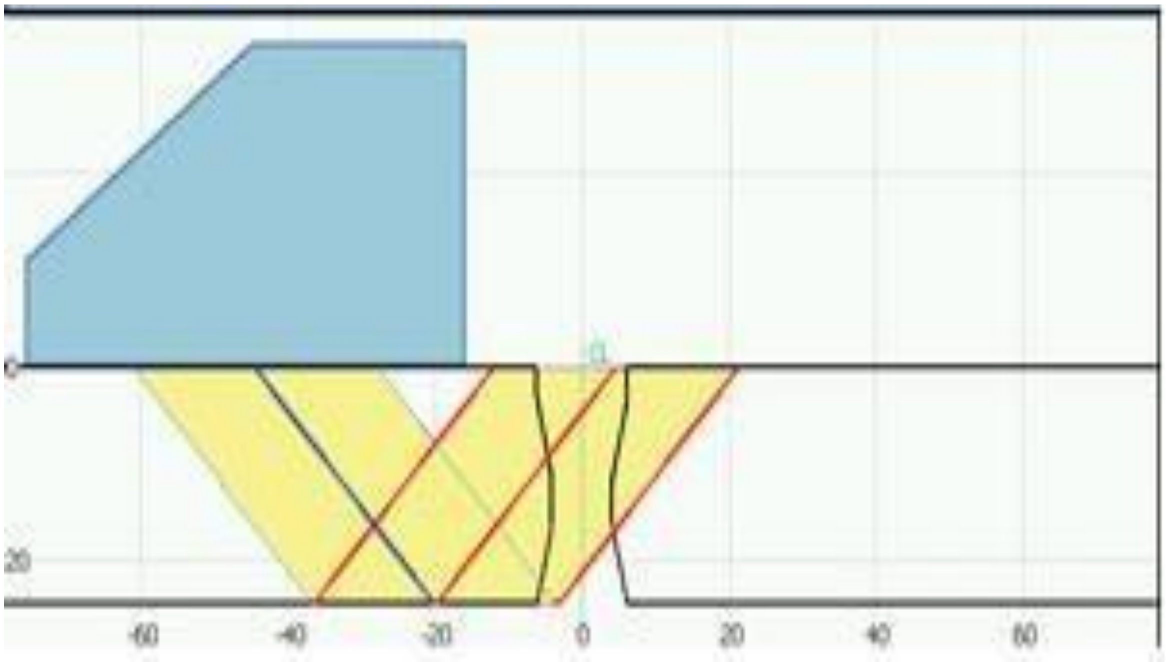
Time of Flight Diffraction (ToFD)

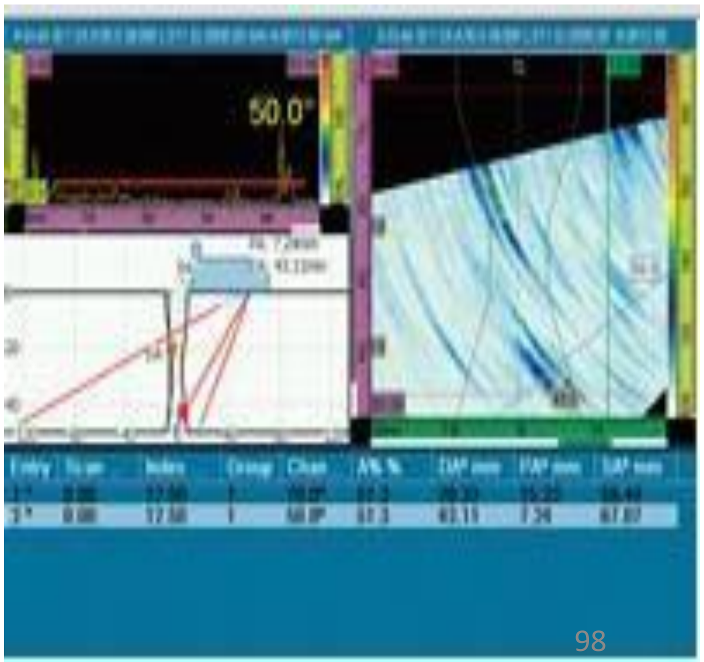
- The ToFD display offers a B-Scan representation of the diffracted signals detected in "pitch catch" conventional UT probes
- As with all other image views ToFD is built off individual A-Scans



Ray Tracing View

- Provides 2D representation of the weld, showing rebounds of the beam path and A gate position for the first, last and active focal law
- Should only be used as a reporting tool

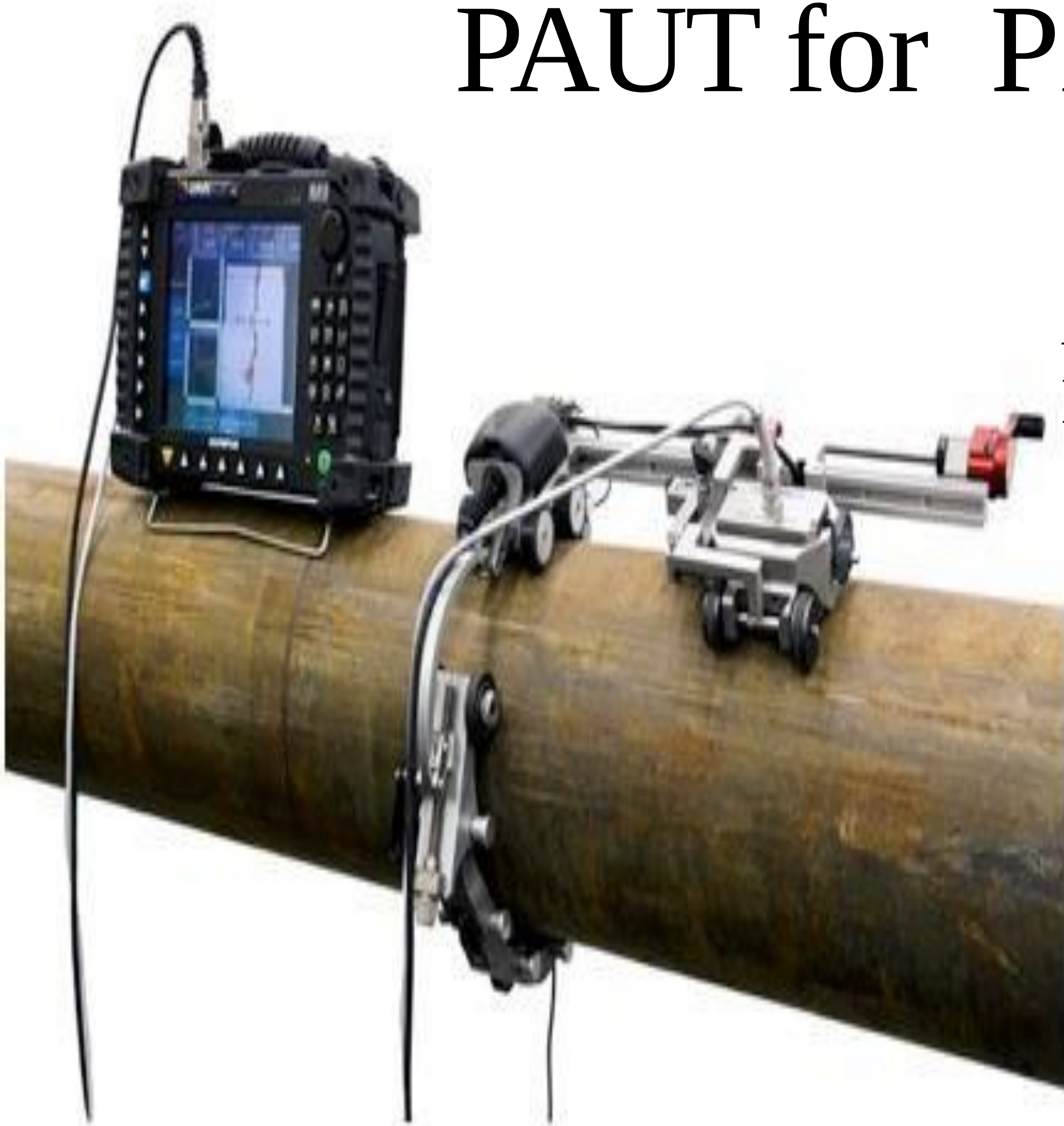




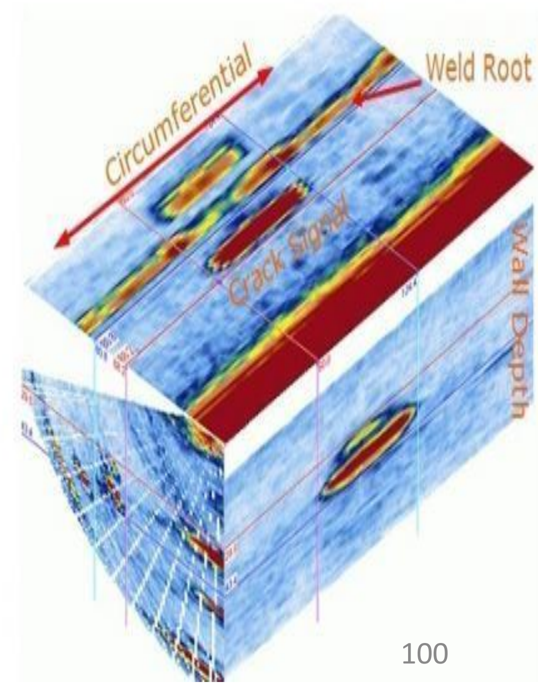
Master Thoughts

- It's still UT
  - Anything UT can do PAUT can do better
- Technology enabled
  - UT is not new, neither is PAUT
  - Computer assistance of proven technology
  - Advancements in transducer material/design
  - Medical use and capability perfected
    - Adapted for use in industrial sector
- Key elements
  - Multi-dimension sizing offers more accurate assessment of integrity
  - Weld images provided in multiple 2D orientations, giving 3D of views
  - Raises production while reducing costs

