Rohini College of Engineering and Technology
(Autonomous)

DEPARTMENT OF MECHANICAL ENGINEERING

OML351
INTRODUCTION TO NON-DESTRUCTIVE TESTING

UNIT V RADIOGRAPHY TESTING

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.

INTRODUCTION

Radiography testing is one of the most important, versatile and widely accepted of all the non-destructive examination methods.

In radiography testing, X-ray or gamma ray is used to determine the internal soundness of the metal, hence it is also called as X-ray or gamma ray testing.

Principle:

The principle involved in radiography is difference in density; the metal surrounding the defect is denser and hence shows up as lighter than the flaws on an X-ray film.

The principle of radiography is similar to the way bones and teeth show up lighter than the rest of the body in X-ray films. Radiography inspection employs the same principles and techniques as those of medical X-rays.

Definition of X-Rays

X-rays are electromagnetic waves of high energy and very short wavelength, which are able to pass through many materials opaque to light.

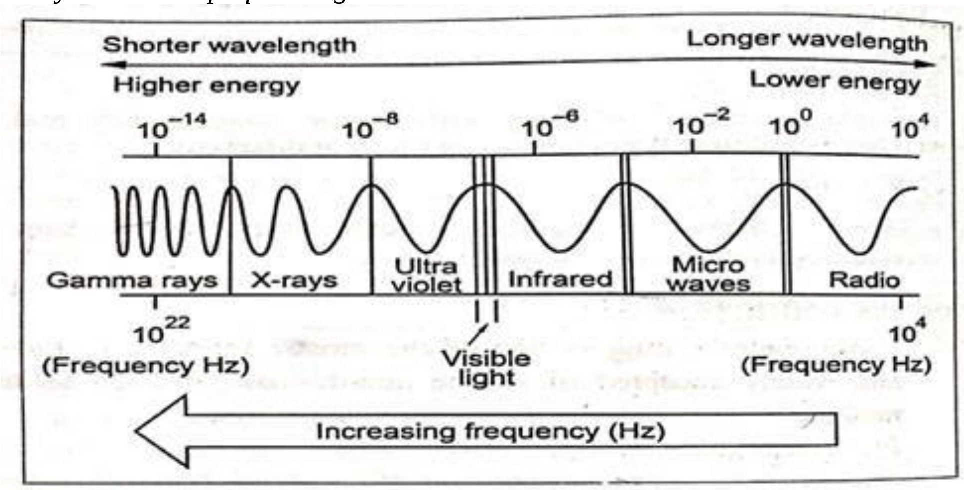


Figure ***Types and wavelengths of electromagnetic radiation***

In radiographic testing, the radiation source can either be X- ray tube or radiation from radioactive elements (Iridium, Ir-192 and Cobalt, Co-60) emitting ɤ-rays. Whether the radiation is emitted from an X-ray tube or gamma ray source, there are essential components that apply to the process of radiographic testing.

The components of radiographic testing are:

1. The source of radiation (X-ray or gamma ray).
2. The test specimen to be examined.
3. Development of the technique.
4. Taking radiograph and processing the film.
5. Interpretation of the radiographic image.

Characteristics of X-Rays and Gamma Rays

Some of the main characteristic of X-rays and gamma rays are given below.

(i) They are invisible.
(ii) They cannot be felt by human senses.
(ii) They can produce fluorescence in certain materials.
(iv) They travel at the speed of the light i.e. 3x1010 cm/sec.
(v) They can penetrate matter, the depth of penetration being dependent on the wave length.

(vi) They can be absorbed by matter.

(vii) They obey the inverse square law. Inverse square law states that intensity of X-rays at a point (I) is inversely proportional to the square of the distance between the source and the point (r^2)

(viii) They affect photographic emulsion.

(ix) They are harmful to living cells.

(x) While passing through a material they are either absorbed or scattered.

PRINCIPLE OF RADIOGRAPHY TESTING

Radiography testing is a method of inspecting materials for hidden flaws/detects by using the ability of short wavelength electromagnetic radiation to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is captured by radiation sensitive film.

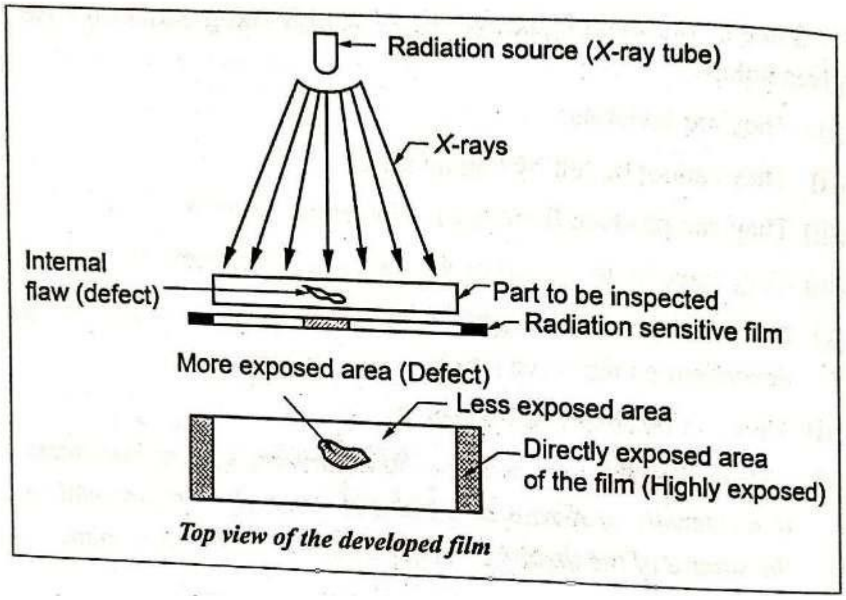


Figure. Principle of radiography testing

In radiography testing, the parts to be inspected are placed between the radiation source (X-ray or gamma ray tube) and a radiation sensitive film, as shown in Figure. The part of inspection will stop some of the radiation where thicker and more dense areas. The radiation that passes through the defective area causes more exposure on the radiation sensitive film resulted in different exposure and shown in the form of shadow graph on the developed film

The film darkness will vary with the amount of radiation reaching the film through the test object where darker areas indicate more exposure (higher radiation intensity) and lighter areas indicate less exposure (lower radiation intensity). This variation in the image darkness would be used to reveal the presence of any flaws or discontinuity inside the materials.

General Procedure for Radiography Testing

Radiography testing is one of the most widely used NDT methods for the detection of internal defects such as porosity and voids The various stages and procedure followed in basic radiography testing of components are as follows:

(i) The test specimen is cleaned and inspected for surface imperfections and placed between X-ray source and properly selected film,

(ii) Image quality indicators and lead identification letters are placed on the source side of the specimen.

(iii) The energy of radiations are determined with the help of exposure charts.

(iv) Exposure is made on the test specimen.

(v) The film cassette is removed and taken to dark room for processing

(vi) The development of the film make the hidden image visible.

(vii) The film is dried after washing.

(viii) Finally the film is interpreted for defects and a report is compiled.

(ix) The report is signed by responsible persons and properly filed for future reference.

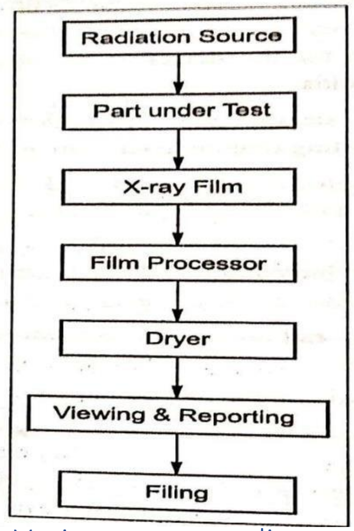


Figure. Various stages radiography testing

EQUIPMENT OF RADIOGRAPHY TESTING

The major components of an X-ray generator are;

1. X-ray tube
2. Focusing Cup
3. Cooling Systems
4. Filters
5. Control Console

1. X-ray tube

X-rays are produced in a vacuum tube when high speed electrons, which are negatively charged, are attracted by a positive potential in the anode and collide with a target material, as shown in Figure.

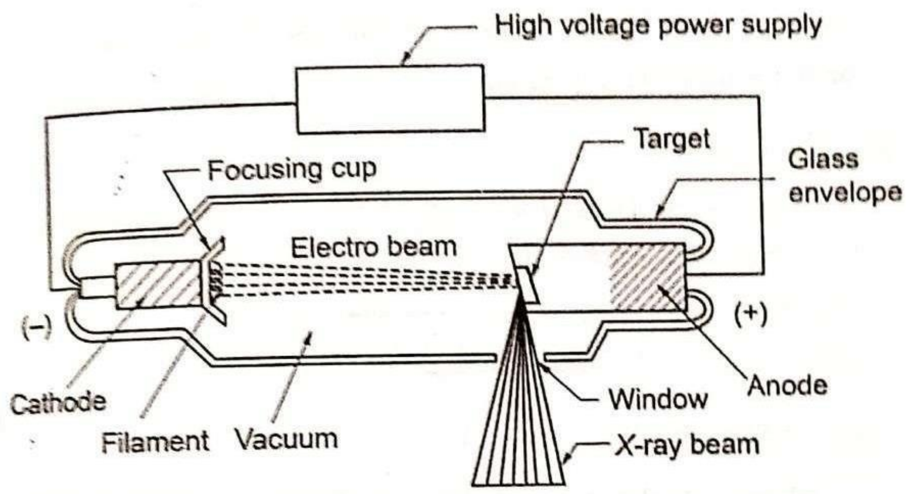


Figure. Schematic arrangement of X-ray tube

The electrons are produced when a filament, usually tungsten, is heated to incandescence. The resulting electrons that break free of the cathode are strongly attracted to the anode target materials. Then the electrons are slowed or stopped by the interaction with the atomic particles of the target, .I-radiation is produced.