PAUT for Pipelines



API 1104 21st Edition



UNIT – V
Acoustic Emission Testing and Application

Acoustic Emission Testing

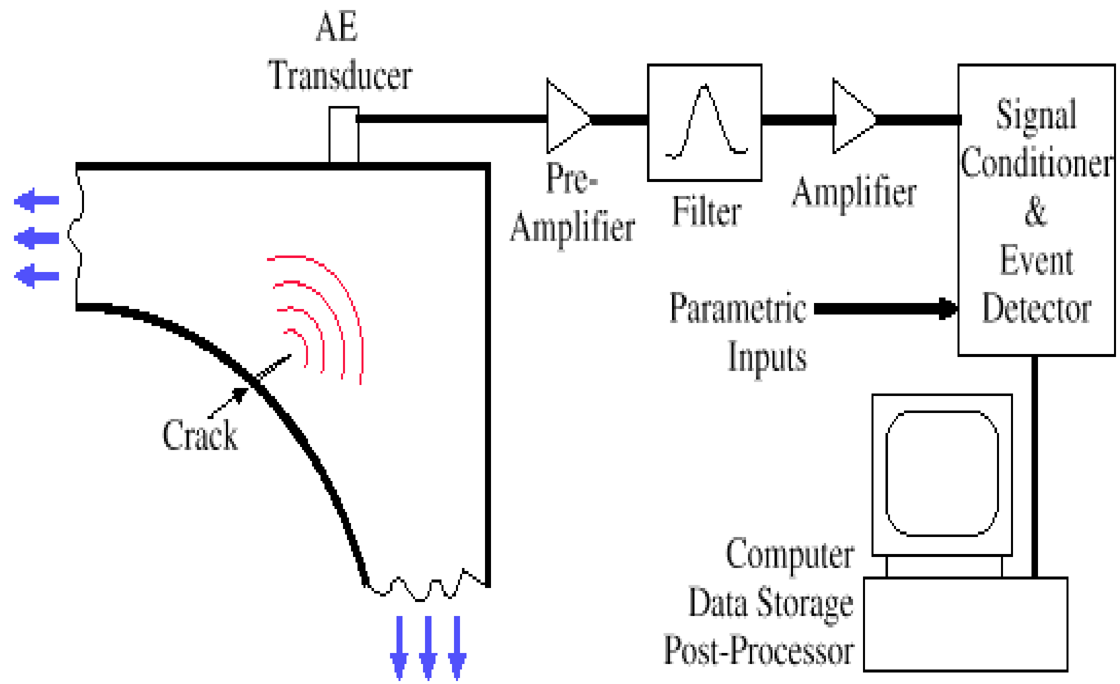
Loaded the structure and cracks are formed

↓

Oscillatory movement in atoms & molecules

↓

Generate elastic stress wave in the sample and come out



Sensor- Piezoelectric element

CONDITION FOR AE

- **Load-** No load (no cracks) no emission
  - Controlled load – Part of the structure has to be loaded by controlled load
  - Load bearing structure – loaded anyway
- **Inspect a big area/volume** – Very Big area inspection can be done in a single examination by placing a number of sensors at different location, where could be a potential source of damage

Sources of AE

- Stress field- stress wave propagate through the sample and received by the sensors

For example Metal

- Micro and macro crakes initiating and propagating
- Micro dynamical events such as twinning or slip
  - It happen due to lattice defect which known as dislocation
  - loaded the metallic system dislocation will move and due to that movement, it create slip
  - Slip is the movement of atomic planes over one another as results dislocation move which lead the AE

Sources of AE

- Fracture of brittle inclusions
- Chemical action like corrosion
- Phase Transformation due to change in volume

  and strain effect due to temperature change

AE source from phase transformation

Example **Martensite** in steel, at high temperature phase called **Austenite**

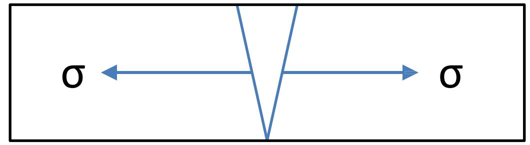
- When we heat it and quench it fast in liquid like water
- Two phase are very different kind of properties and structure
- Hence, the volume of parent phase and transformed phase are different and due to that some stresses can be generated which may lead to acoustic emission

Composite Materials

- Fiber fracture at medium strain level
- Delamination at high strain level
- Fiber pull out
- Matrix cracking and fibers debonding at low strain level
- Concrete
    - Micro and macro cracks
    - Separation of reinforcement members
    - Mechanical rubbing of separated surfaces

Parameter of AE

Type1- Loading



Relationship between stress and cracks size

$$6\,a^2\,V \geq 5 \times 10^4\, x\, h\ (watts)$$

σ = stress

a = radius of detectable AE cracks

V = radial velocity of cracks propagation

h = distance between the source and receiver

x = smallest displacement that the sensor can sense

σ a V are called the source parameter for an acoustic emission events

Stress change,

where,

$$\Delta\sigma(t) = [\, I + \Delta c D]^{-} \; [(c + \Delta c)\beta^{*} \; - \Delta c \beta^{o}]\, V(t)$$

I = n × n square matrix

c = stiffness tensor

c + Δc = stiffness tensor of product phase

Δc = change in the stiffness

β^{*} = unconstrained shape

β^{o} = pre – existing stress or residual stress

D = shape matrix

V = volume of transformed phase

If the stiffness $\Delta c \ll c$ and there is no residual strength that means $\beta^{o} = 0$

$$\Delta\sigma(t) = c\beta^{*} \; V(t)$$

- Change in stress will depend on shape change (transformation one material another material) , c is the constant which is the material property
- This parameter will control the intensity or the level of acoustic emission

Characteristics of AE signal

- Cover the wide range of energy levels which depend on types of sources and frequencies
- Two types of basic source
  - **Continuous emission-signals** coming from rapidly occurring source
  - **Burst type-** continuous emission source and suddenly burst
- Radiation pattern same as ultrasonic wave
- Radiate the energy in all direction, for a cracks of sufficient length it can become directional
- Frequency is generally broadband
- Received frequencies cover a wide range from available to 400 KHz or higher