Energies of the electrons and X-rays are usually given in kilo electron volts (keV) or million electron volts (MeV). The unit kilo-electron volt corresponds to the amount of kinetic energy that an electron would gain when moving between two points that differ in voltage by 1 kV.

The high voltage between the cathode and the anode affects the speed at which the electrons travel and strike the anode. The higher kilo voltage, the more speed and therefore, energy the electrons have when they strike the anode. Electrons striking with more energy result in X-rays with more penetrating power.

2. Focusing Cup

A focusing cup is used to concentrate the stream of electrons to a small area of the target called the focal spot.

The focal spot size is an important factor in the system's ability to produce a sharp image.

3. Cooling Systems

Much of the energy applied to the tube is transformed into heat at the focal spot of the anode. Though the anode target is commonly made from tungsten, which has high melting point, cooling of the anode by an active or passive means is necessary

Water or oil re-circulating systems are often used to cool tubes.

Some low power tubes are cooled simply with the use of thermally conductive materials and heat radiating fins.

4. Filters

X-ray generators usually have a filter along the beam path, placed nearer to the X-ray port. Filters consists of a thin sheet of material usually made up of lead, copper or brass placed in the useful beam to modify the spatial distribution of the beam.

Filtration is required to absorb the lower energy X-ray photons emitted by the tube before they reach the material to be inspected in order to produce a cleaner image.

Advantages of using filters are:

(i) Increased contrast around the specimen edge.
(ii) Reduced undercut scatter at the edge of thinner sections,
(iii) Record wide range of specimen thickness.
(iv) Radiograph of parts with complicated geometry.

5. Control Console

One of the important components of an X-ray generating system is control console. The three main adjustable controls in control console are:

1. Control to regulate the tube voltage (in kilovolts);
2. The tube amperage (in milliamps); and
3. The exposure time (in minutes or seconds).

Few systems are provided with keyed lock to prevent unauthorized usage of the system and switch to change the focal spot size of the tube.

Advantages of X-Ray Radiography Testing

Some of the advantages of X-ray radiography testing are as follows:

(i) Wide variety of materials can be inspected.
(11) Ability to inspect assembled components.
(ii) Surface preparation required is minimum.
(iv) Sensitivity to changes in thickness, corrosion, voids and cracks.
(V) Both surface and sub-surface defects can be detected.
(vi) Permanent record of inspection is possible.

Limitations of X-Ray Radiography Testing

Some of the limitations of X-ray radiography testing are as follows:

(i) Access to both sides of the specimen is essential.
(ü) Orientation of the sample is critical to assess the defects.
(ii) Determination of flaw depth is impossible without additional angled exposures.
(iv) Special operator training is required.
(v) Additional safety measures are essential to prevent radiation hazard for personnel.

Applications of X-Ray Radiography Testing

Some of the applications of X-ray radiography testing are as follows:

(i) Detect internal discontinuities such as shrinkage, cracking and porosity in castings.
(i) Verify the integrity of internal components.
(iii) Determine the quality of welded sections and pipes.
(iv) Identify the extent of corrosion.
(v) Inspection of variety of non-metallic parts.
(vi) Locating discontinuities in fabricated structural assemblies.

GAMMA RAY RADIOGRAPHIC TESTING

Gamma rays are electro-magnetic radiation emitted from an unstable nucleus. Isotopes with unstable nucleus will emit radiation with sufficient intensity required for inspection of materials.

Gamma rays are similar to X-rays, except that they are emitted by the nucleus of the atom. Gamma rays consist of discrete wavelengths much shorter than X-rays. Energy levels of gamma ray remain constant for a particular isotope but the intensity diminishes with time indicated by the half-life.

Gamma Ray Source

Wide variety of radio isotopes is available to produce gamma rays, but only few selected isotopes are used for the purpose of radiography.

Due to shorter half-life, many of the isotopes are found unsuitable for radiography testing.

Gamma Ray Testing Arrangement

Gamma ray equipment consists of an isotopic source (cobalt 60 or iridium 192) and a container for positioning the source.

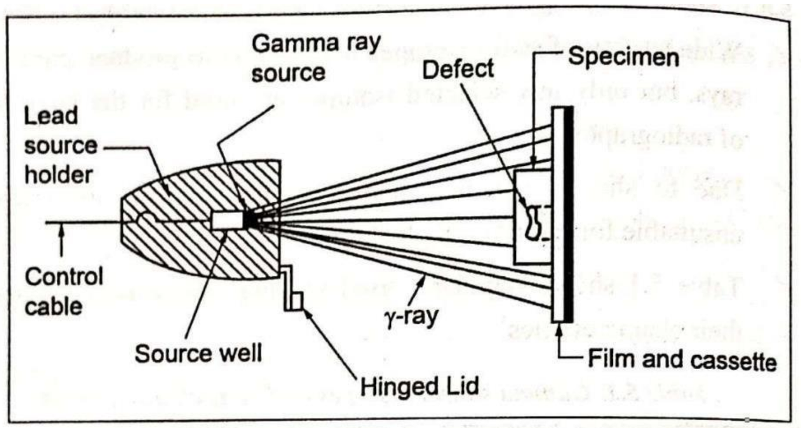


Figure. Gamma ray testing

Basically the equipment consists of: (i) gamma ray source container, (ii) a camera, and (iii) crank-out mechanism.

A cylindrical isotopic sources are placed inside the container, as shown in Figure. The container is made of steel, aluminium or an alloy of magnesium and aluminium for safe handling of the source and for easy portability. Most of the applications, the source cylinder size is approximately 3 mm x 3 mm. The source is placed at the one end of the container and the other end connected with manipulator rod or crank mechanism.

The source camera is designed in such a way that there is no leakage of radiation. The camera is usually made of lead or depleted uranium. The camera is also provided with facilities like easy loading, exchange of the source and easy opening and closure of shutters. Cameras are often fixed to a trailer and transported to inspection sites. When the source is not being used to make an exposure, it is locked inside the exposure device.

Crank-out Mechanism for Gamma Ray Radiographic Exposure

To make a radiographic exposure, a crank-out mechanism and guide tube are attached to opposite ends of the exposure device.

To make the exposure, the radiographer quickly cranks the source out of the exposure device and position into the collimator at the end of the guide tube.

After the exposure is completed, the source is cranked back into the exposure device.

The figure shows the arrangement of crank-out mechanism guide tube to inspect components by radiography testing.

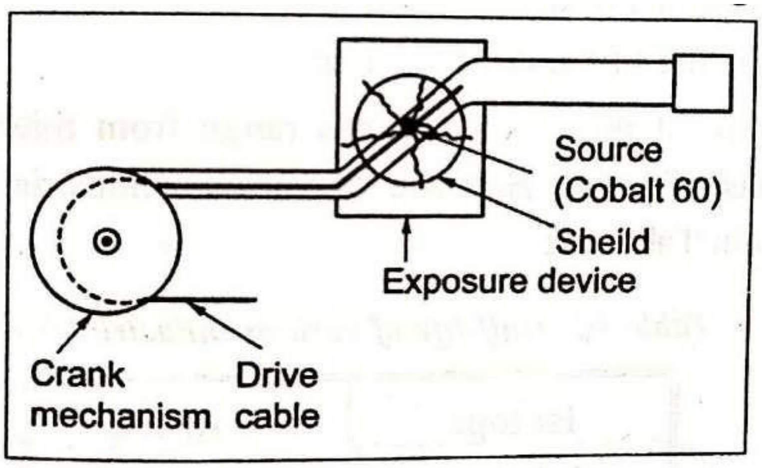


Figure (a). Source in stored position (crank-in) Collimator

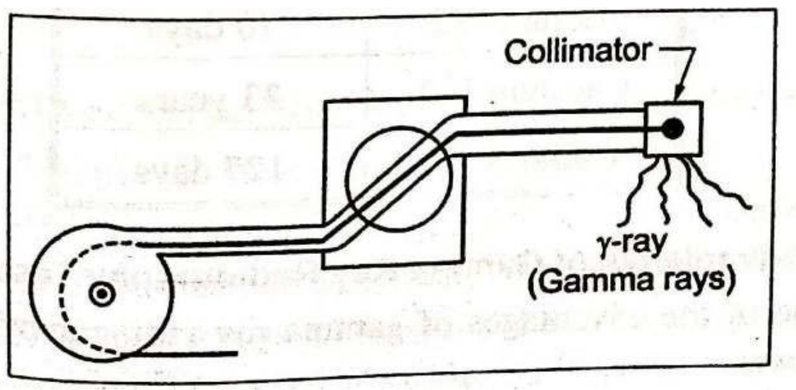


Figure (b). Source in exposure position (crank-out)

Series of safety procedures must be accomplished while making exposure with a gamma source to ensure safety of the radiographer and equipment.

Half-Life of Radioactive Isotopes in Gamma Ray Testing (Isotope Decay Rate)

Definition: Half-life of the radio isotope is defined as the time required for the activity of any particular radio nuclide to decrease to one half of its initial value.

Nuclide is a distinct kind of atom or nucleus characterized by specific number of protons and neutrons. Each radio nuclide decays at its own unique rate which cannot be altered by any chemical or physical process. A useful measure of this rate is the half-life of the radio nuclide.

Half-life of the radio nuclides range from micro seconds to billions of years. Half-life of various industrial isotopes are given in Table below.

Table . Half-life of various industrial isotopes

Isotope	**Half-life**
Cobalt 60	5.3 years
Iridium 192	70 days
Caesium 137	33 years
Thulium 170	127 days

Advantages of Gamma Ray Radiography Testing

Some of the advantages of gamma ray radiography testing are as follows:

(i) The sources are very portable.
(ii) Highly suitable for field radiography
(iii) Low initial cost of the equipment.
(iv) Thicker plates can be inspected (i.e., greater penetrating power).
(v) Loss scatter.
(vi) No special cooling arrangement and water is required.

Limitations of Gamma Ray Radiography Testing

Some of the limitations of gamma ray radiography testing are as follows:
(i) More exposure time is required. (ii) Sources must be replaced periodically. (iii) Poor quality radiographs.

X-RAY FILM

What is it?

The X-ray film is the medium that record the image of part exposed with X-rays. The X-ray film is similar to photographic film in its basic construction, Radiation sensitive emulsion is usually coated on both sides of the base of X-ray film and it is used along with intensifying screens.

Construction and Structure of Industrial X-Ray Film

X-ray film for industrial radiography consists of an emulsion and blue tinted base of polyester. The emulsion is coated on both sides of the base in layers and protected by thin outer protective layers, as shown in Figure. The emulsion consists of silver halides (silver bromide or silver chloride) as the photo sensitive material, additives and gelatine.

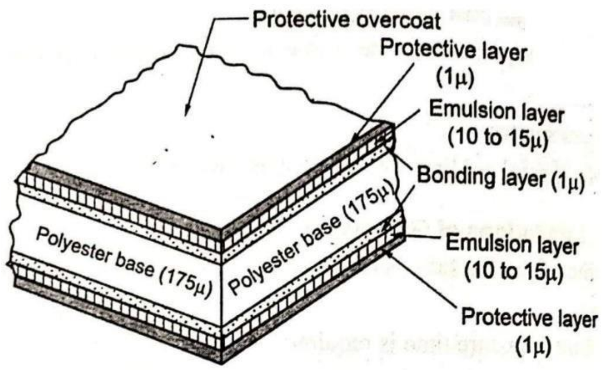
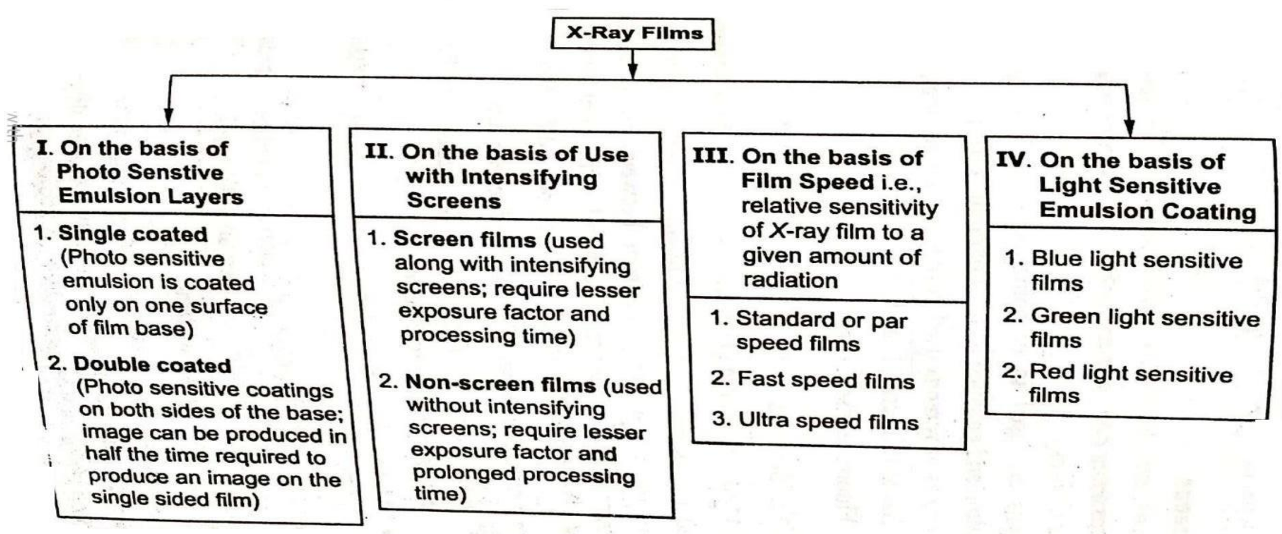


Figure. Structure of X-ray film

The structure of a typical X-ray film consists of several layers. Different layers are:
(i) Base: Thicker layer of X-ray film and is made up of cellulose acetate or polyester. This base has high transparency, toughness and flexibility.
(ii) Bonding layer: The bonding layer contains a mixture of gelatin and cellulose, ester solvents.
(iii) Emulsion layer: The sensitive emulsion layer consist of silver bromide, suspended in gelatin.
(iv) Protective layer: An anti-abrasion layer consists of only gelatin is coated on the sensitive emulsion layer, for protection from physical damage.

When X-rays, gamma rays or light strike the film, some of the halogen atoms are liberated from the silver halide crystal and thus leaving the silver atoms alone. This change creates a latent (hidden) image on the film. When the exposed film is treated with a chemical solution (the developer), takes place causing formation of black metallic silver and this film is a reaction constitutes the image of the detects.



Classification of X-ray film

Figure. Classification of X-ray film

Screens

Screens, also known as intensifying screens, are ray cassettes and interact with X-rays to convert most of their radiant energy.

Screens are used in combination with films to utilize the radiation and enhance the photographic effect. Two types of screens used in radiography testing are:
1. Metal foil screens, and
2. Fluorescent screens.

1. Metal Foil Screens

Lead foil screens are generally used as metal foil screens. Lead foil is mounted on cardboard or plastic and is used in pairs by sandwiching the film between them, one of the screens facing the source side is called the front screen and the other is back screen which is placed behind the film.

The main advantages of using lead screen are:

- ✓ Enhancement of photographic action in the film by emission of photo electrons.
- ✓ More soft scattered radiation is absorbed than primary radiation.
- ✓ The harmful effect of scattered radiation is reduced, thus producing greater contrast and clear image.
- ✓ Reduced exposure time.

In addition to lead intensifying screens, other metal screens such as copper, tantalum, tungsten screens also used in high power X-ray and Co_{60} gamma ray radiography,

2. Fluorescent Intensifying Screen (or Salt Screens)

In fluorescent screens, fluorescent crystals like calcium tungstate or barium lead surface layer is spread with a suitable binder on a card board or a plastic support.

The fluorescent material emits visible or ultraviolet light when exposed to X-rays or gamma rays. The intensity of emitted light depends on the intensity of incident radiation.

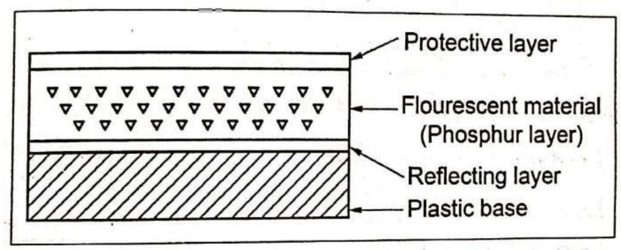


Figure. Structure of fluorescent screen

The structure of fluorescent screen consists of several layers Figure and they are:
(i) Plastic base: Provides a strong support to the fluorescent layer.
(ii) Reflecting layer: It is the bonding layer between the base and phosphor layer, it is reflective also.
(iii) Phosphor layer: Active layer of the screen that consists of fluorescent crystals.
(iv) Protective layer: This is a transparent external protective layer which helps in resisting surface abrasion.

The main advantage of using fluorescent salt screens is to drastically reduce the exposure time. Fluorescent screens are not suitable for gamma ray radiography, as manifestation is poor with long exposures.

CHARACTERISTIC CURVE OF X-RAY FILMS

The properties of X-ray film can be expressed in several ways. The most widely used is characteristic curve.*A film characteristic curve shows how a film responds to different amount of radiation exposure.* The characteristic curve furnishes information on the speed, contrast (average gradient) and fog of X-ray film.

It is difficult to measure the absolute strength of the X-rays and gamma rays, so log relative exposure is considered and is plotted in the horizontal axis. Density is plotted along the vertical axis. The shape of the characteristic curve and its position on the graph differs from one type of film or radiation source.

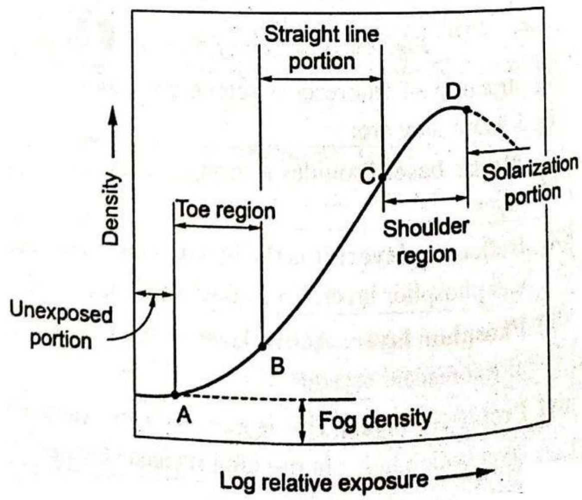


Figure. Characteristic curve of X-ray film

Generally a characteristic curve is divided into five sections as shown in figure. The five sections are:

(i) Unexposed portion,
(ii) Toe region,
(iii) Straight line portion,
(iv) Shoulder region, and
(v) Solarization portion.

The five sections of the characteristic curve are briefed below.

(i) Unexposed portion: A density which is just noticeable appears in the unexposed areas of processed film and this density is called fog.

(ii) Toe region: Underexposed films generally have a density in the range indicated by this section AB, as shown in Figure.

(iii) Straight line portion: Properly exposed films generally have a density in this range indicated mainly by the straight line section and toe (section BC in Figure). Contrast is most closely related to the straight line section.