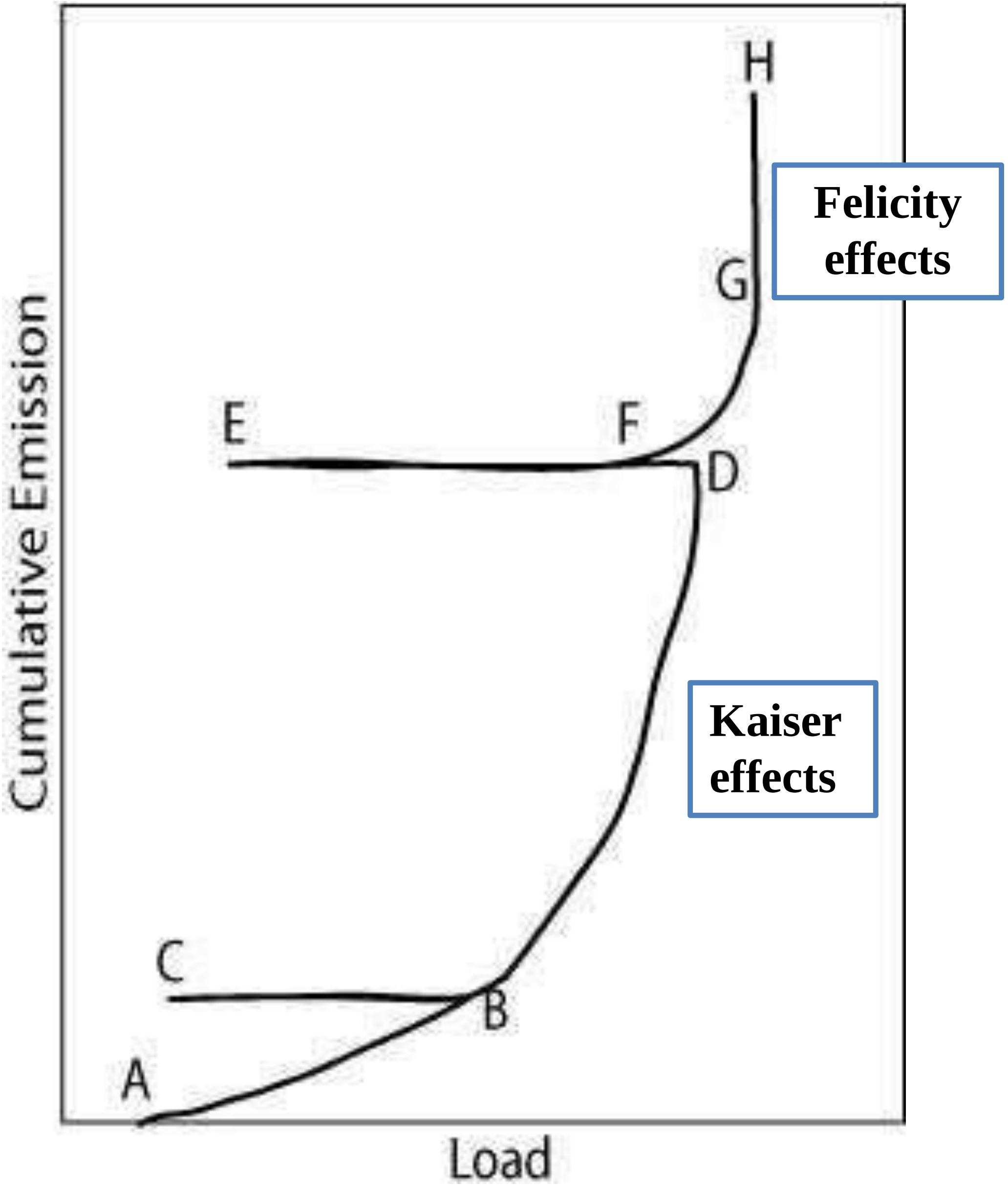
Kaiser and Felicity effects

It describe a relationship between AE events and the previous load history

- Kaiser describe AE events occurring when the structure first loaded to threshold, unloaded and loaded again
- It states no AE is generated until the previous maximum load is exceeded and the structure that inspecting is still sound
- Emission that occurs in the later loading below the previous maximum load is due to structural damage

Kaiser effects -No emission before the previous maximum load

Felicity effects – Emission before the previous maximum load



AB- loading
BC- unloading
CB – reloading
BD – loading
DE – unloading
ED – reloading

- F < D emission are occurring before the previous maximum load
- Steep rise in the emission
- GH - always happening with no increment in the load, this is known as **load hold**
- It is the particular value , load is not increasing but lot of emission coming out, which indicate some kind of damage

Felicity effects

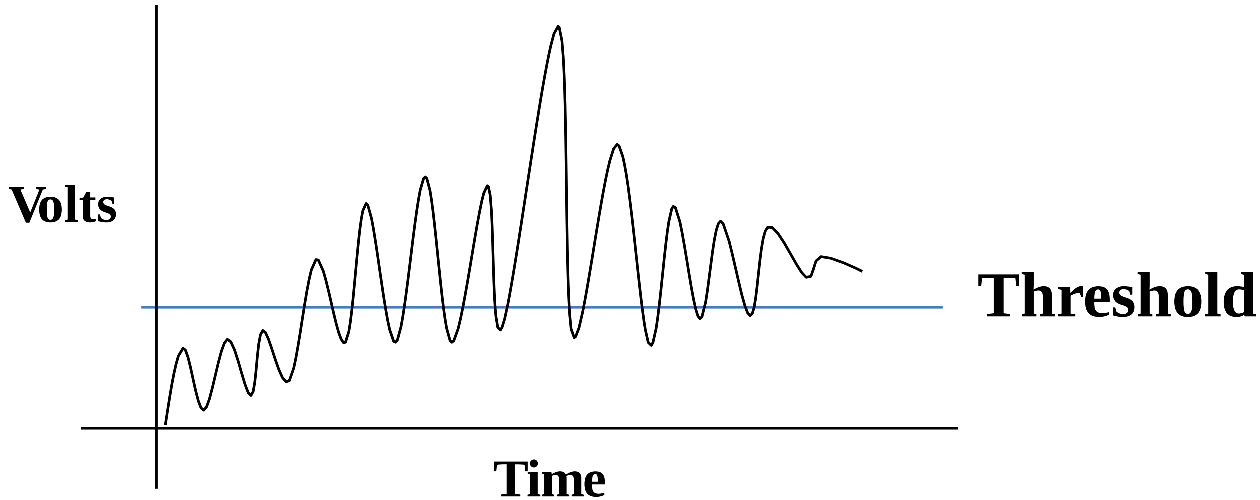
Emission before the previous maximum load

Felicity ratio, Fr= $\dfrac{P_e\,(existing\;load)}{P_m(previous\;maximum\;load)}$

Fr > 1 – there is no damage has occurred since the last inspection

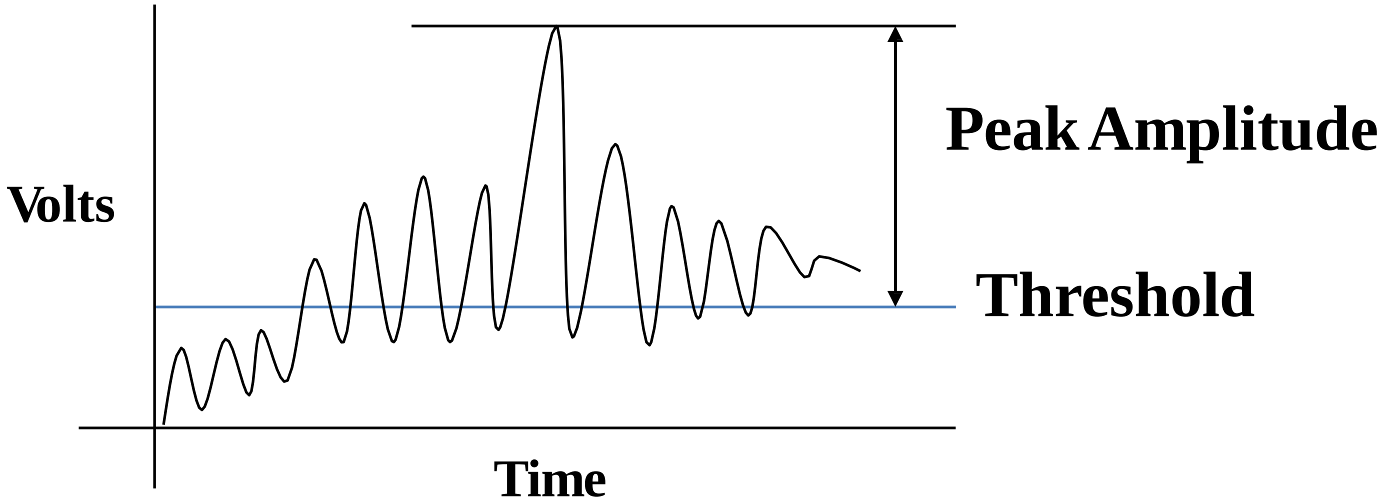
Fr < 1 – indicate of cumulative or permanent damage

Signal Parameter



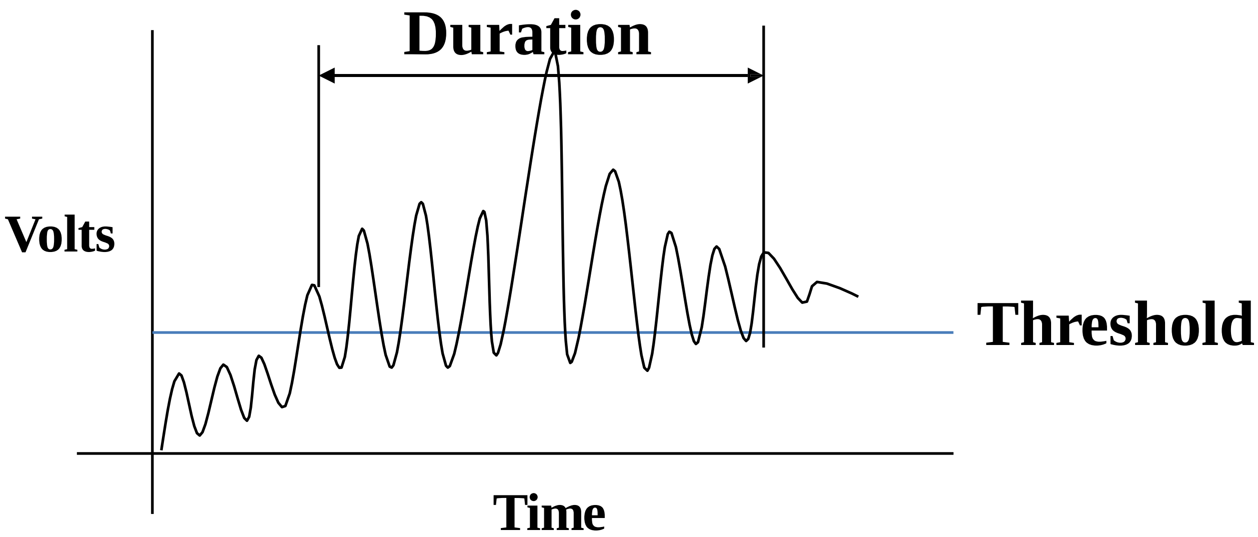
- Counts N- Number of expression above the threshold is considered as AE
- Below the threshold, it is considered as noise
- It is the function of the threshold and frequency
- It depends of the magnitude of the AE sources
- It also depend upon the properties of the sample and the sensor