(iv) Shoulder region: Overexposed film generally has a density in the range indicated mainly by the shoulder and straight line portion (section CD, in Figure).

(v) Solarization portion: The density may even fall again upon increasing exposure above that indicated by the shoulder. This portion is not included in exposures used for the formation of photographic images.

Film Density and Film Speed

1. Film Density

The ratio of light incident on one side of a radiograph to the light transmitted through the radiograph in logarithm scale is known as density of the X-ray film.

Mathematically, the film density is given as

$$D = \log_{10} \frac{I_o}{I}$$

where D = Film density, I_o= Intensity of the incident light, and I Intensity of the transmitted light.

From the characteristics curve, it is apparent that as exposure increases, overall film density increases and more importantly, film contrast increases.

In industrial radiography, films should be exposed for a density of at least 1.5. The upper and lower density limits are usually 1.8 to 4.0

2. Film Speed

Film speed refers to the relative sensitivity of X-ray films to a given amount of radiation. The speed of the radiographic film is usually expressed by the reciprocal of the exposure as determined by the characteristic curve.

High speed film needs only low exposure, whereas slow speed film requires more exposure to attain the same film density.

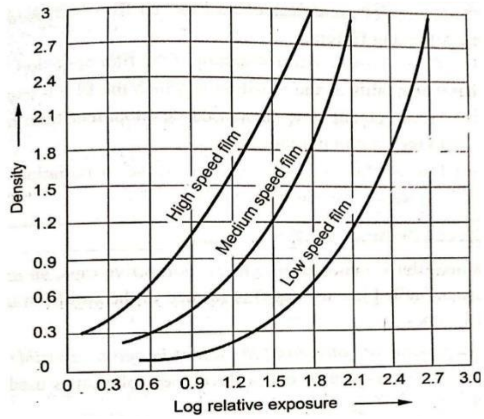


Figure. Characteristic curve for different film speed

Film Graininess

Film graininess is the visible evidence of the cluster of the minute silver particles (grains) that form the image on the radiographic film.

Film graininess occurs during the development process when the developer used tends to cluster many silver grains together into a mass. The degree of graininess is a function of both film type and processing.

Graininess affects films contrast and image definition and all film is subjected to it.

- ✓ Small grains provide better definition (i.e., they provide better outline of small areas of film).
- ✓ Larger grains cause blurring of the outline of discontinuities.

The degree of graininess of an exposed film is dependent on the following factors:

(i) Fine or coarse grain structure of the film emulsion.
(ii) The quality of the radiation to which the film is exposed.
(iii) Development time (increased development time resulted in increase in graininess).
(iv) Use of fluorescent screens (increase in radiation causes increase in graininess) energy

DEVELOPMENT OF X-RAY FILMS

When film is exposed to light or radioactive rays, an invisible image (called latent image) is formed in the emulsion layer of the film.

The process of converting the latent image to a visible image is called development and a developer solution is used in the process.

Various stages of development of a radiographic film include:

(i) Developing with the use of developer,
(ii) Stop bath,
(iii) Fixing,
(iv) Quick washing, and
(v) Wetting.

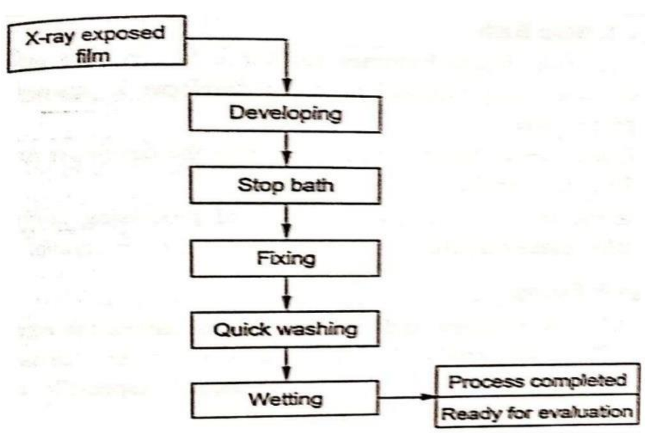


Figure. Stages of film processing and development

Stage 1: Developing

- ✓ After exposing the radiographic film, it is necessary to reduce only silver compound deposited in the latent image during exposure to metallic silver to form a visible images.
- ✓ The chemical which is chosen to reduce exposed silver compound to metallic silver is called a developing agent. Developing agent is used along with other ingredients to perform special functions.The other ingredients used are:
  (i) Accelerator (to activate the developing agent);
  (ü) Preservative (to reduce the aerial oxidation of the developer);
  (iii) Restrainer (to prevent development of fog); and
  (iv) Additives (to soften the water used in development process)

Stage 2: Stop Bath

The silver image becomes too dense to serve the intended purpose unless the action of the developer is stopped at a proper time.

If the film is directly transferred from the developer into the fixer, uneven fixation is liable to occur. If the stop bath is not used, lack of processing uniformity takes place resulted in stain formation in the radiograph.

Stage 3: Fixing

After development and stop bath neutralization, the emulsion still contain unreduced silver halide which is not necessary for the image. Such material is detrimental, especially to the radiograph as viewed by light. *The fixer is used to remove the unreduced silver halide.*

Stage 4: Quick Washing (Wash Accelerator)

The film removed from the fixing bath retains not only the fixer ingredients but other compounds which were formed in dissolving the silver halides. To remove these, the film is washed in running water for 20 minutes or more.

To reduce the washing time, wash accelerator is used. Wash accelerator can reduce the washing time to one-third to one- fifth of that required without its use.

Stage 5: Wetting

After washing, water adheres to the film in streaks and drops. If the film is dried in this condition, watermarks will be left on the radiograph.

To reduce drying time and prevent water marks, wetting agent is used. After wetting and drying, the film processing is completed and it is ready for evaluation of defects.

INTERACTION OF X-RAYS WITH MATTER

X-rays are not simply passing through the material to be inspected. On reaching a material, some of the X-rays will be absorbed, and some scattered if neither process occurs, the X-rays will be transmitted through the material.

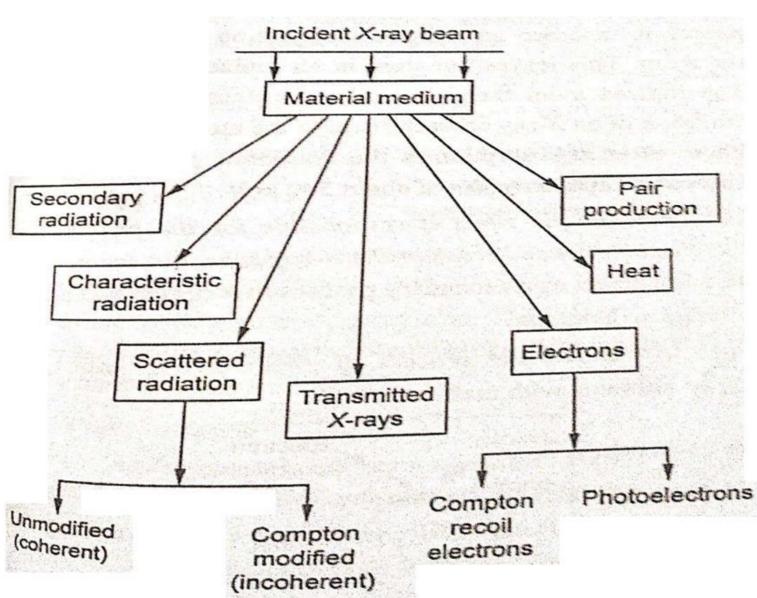


Figure. Interaction of X-rays with matter

The four important processes, when X-rays interact with the matter are:

1. The photoelectric effect,
2. The Compton effect,
3. Pair production, and
4. Thomson (or Raylagh) scattering.

Photoelectric Effect

The photoelectric effect occurs when photons interact with matter resulting in ejection of electrons from the matter.

Photoelectric absorption of X-rays occur when the X-ray photon is absorbed resulting in the ejection of electrons from the atom. This leaves the atom in an ionized (charged) state. The ionized atom then returns to the neutral state with the emission of an X-ray characteristic of the atom.

Photo electric absorption is the dominant process for X-ray absorption up to energies of about 500 keV. The photoelectric effect is responsible for the production of the characteristics X-rays in the X-ray tube, but the process is also important as a secondary process that occurs when X-rays interact with matter.

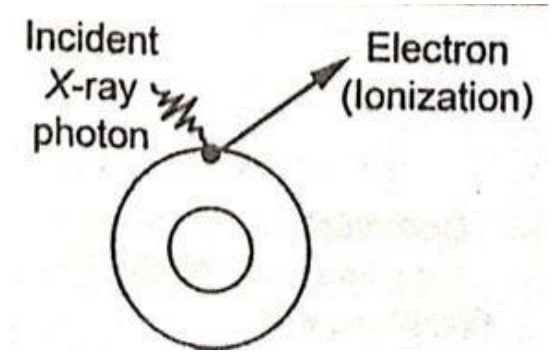


Figure. Photoelectric effect

The Compton Effect

The Compton effect or Compton scattering, also known as incoherent scattering, occurs when the incident X-ray photon ejects an electron from an atom and an X-ray photon of lower energy is scattered from the atom.

The Compton effect will occur with very low atomic weight targets even at relatively low X-ray energies.

In Compton scattering, the incident X-ray changes direction and loses energy, imparting the energy to the electron called as Compton electron. The Compton electron will typically interact with other atoms producing secondary ionizations.