Peak Amplitude



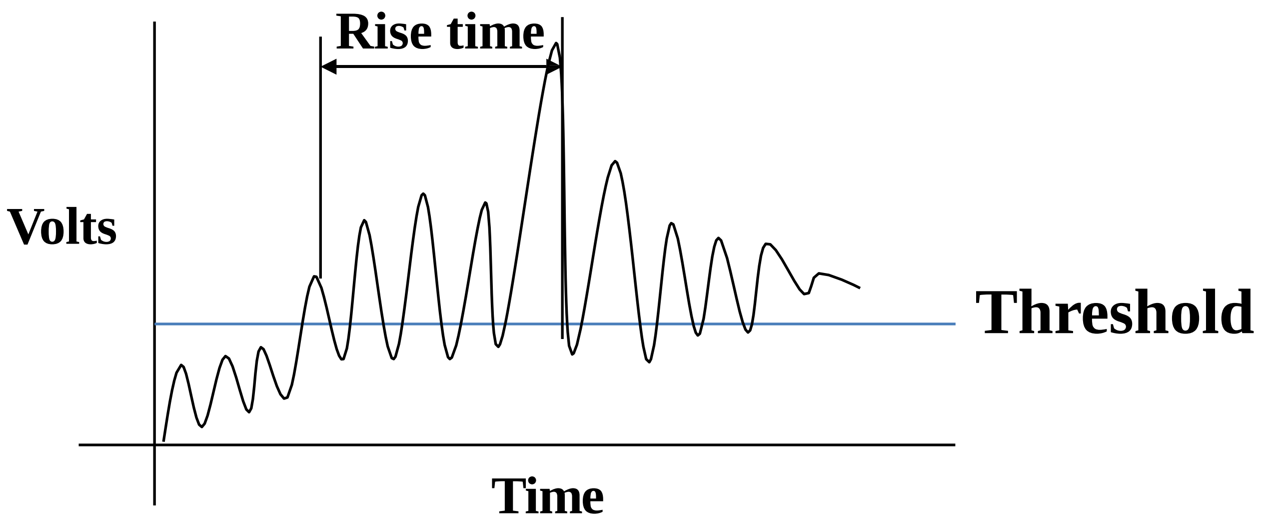
- Highest measured voltage or amplitude
- Express in dB
- Directly related to the energy in the AE signal

Duration (D)



- It will depends on the magnitude and frequency of the AE source
- Duration can be used to identify different types of emission source
- The noise which are coming out from the some other source, which are not related to the defect hence useful for filtering the noise

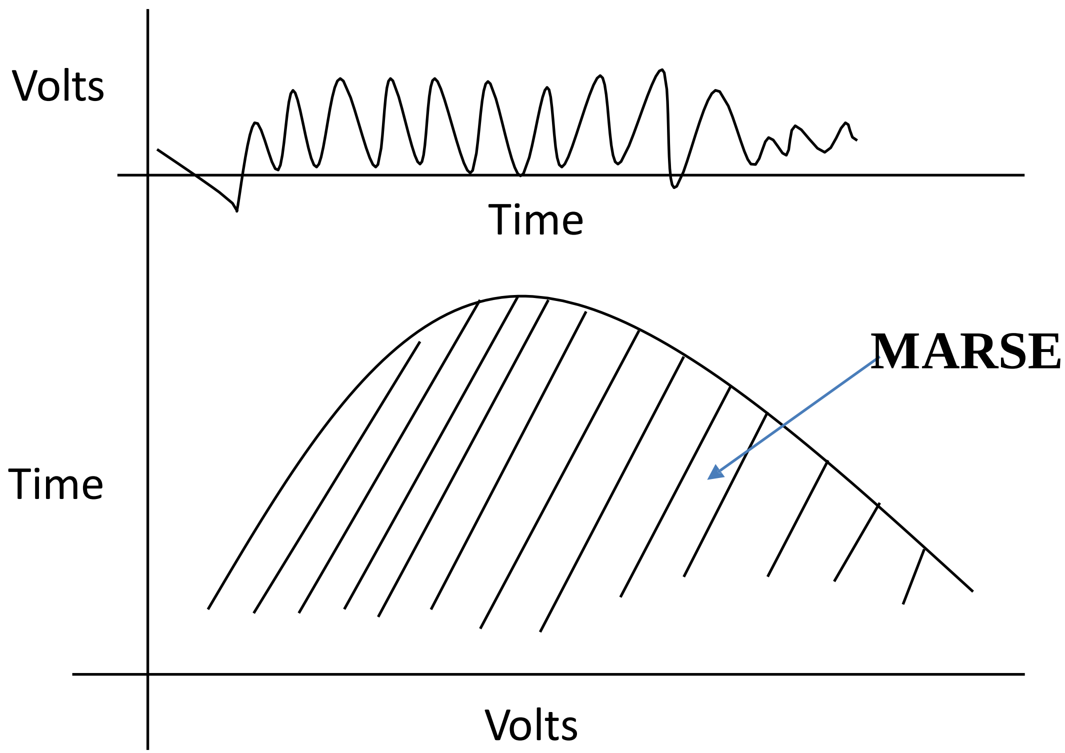
Rise Time (R)



- Time interval between first threshold crossing and the signal peak
- Related to the propagation of the wave between the source and the sensor

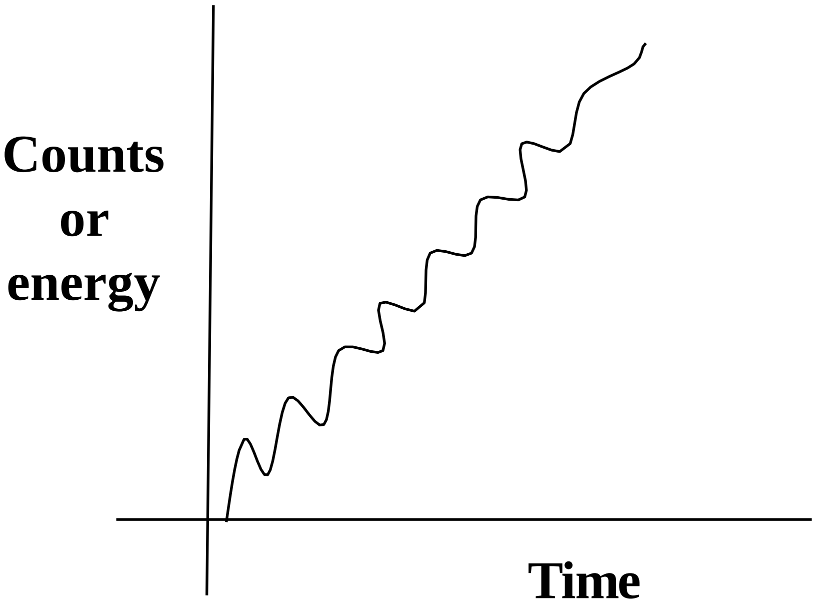
Measured Area Under The Rectifies Signal Envelope (MARSE)

- It used to qualify AE signal and filter out noise
- This the measure of the signal strength
- Sensitive to the duration and peak amplitude but does not take into account the user defined threshold and the operating frequency