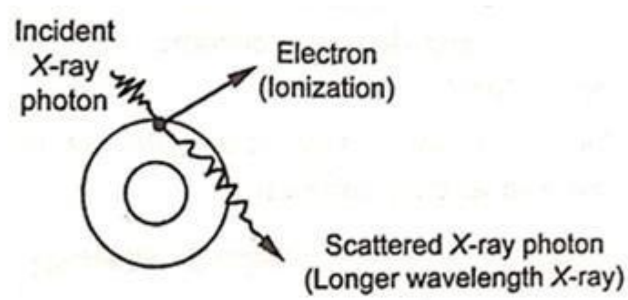


Figure. Compton scattering

Since they possess relatively low energy, the X-rays produced will generally be low energy also. The lower energy, therefore resulted in longer wavelength according to Planck relationship

Pair Production

Pair production (PP) occurs when an electron and positron are created with the disappearance of X-ray photon.

Positrons are very short lived and disappear with the formation of two photons of 0.51 MeV energy. Pair production is of particular importance when high energy photons pass through materials of a high atomic number.

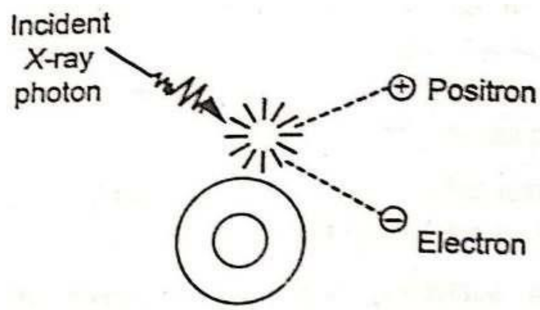


Figure. Pair production

Pair production is a rare process and only occurs at high X-ray photon energies with high atomic weight targets. Pair production is impossible unless the incident X-rays exceed 1.02 MeV and does not become important until this exceeds about 2 MeV. Pair production is not a significant process at the X-ray energies involved in X-ray diffraction.

Thomson Scattering (or Rayleigh Scattering)

Thomson scattering, also known as Rayleigh scattering, coherent, or classical scattering, occurs when the X-ray photon interacts with the whole atom so that the photon is scattered with no change in internal energy (neither to the scattering atom nor to the X-ray photon).

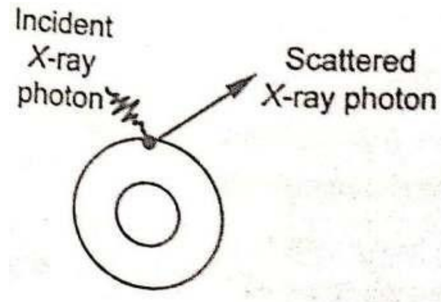


Figure. Thomson (or Rayleigh) scattering Scanner

The scattering occurs without the loss of energy. Scattering is mainly in the forward direction. This effect is minor when related to absorption, but is the primary effect which makes X-ray diffraction possible.

PRODUCTION OF X-RAYS

X-rays are generated through interactions of the accelerated electrons with electrons of tungsten nuclei within the tube anode. There two types of X-rays generated are:

1. Characteristic X-ray, and
2. Bremsstrahlung X-ray.

Characteristic X-Ray

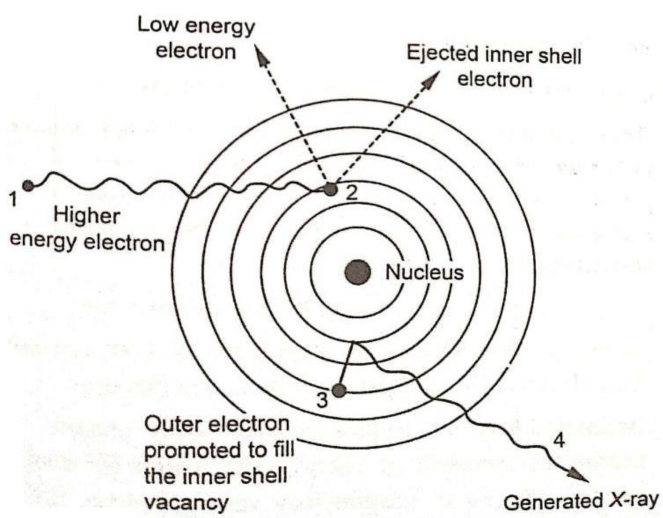


Figure. Generation of characteristic X-ray

When high energy electron collides with an inner shell, electron both are ejected from the tungsten atom leaving a hole in the inner layer. This is filled by an outer shell electron with loss of energy emitted as an X-ray photon.

Bremsstrahlung X-Ray

When an electron passes near the nucleus, it is slowed and its path is deflected. Energy loss is emitted as a Bremsstrahlung X-ray photon. Bremsstrahlung radiation is also known as breaking radiation.

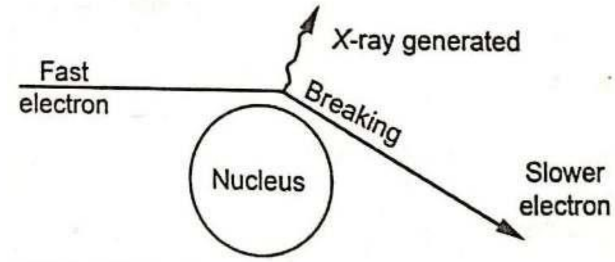


Fig. 5.19. Generation of Bremsstrahlung X-ray

Approximately 80% of the population of X-rays within the X-ray beam consists of X-rays generated in this way. Bremsstrahlung interactions generate X-ray photons with a continuous spectrum of energy. The reason for continuous spectrum is due to continuously varying voltage difference between the target and the filament.

INTENSITY OF X-RAYS IN RADIOGRAPHY TESTING

Inverse Square Law

The inverse square law states that the intensity of an X- ray beam varies inversely with the square of the distance from the radiation source.

X-rays like visible light rays, diverge an emission from their source and cover increasingly larger areas as the distance from the source increases. It is major consideration, in computing radiographic exposures and safety procedures.

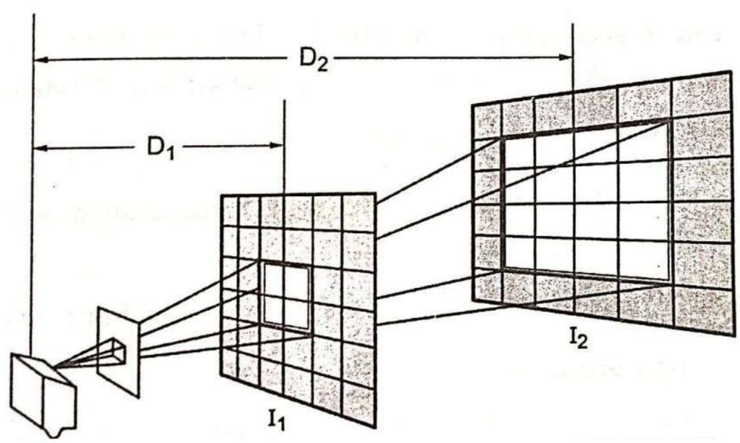


Figure. Principle of inverse square law

When the distance between the individual from a known source of radiation is doubled, the intensity to the individual will be reduced by a factor of four. Conversely, if the distance to the radiation source is cut in half, the intensity is four times greater.
The relationship of inverse square law can be expressed as

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

where $1_1 I_2$ are intensities at distances D_1, and D_2 respectively.

X-Ray Beam Attenuation

As the X-ray beam passes through the material, photons get absorbed so there is less energy, this is known as attenuation.

The total absorption/attenuation is a combination of follow three absorption processes:

(i) Photon electric effect,

(ii) Compton effect, and

(iii) Pair production.

In all three absorption processes, the energy of X-rays lowers and it gets scattered in different directions with different wavelengths. The probability of photo-electric absorption is approximately proportional to $(Z/E)^3$

where Z =Atomic number of the material atom, and E = Photon energy;As 'E' gets larger, the likelihood of interaction drops rapidly.

Half-Value Layer

In radiography testing, the penetration of radiation can be expressed with the term "half-value layer".

Definition: *The half-value layer (HVL) is defined thickness of a specific material that will reduce the radiation intensity to one half of that entering the part.*

If the initial radiation intensity is 100 roentgens (100R), a material that is exactly one half-value layer will reduce that 100R to 50R. Another half value layer thickness will reduce that 50R to 25R, and so on. If this is carried forward, the radiation never reaches zero.

The factors involved with the half-value layer are:

(i) Energy (higher the energy, the thicker the half-value layer);

(ii) Material type (the greater the material density, the thinner the half-value layer); and

(iii) Thickness (as the material thickness increases, the absorption and scatter increases).

The relationship between half-value thickness and linear attenuation co-efficient is expressed as

$$HVT=0.693/\mu$$

where HVT Half Value Thickness (mm), and **μ** = Linear attenuation co-efficient (mm^{-1}).

IMAGE QUALITY IN RADIOGRAPHY TESTING

Image Quality Indicators (IQI) (Penetrometers)

The quality of the radiographic techniques is established by comparison with the image of "Image Quality Indicators (IQI), also referred to as penetrometer, on the completed radiograph.

Indicators are fixed on the test piece to be inspected for defects during exposure with X-ray or gamma ray source. Two major types of penetrometers widely used in radiographic applications are:

(i) Shim type penetrometer, and

(ii) Wire type penetrometer.

1. Shim Type Penetrometer

The shim or hole type penetrometer, shown in Figure, contains a lead identification number at one end and three holes of different diameters.

The thickness of the shim type penetrometer is based on the percentage of material thickness that is being radiographed. Generally 2% of the thickness of the material to be inspected is the thickness of the penetrometer.

Figure shows the shim type penetrometer with three holes. Three holes have different diameters, which are based on the penetrometers thickness.

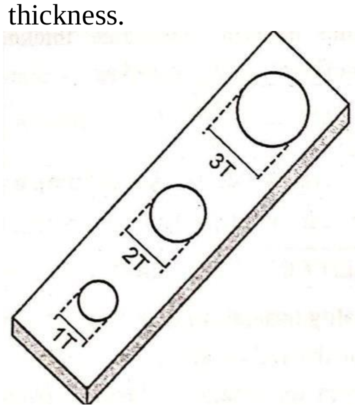


Figure. Shim type penetrometer

The smallest hole located in the shim is referred to as the 1T. The 'T' refers to the penetrometer thickness. Therefore 1T hole will have diameter equivalent to the thickness of the penetrometer, which is usually 2% of the thickness of the material being radiographed.

Similarly 2T hole refers to two times of penetrometer thickness and “3T hole refers to three times of penetrometer thickness.

The outline of the penetrometer and the image of the holes on radiographic technique. Penetrometers have sharp edges and holes are precisely machined. Defects/discontinuities on the part to be inspected are quite different from these holes. The penetrometer is used to establish the quality level of the radiographic technique and should be compared with discontinuities.

2. Wire Type Penetrometer

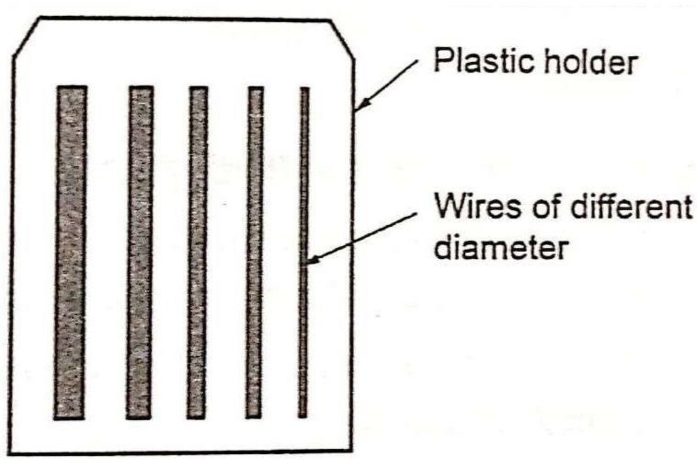


Figure. Wire type penetrometer

Wires of various diameters placed parallel at equal distance manufactured with wires of steel, aluminium, titanium or copper.

A series of wires usually six in numbers are encased in a clear plastic holder with lead identification numbers. Wire type penetrometers must be placed on the source side of the object being radiographed.

Filtering

In radiography testing, filtration is required to absorb the lower energy X-ray photons emitted by the tube before they reach the target.

The use of filters produce a cleaner image by absorbing the lower energy X-ray photons that tend to scatter more. Two types of filtration followed in radiographic testing are:

1. Inherent filtration (filter is part of the X-ray tube and housing), and
2. Added filtration (thin sheets of a metal are inserted in the X-ray beam).

Filters added to the X-ray beam are most often made of high atomic number materials such as lead, copper or brass. The degree of filtering depends on the type and the thickness of the material used. In gamma radiography testing, filtration is not a useful technique.

Contrast and Definition in Radiography

Exposure to radiation creates latent (hidden) image on the film and chemical processing makes the image visible.

When X-rays or gamma rays hit the grains of the silver bromide (coated on the surface of the film), a change takes place in the physical structure of the grains. This change cannot be detected by ordinary physical methods. Hence the film is treated with chemical solution; a reaction takes place causing the formation of black metallic silver.

When the radiographer interprets a radiographic image, the details of the image are seen in terms of amount of light passing through the processed film. The images may appear dark grey or light grey depends on the radiation intensity.

Areas exposed to relatively large amount of radiation will appear as dark grey. Areas exposed to less radiation will appear as light grey.

Always, there is a difference between the darkness (density) of the image. *The density difference between two film area is known as radiographic contrast. The sharpness of any change in density is called definition.* Interpretation of any radiograph relies on contrast and definition in the radiograph.

Factors affecting film contrast: Film contrast is determined by the following factors:

(i) Grain size or type of film;
(ii) Chemical composition of the processing chemicals;
(iii) Concentrations of the processing chemicals;
(iv) Development time;
(v) Development temperature; and
(vi) Type of agitation.

Geometric Factors (Principle of Geometric Exposure)

A radiograph is a shadow picture of a test piece placed between the film and the X-radiation or gamma radiation source.

To create a radiographic image, there must be a source of radiation, a test object and film. To get sharp and accurate images, proper placement of the film from the radiation source and the test object is important.

Geometric factors have the influence on radiographic definition. These **geometric factors** are:

(i) Focal spot size of the radiation source;
(ii) Source to film distance;
(iii) Specimen to film distance;
(iv) Angle between source and features of interest (defects in the specimen); and
(vì) Sudden changes in the thickness of the test object.

If the film is placed too far from the test object, the defect image in the test piece will be enlarged. On the other side, if the test piece has a defect and is too close to the source, the image will be greatly enlarged, resulting in loss of dimensional accuracy. This enlargement cannot be eliminated entirely using an appropriate source to film distance, enlargement can be minimized to an accepted level.

Figure shows a radiographic exposure showing basic object and the film on which the images are recorded.

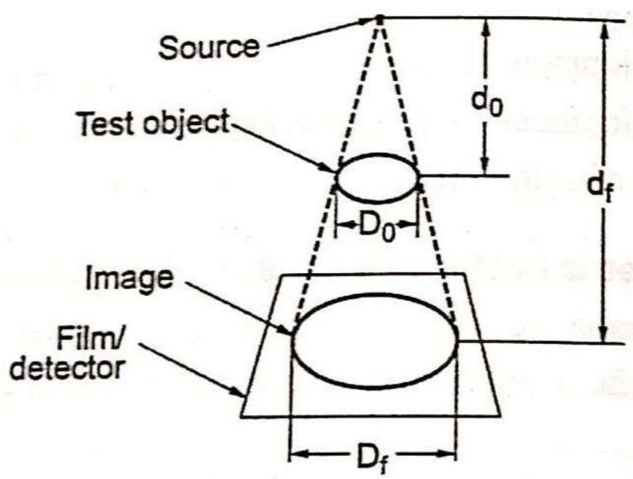


Figure. Geometric relationship

Mathematically, the degree of enlargement will be

$$\frac{D_o}{D_f} = \frac{d_o}{d_f}$$

Where,
D_o = Size of the test object,
D_f = Size of the radiographic image on film,
d_o =Distance between source to test object, and
d_f = Distance between source to the film.

Since X-rays and gamma rays obey the common laws of light, the radiographic image formation may be explained in a simple manner in terms of light. The ratio of the test object diameter D_o to the image diameter D_f is equal to the ratio of the source to object distance d_o to the source to film distance d_f.

Conditions for radiographic image to be closer to the same size as the test object are:

(i) The film must be placed close to the test object as possible; and

(ii) The radiation source must be placed as far from the film as practically possible.

Image Sharpness

The degree of sharpness of the image is determined by (i) the size of the radiation source, and (ii) the ratio of the object to film distance and source to object distance.

In In radiographic testing, unsharpness is caused due to, geometrical factors as well as quality of film.

In practice, unsharpness is reduced to acceptable level by optimizing the geometric variables (i.e., distance between source to object and distance between source to film).

Geometric unsharpness can be expressed as

$$U_g = \frac{F \cdot d}{D}$$

Where,
Ug= Geometric unsharpness,
F = Source size (focal spot size),
D=Distance between source to object, and
d = Distance between source to film.

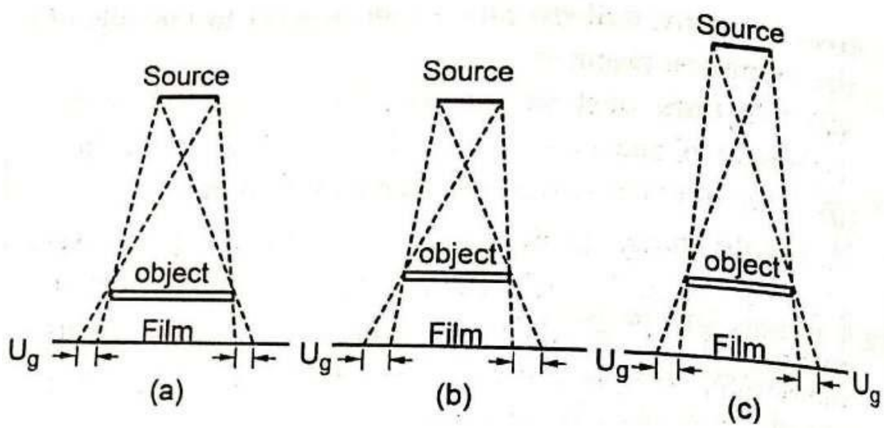


Figure (a) Small geometrical unsharpness (i.e., test object is close to the film); (b) Greater geometrical unsharpness (i.e., source to film distance is same but object to film distance is increased);

(c) A minimum geometrical unsharpness (i.e., object to film distance is same but source to film distance is increased)

Determination of Exposure Parameters in Radiography Testing

1. Exposure Charts

In radiography, it is necessary to make an appropriate prior choice of exposure method according to the material and shape of the specimen to the examined. Exposure conditions determine the image density and definition of the radiographic image.

Exposure parameters for a given components of known composition are determined with the help of exposure chart.

An exposure chart is a graphical relationship between material thickness, beam energy (kV) and quantity of radiation (mA x time of exposure).

Factors influencing exposure in radiography inspection are:

(i). Beam energy;
(ii) Focus to film distance;
(iii) X-ray tube current;
(iv) Orientation of the object : rith respect to the axis of the radiation beam;

(v) Thickness of specimen; and
(vi) Size of radiation source (i.e., focal spot size in X-ray source or capsule size in gamma ray source).