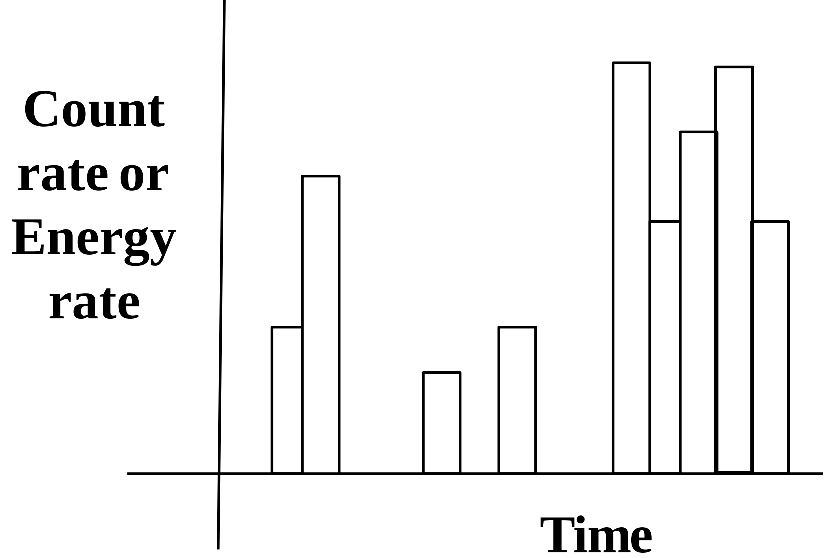


Data Display

Count or Energy v/s time



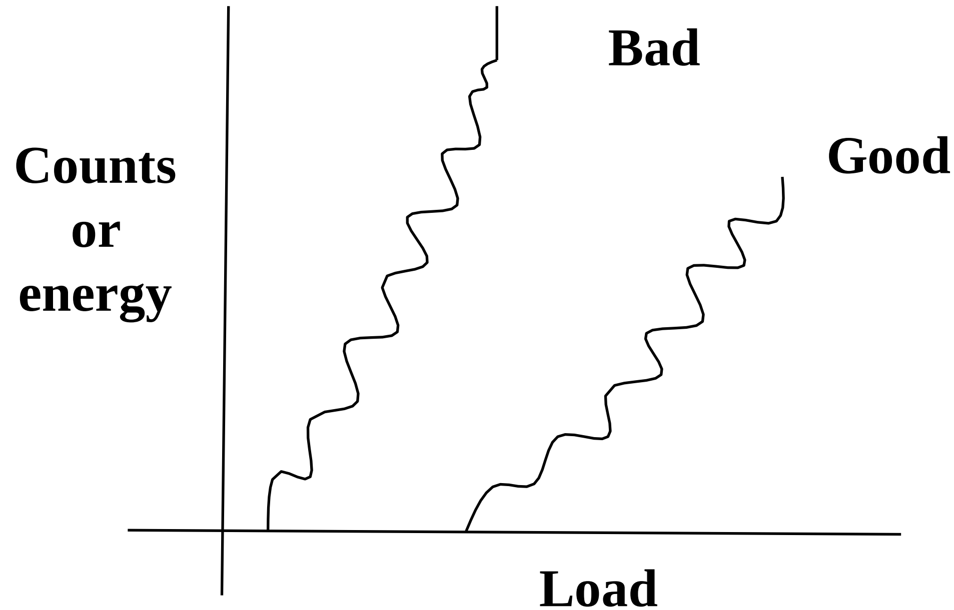
Count rate or Energy rate v/s time



- Hit signal – A Signal above the thresholds
- If signal above the thresholds, counts the signal
- Below thresholds counts as noise

- At particular instant, we know what is going inside the component
- At given time, how much acoustic emission or signals coming out at certain location

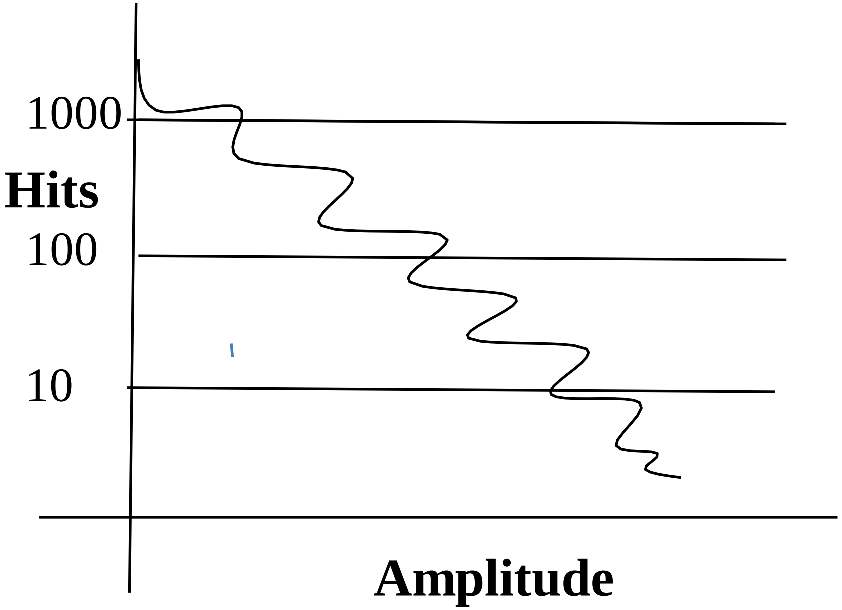
Counts or energy vs Load



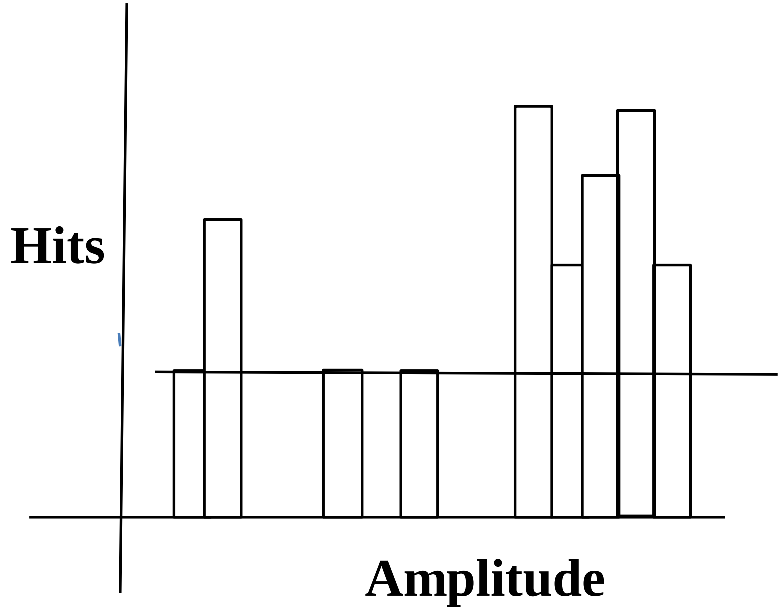
- By the figure we have to know that lot of emission happen or lower amount of emission happen
- **Very steep curve-** small amount of increase in load lead a lot of emission
- With increasing the load very high emission generate which would indicate bad structure
- **Gradual slop-** Gradual increase in load with respect to load which indicate that structure is good

Hit v/s Amplitude

Cumulative Plot



Differential Plot



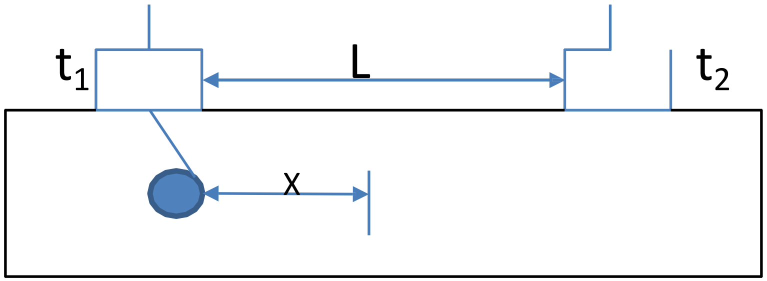
If we considered how many hits are above particular amplitude is known as **cumulative plot**

At given hit with particular amplitude is known as **Differential plot**

Source location

- This technique is primarily qualitative, it does not give quantitative information
- Location of source is very important to know about the zone from which these emission coming out
- Hence we provide some corrective measure around the particular area

Linear location scheme



If, $t_1 < t_2$

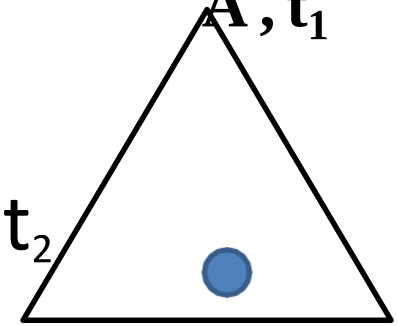
velocity of sound wave inside the sample V

X= V t

Difference t_1 and $t_2 = \Delta t$

$X = V * \Delta t$

Zonal location technique



$t_1 = t_2 = t_3$

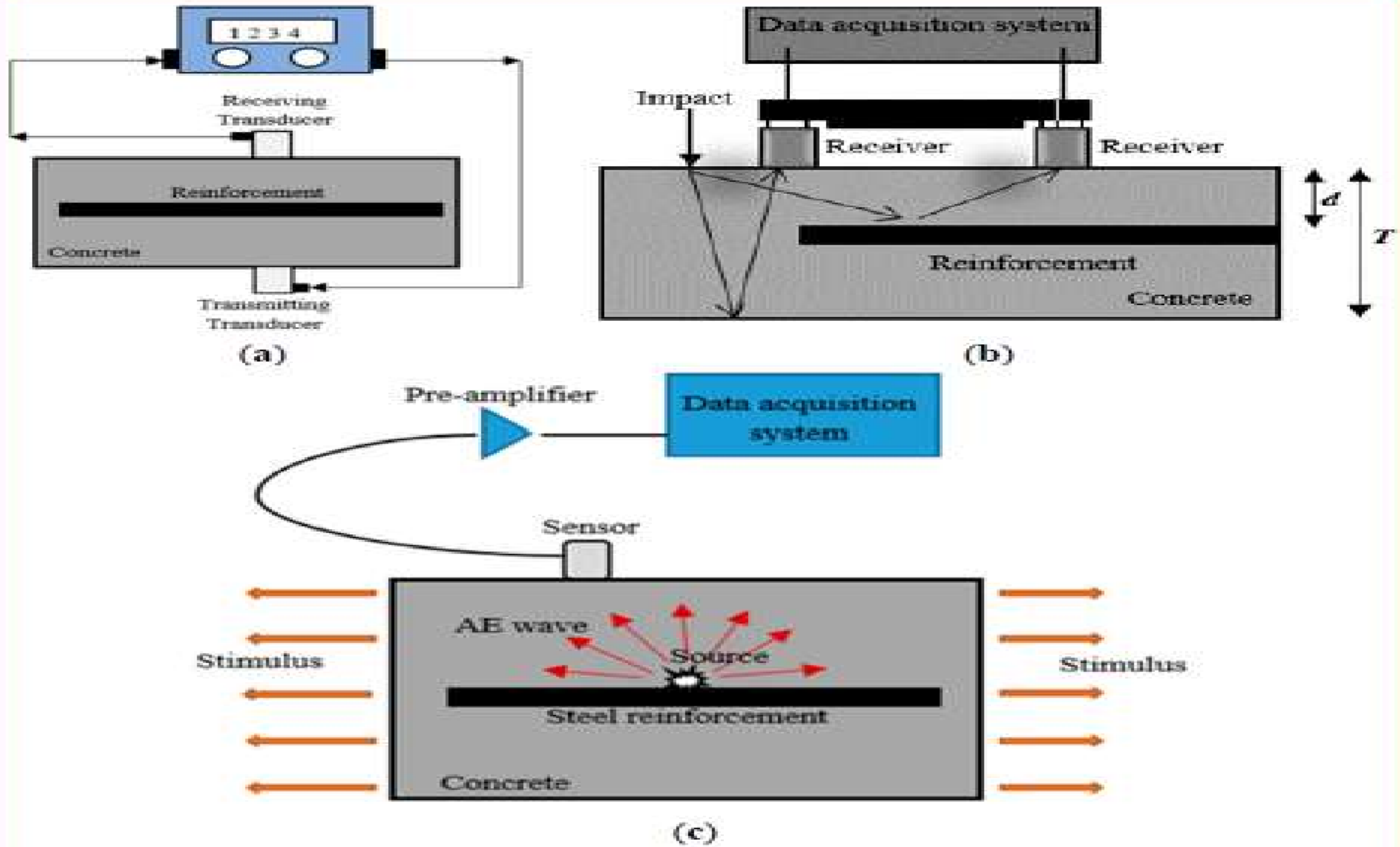
Source of emission at the center of the triangle