Generally X-ray equipment manufactures supply exposure charts for various thickness of steel. Suitable corrections are made while using other materials. When X-rays are used, a radiograph of high definition can be obtained by using low kilo voltage with long exposure time.

Exposure charts are plotted by laying off the thickness of the specimen in the horizontal axis and the exposure (mA-min or mA-sec) or kilovoltage (kVp) along the vertical axis of the graph. However, it is recommended that appropriate exposure charts be plotted according to exposure conditions for each case.

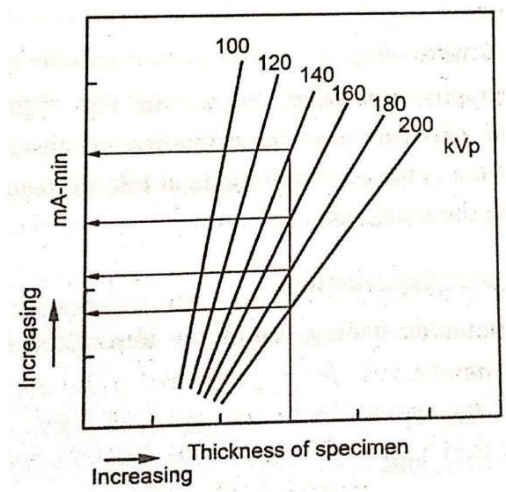


Figure. Exposure time Vs Thickness (to determine kilo voltage)

Figure shows a typical exposure chart through which the kilovoltage is determined from the thickness of the specimen and the exposure time.

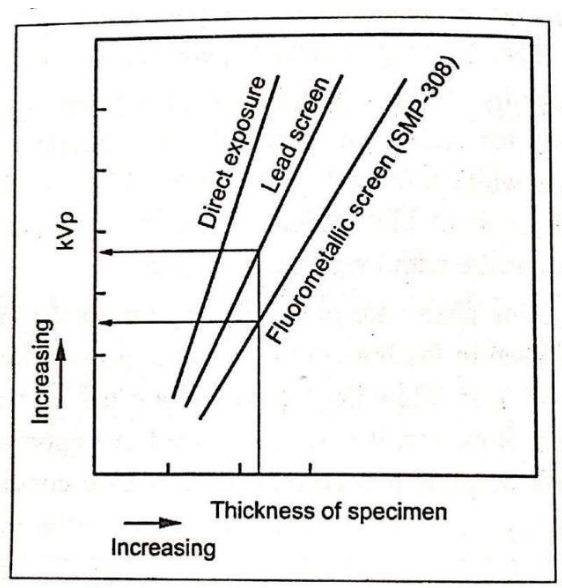


Figure. Kilo voltage Vs Thickness (to determine type of screen)

Another exposure chart, shown in Fig. 5.26, is used to determine intensifying screen relative to the thickness of the specimen and the exposure made at kilo voltages suited to the type of screen selected.

2. Radiographic Equivalence

In radiographic testing, the X-ray absorption of a specimen depends on its:

(i) Thickness,

(ii) Density, and

(iii) Atomic nature of the material.

It is obvious that two specimens of same thickness, the more dense will absorb more radiation, necessitating an increase in kilo voltage or exposure to produce same photographic result. However, the atomic elements in the specimen have greater effect on absorption than thickness and density.

For example, lead is about 1.5 times as dense as steel but as 220 kV, 2.5 mm lead absorbs as much as 25 mm of steel. From this example, it is evident that X-ray absorption varies according to the atomic nature of material.

Generally, exposure charts are drawn for steel or aluminium as standard material. It is possible to use these charts for other materials by considering radiographic equivalence factors.

The radiographic equivalence factor of a material is that factor by which thickness of the material must be multiplied to give the thickness of a "standard material" (steel) which has the same absorption.

The factors may be used to determine:
(i) the practical thickness limits for radiation sources for materials other than steel; and
(ii) the exposure factors for one metal from exposure techniques for other metals.

RADIOGRAPHY TECHNIQUES

The majority application of radiography testing is grading and inspection of welds on pressurized piping, pressure vessels, high capacity storage containers, pipelines and some structural welds.

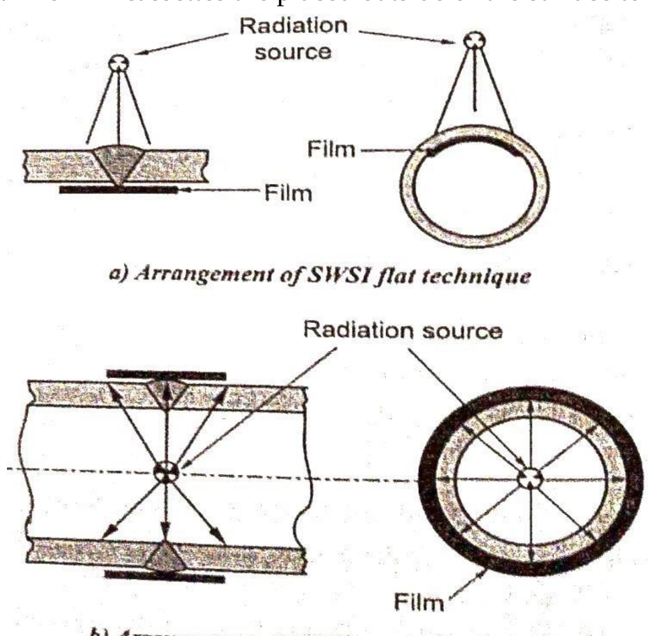
For the purpose of inspection, several techniques (exposure arrangements) are used. Radiography of flat plates and large cylinders permit entry for placement of the film is a simple operation, whereas radiography inspection of pipes, access to the bore to place the film presents some problems.

The radiography techniques followed for various engineering components are:
(i) Single Wall, Single Image (SWSI) technique,
(ii) Double Wall, Single Image (DWSI) technique, and
(iii) Double Wall, Double Image (DWDI) technique.

Single Wall, Single Image (SWSI) Technique

In single wall, single image (SWSI) flat technique, the radiographic source is placed outside the plate or pipe, The film is placed inside the surface to be examined.

In single wall, single image panoramic technique, the radiographic source is placed inside the pipe by some suitable method. The film cassettes are placed outside of the surface to be examined.



a) Arrangement of SWSI flat technique

b) Arrangement of SWSI panoramic technique

Figure. Single wall, single image (flat and panoramic)

The image quality indicator is places on the outside of the pipe immediately below the film. Both X-ray and gamma rays can be used.

The source of radiation is place at the center of sphere or cylinder (tanks, vessels, and piping). The source positions and moved by means of crawler unit

This method is commonly used for inspection of pipe fines where the weld can be radiographed in one exposure, making the technique rapid and cost effective.

Advantages: Some of the advantages of SWSI technique as follows:

(i) Exposed film will be of the same approximate density

(ii) Taking less time than other techniques.

(iii) Radiation source penetrate the total wall thickness,

(iv) Radiation source travel the radius of the inspection of the component, not its full diameter.

Limitations: Some of the limitations of SWSI technique me as follows:

(i) In panoramic method, it may be impractical to reach the centre.

(ii) The radiation source may be too weak for the inspection of the larger vessels and tanks.

Double Wall, Single Image (DWSI) Technique

The double wall, single image (DWSI) technique usually adopted for very small diameter piping or parts, where access to the bore is not possible to permit the use of an internal source. The film is placed on the outside of the pipe on the side from the radiographic source.

The source may be offset slightly to avoid an image of the upper part of the weld to be projected onto the film or directly in line. The source may be close to or a substantial distance from the pipe, the location being compromise between a less sharp image but short exposure time for a small stand-off and sharper image but longer exposure time for large stand-off.

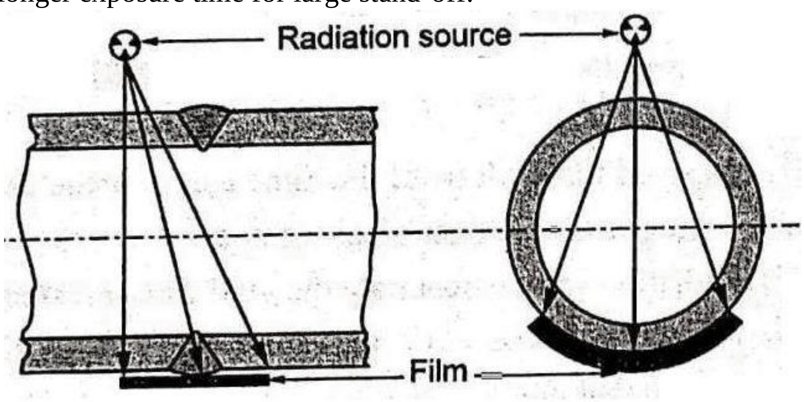


Figure. Double wall, single image technique

The need to penetrate two wall thicknesses means that the sensitivity will be poorer than with single wall single image technique. This technique also requires multiple exposures to enable the complete circumferences of the pipe to be examined. This technique is widely used on pipes over 80 mm diameter.

Double Wall, Double Image (DWDI) Technique

The double wall, double image (DWDI) technique is generally used only on pipes less than 75-80 mm in diameter. The radiation source is kept at a distance with an offset from the axis of the weld, to avoid the super imposing of the source side welds over the film side weld and to obtain an elliptical image on the film.