Because sensor receiving signal at the same time

$t_1 \neq t_2 \neq t_3$

- More than two sensor
- Placement of sensor is important- Potential source of AE
- Sensor should be placed in a pattern or geometric shaped
- Based on the possible source of location then, we target those area while inspecting and taking corrective measure

Elastic Wave Method – Principle



Source: Ref.5

Elastic Wave Method

NDT Method	Principle	Advantage	Disadvantage	Corrosion Evaluation	Specific Equipment
Ultrasonic pulse velocity (UPV)	Mechanical energy propagates through the concrete as stress waves and converted into electrical energy by a second transducers	A large penetration depth and it is easy to use for estimating the size, shape, and nature of concrete damage	The evaluation of UPV data is a highly specialized task, which requires careful data collection and expert analysis	Pulse velocity (V)	Transducers(transmitter and receiver), amplifier, and oscillator
Acoustic emission(AE)	Elastic wave are generated due to rapid release of energy from a localized source within an RC structure	A cost-effective and sensitive technique that can detect and locate the active cracks	Passive defects can not be effectively detected	AE parameter	Transducers, preamplifier, filter amplifier, and storage equipment , mechanical impactors

Elastic Wave Method

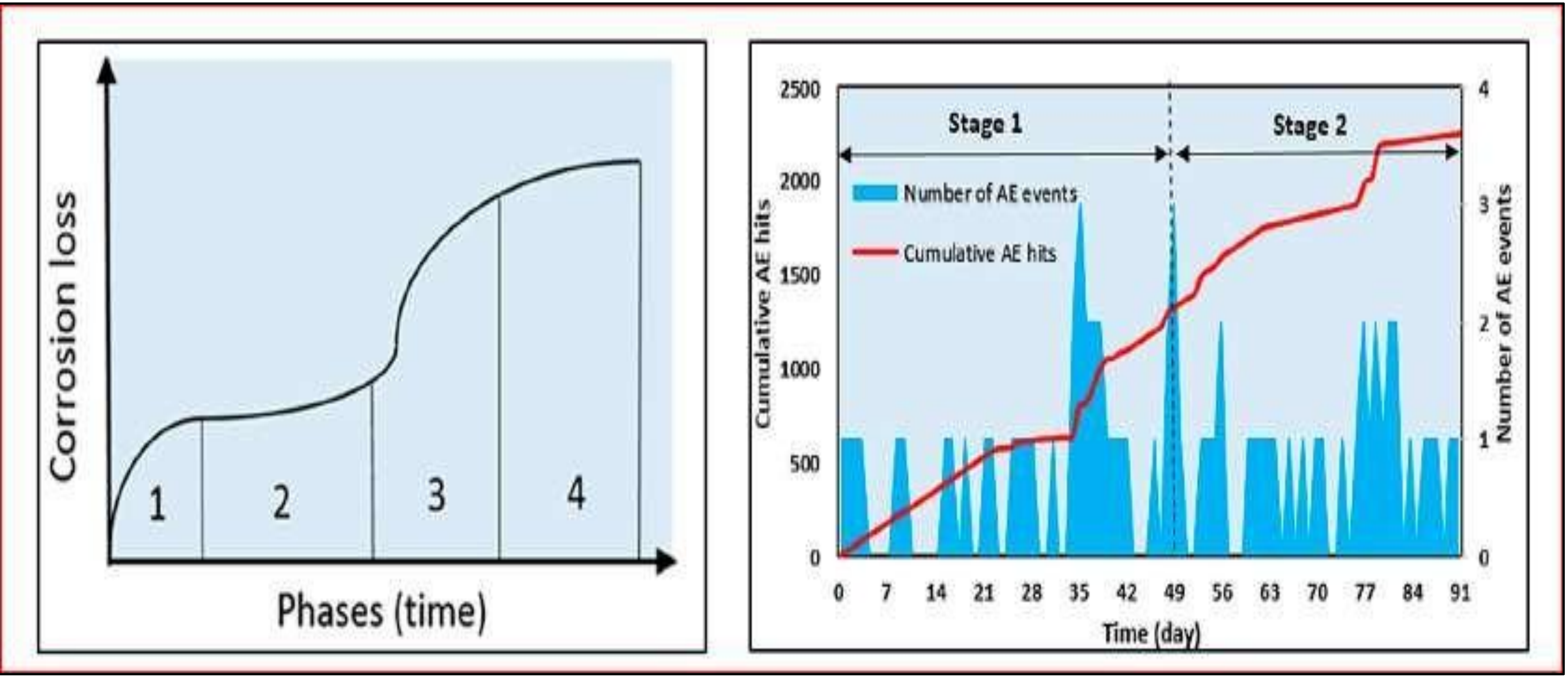
NDT Method	Principle	Advantage	Disadvantage	Corrosion Evaluation	Specific Equipment
Impact echo (IE)	Stress wave are propagated within the RC structure through vibrations and impact load	A simple fast reliable method for inspecting the concrete is to impact the surface with a hammer and listen to the result	The reliability of IE method decrease with an increase in thickness	Wave Velocity (Vp)	Highly-friendly receiver and data acquisition

Hits-Detection of an AE signal

- In the below figure AE activity observed corresponds to the corrosion loss of steel reinforcement in a marine environment (Melcher and Li)

Phase 1- Onset of corrosion is initiated and the phase is dominated by the presence of oxygen and water
Phase 2- Corrosion loss decrease and stabilize
Phase 3 – corrosion penetrates inside
Phase 4 – expansion of corrosion products occurs due to anaerobic corrosion

- Based on the above phase corrosion activity are characterized **Onset of corrosion** and the growth of **corrosion products (nucleation of cracks)**
- On the basis of above phase AE technique could detect the corrosion at an early stage



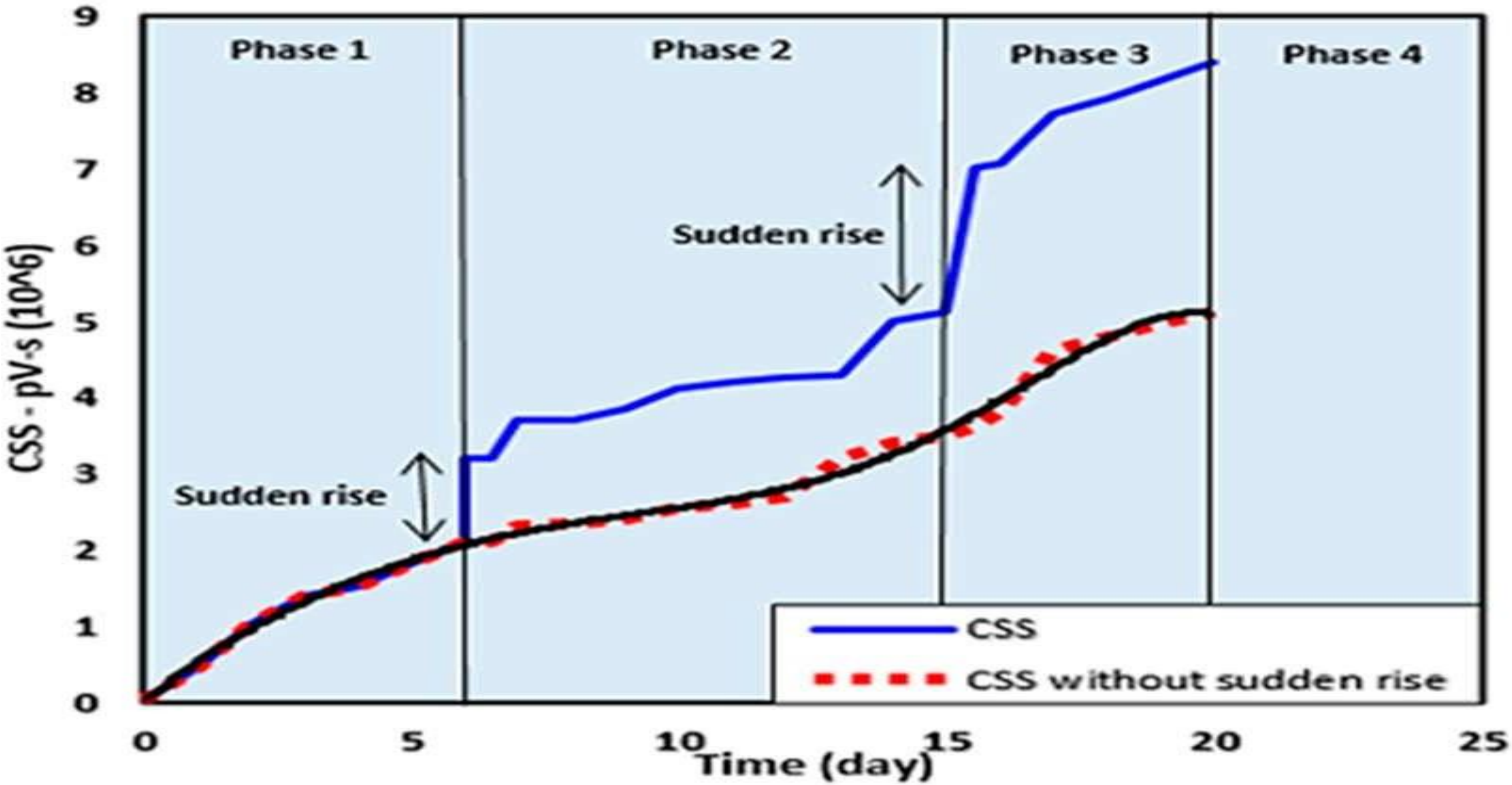
Corrosion loss of steel reinforcement due to chloride immersion and cumulative AE hits and number of AE events during corrosion test
Source- Ref.5

- AE hits to be one of the AE parameters used to study the onset of corrosion and the nucleation of cracks in RC structure
- It observed that AE hits increased with an increase in the degree of corrosion

Signal strength (SS) and Cumulative Signal Strength (CSS)

- **Signal strength (SS)** is one of the AE parameter, it is defined as the area under the voltage signal of AE over the duration of the waveforms.
- Since it provides a measure of the waveform energy released by the specimen, it is rational damage indicator **(Velez et al.)**
- The SS of **prestressed specimen** is attributed to the nucleation of cracks caused by the accumulation of corrosion products at the steel concrete interface
- The SS **non prestressed** specimen it could be indicator of early cracks formation due to corrosion

- **The CSS** exhibits a clear rate change before the onset of corrosion according to electrochemical method, which suggest that the AE technique could detect the onset of corrosion
- The CSS rate increase slowly in Phase 1 indicating de-passivation of the layer surrounding the steel reinforcement and the onset of steel corrosion
    - The presence of **sudden rise** at the end of phase 1 might indicate crack initiation due to steel corrosion
- The rise of Phase 2 indicates corrosion activity
    - The **sudden rise** at the end of phase 2 indicate cracks propagation leading to macro- crack.
- If the sudden rise excluded from the CSS curve, dotted line will be obtained and it is the agreement with conventional curve

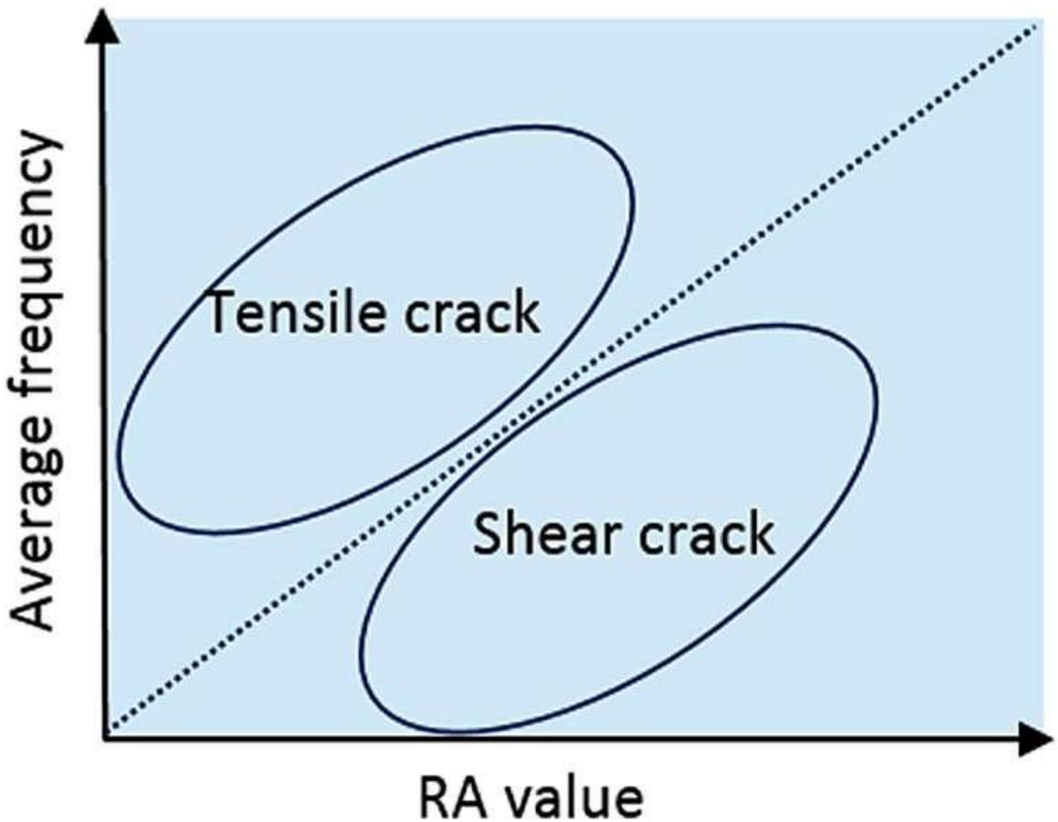


The variation in the CSS parameter
Source- Ref.5

- AE detects the sudden release of micro-fractures in the RC structure. Increasing the steel diameter due to corrosion is found to increase the absolute energy of AE **(Ing et al.)**

Rise amplitude (RA) and Average Frequency

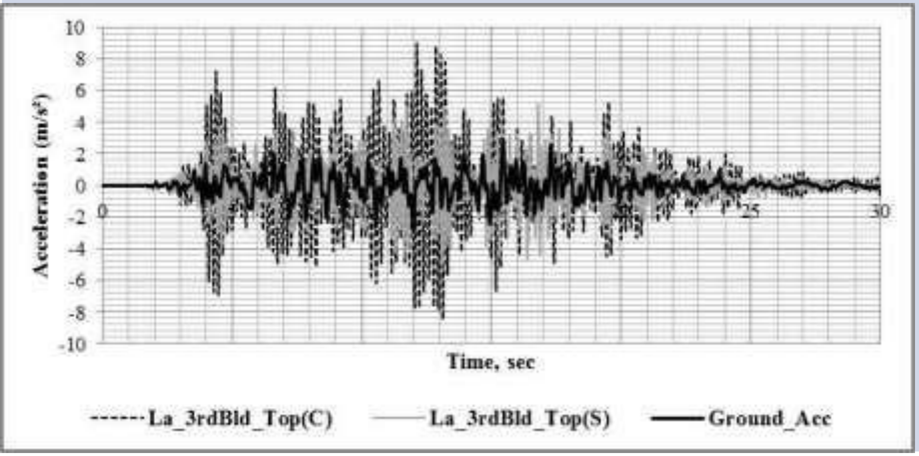
- RA value = Rise Time/Amplitude
- Average Frequency = Counts/Duration

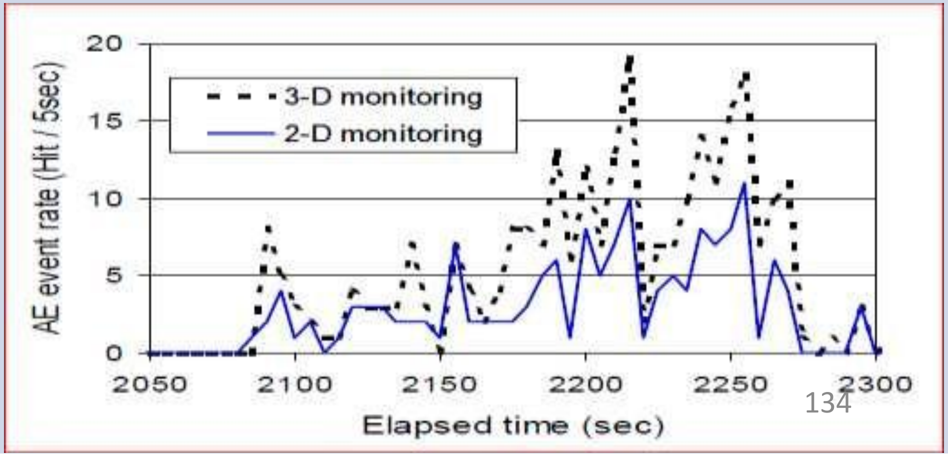


Classification of cracks by AE indexes
Source- Ref.5

- Tensile type cracks – When AE signal with high average frequency and low RA value
- Shear type cracks – low average frequency and high RA value

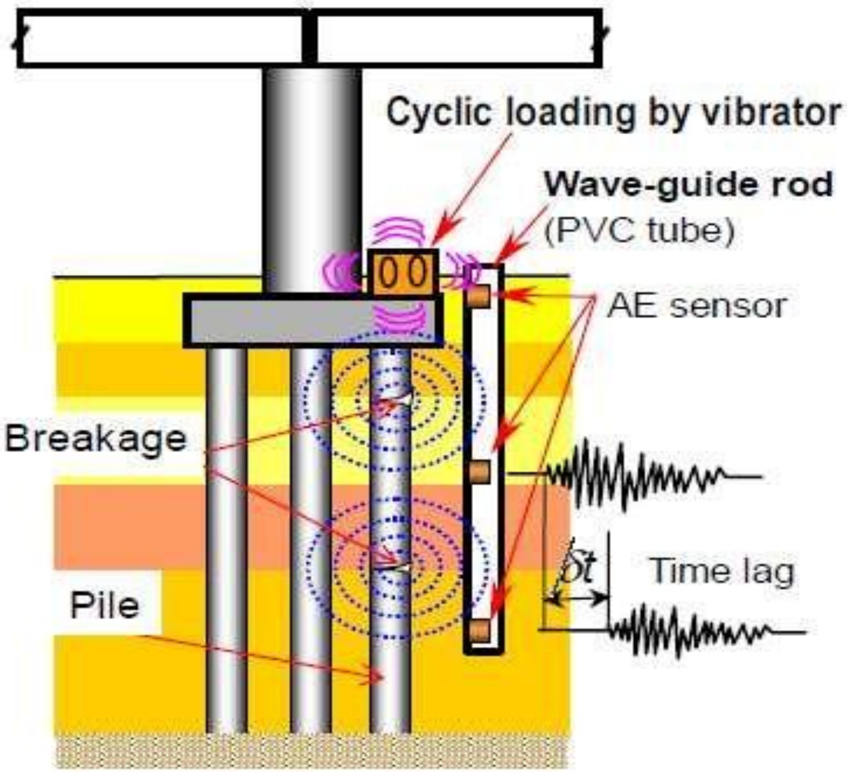
Earthquake	AE
Principle	
Vibration of the earth produced by the rapid release energy	Measured the intensity (energy released) of the source
Parameter	
Shocks, epicenter, origin, time, depth, magnitude and intensity	Threshold, peak amplitude, rise time , duration, measure area under the rectifies signal envelope
Instrument	
Seismograph, Richer scale, Mercalli scale	Piezoelectric sensor



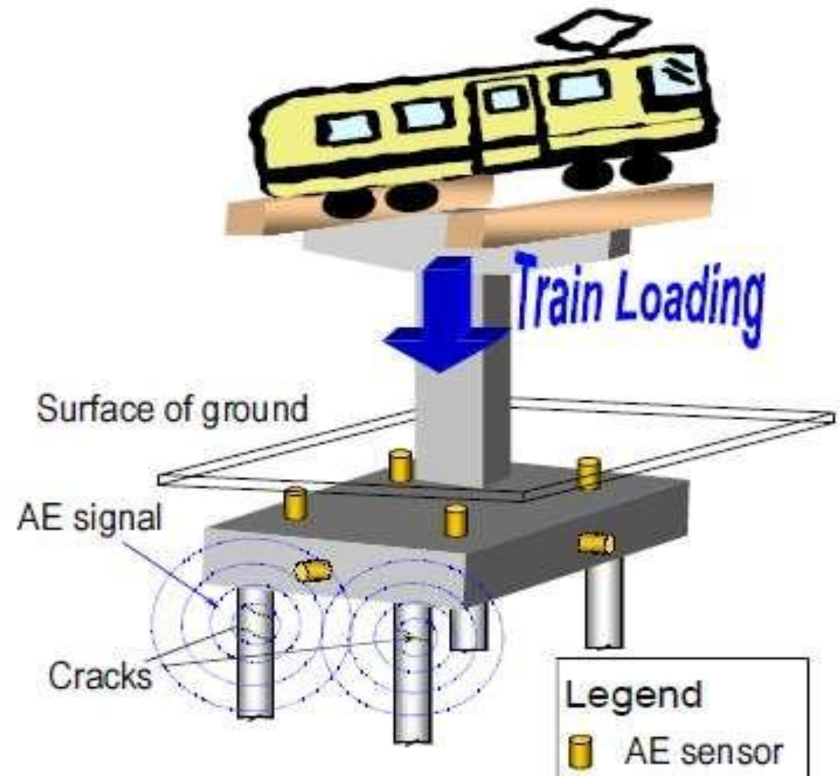


DIFFERENCE BETWEEN CONVENTIONAL AND PROPOSED AE METHODOLOGY

AE method, the same principle can be applied to determine the scaling of the amplitude distribution of the AE waves during the fracture process

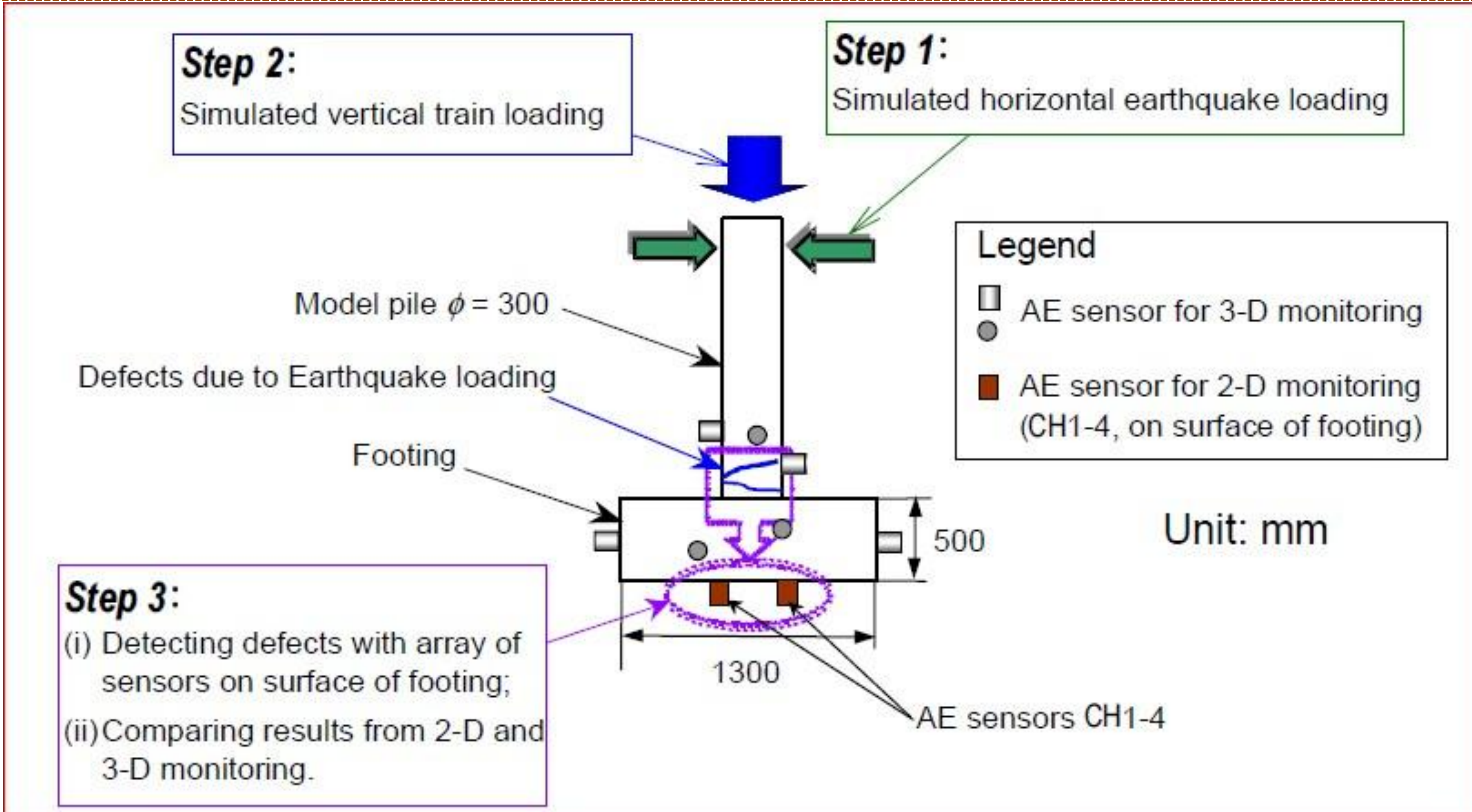


Conventional AE technique for seismic diagnosis of piles



AE technique proposed for seismic diagnosis of railway structures

Schematic illustration of procedure for AE experiment in an inverted model pile



Source- Xiu Luo at al. STUDY ON SECONDARY AE TECHNIQUE FOR SEISMIC DIAGNOSIS OF RAILWAY SUBSTRUCTURES. 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada

A set-up for secondary AE monitoring under simulated train Lloading