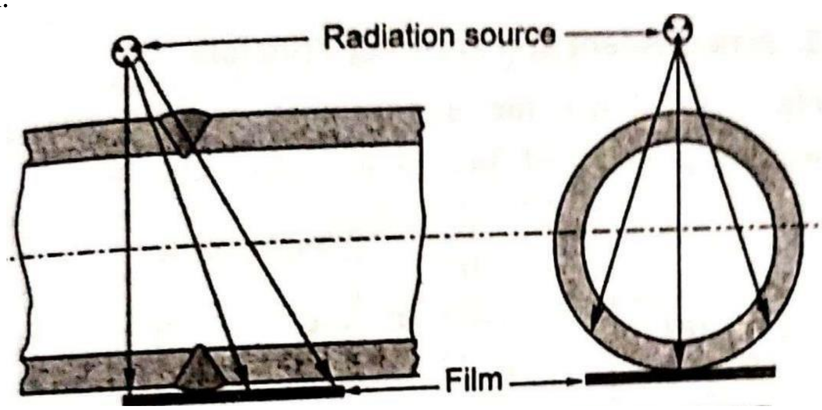


Figure. Double wall, double image technique

By offsetting the radiation source from the weld center line and using a long source to film distance, it is possible to project an image onto the film of both upper and lower parts of the weld. Multiple exposures are required to achieve the complete coverage.

SPECIAL /ADVANCED RADIOGRAPHY TECHNIQUES

FLUOROSCOPY (RADIOSCOPY) TESTING

What is Fluoroscopy?

Fluoroscopy, also known as radioscopy, is a technique whereby "real time" detection of defects is achieved by the e of specialized fluorescent screen technology.

In this testing method, image of the defects in the component is produced by ionizing radiation on a radiation detector such as a fluorescent screen or an array of solid state sensors which is then displayed on a computer or television screen. These radiography systems work in real time and can provide continuous inspection of objects, hence it is also called as "Real Time Radiography (RTR)".

Arrangement and Working Principle

Figure shows the arrangement of equipment and the working principle of fluoroscopy radiography testing.

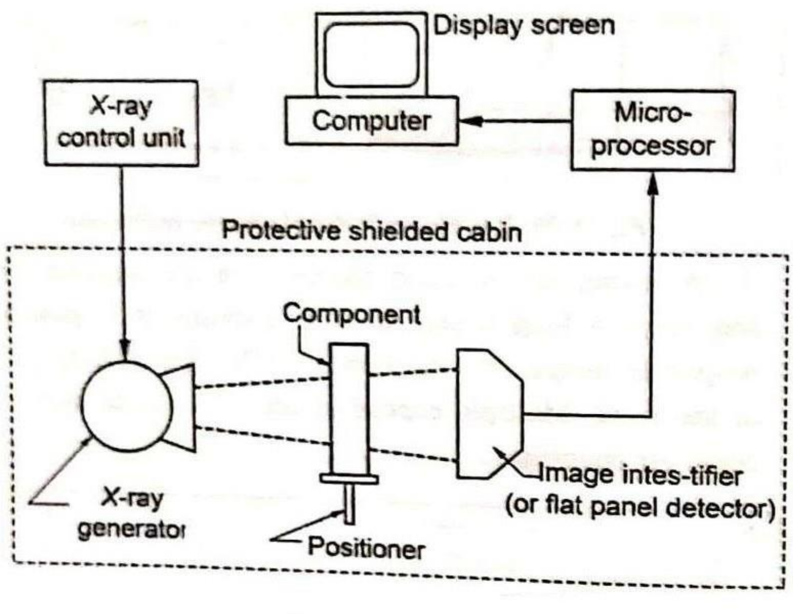


Figure. Schematic arrangement of fluoroscopy testing

In fluoroscopy testing, the film is replaced by a fluorescent screen then the image of the test piece can be visually seen.

Image intensifier or flat panel detector is used to convert ionized radiation into images. The image intensifier commonly used as a converter device, contains a fluorescent material such as ceisium iodide.

The X-ray are passed through the object excite the fluorescent material producing bright spots in the more heavily irradiated areas. These photons are converted to electron, accelerated and reconverted into light on the output Screen.

Flat panel detectors contains an array of sensors provide various pixel sizes with extensive image dynamics. Since the signals received are digital, the screen image can be optimized for interpretation.

Advantages of Fluoroscopy Testing

Some of the advantages of fluoroscopy testing are as follows:

(i) Immediate viewing of the objects for defects.
(ü) Ability to study moving parts in action.
(m) Less expensive on film and film processing cost.
(iv) Possibilities of comparing obtained image with a reference image for defect interpretation.

Limitations of Fluoroscopy Testing

Some of the limitations of fluoroscopy testing are as follows:

(i) Initial cost of equipment is very high.
(ii) Not portable as in gamma ray testing.
(iii) Special cabinet is required to keep exposure to radiation within regulations.

Applications of Fluoroscopy Testing

Fluoroscopy radiography testing is widely used for the inspection of:

(i) thin wall section castings;
(ü) welded assemblies;
(iii) coarse sandwich constructions;
(iv) plastic parts are checked for the presence of metal particles or
(V) electric equipment such as switches, capacitors and radio cavities, and tubes.

XEROGRAPHY (XERO RADIOGRAPHY)

What is Xerography?

In conventional X-ray radiography, an image is produced by using photo chemical techniques in which X-rays are passed through the part on to a film coated with photo sensitive material like silver nitrate.

Xerography uses the same physical principle but is a photoelectric process, rather than a photo chemical process.

Xerography process is considered as a "dry" method of radiography in which a xerographic plate takes the place of X-ray film.

Arrangement and Working Principle

Figure shows the arrangement and working principle of xerography testing.

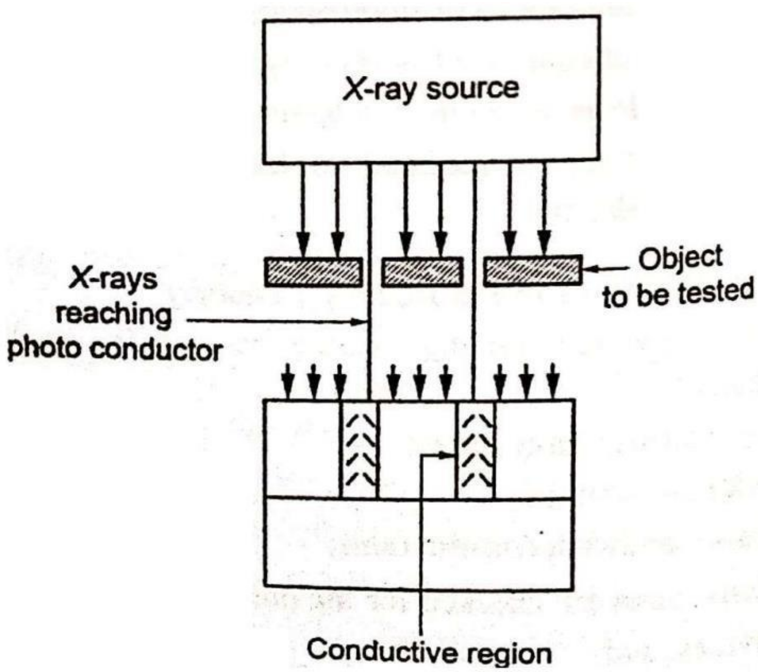


Figure. Principle of xerography testing

A thin layer of photo conducting material, like selenium, is attached to a rigid aluminium plate. A charge is applied to the base in total darkness, and the photo conducting material (selenium) acts as an insulator.

When exposed to X-rays, the conductivity of the selenium is increased and the surface is discharged according to the thickness of the material through which the radiation is passed. In this way, a hidden image of defect in the part is created on the surface of the plate in the form of electro static charge pattern. This image is then developed in a closed chamber by spraying a charged blue powder on the surface of the plate, where it is attracted to the charged pattern and forms a powder image.

This powder image is made permanent by transforming into plastic coated paper by heating and fusing. The image is now ready for viewing and evaluation.

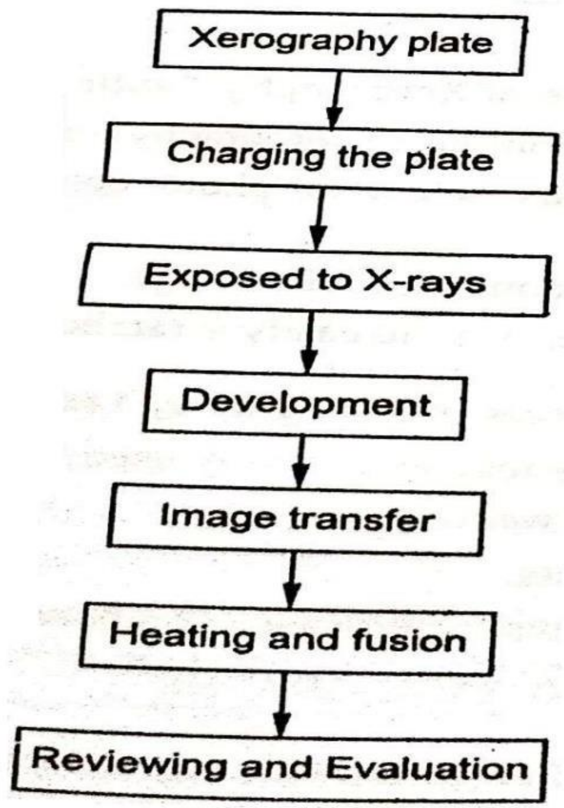


Figure. Functional steps of xerography

techniques Advantages of Xerography Testing

Some of the advantages of xerography testing are as follows:

(i) Reduced cost of material (no film is required).
(ii) High degree of image sharpness (due to free of graininess of the selenium).
(iii) Ease of reviewing.
(iv) Reduced exposure to radiation hazards.
(v) Better speed of production (entire process may be completed within 60 seconds).
(vi) No dark room requirement as in conventional radiography testing

Limitations of Xerography Testing

Some of the limitations of xerography testing are as follows:

(i) The amorphous selenium photo conductor coat is highly fragile.
(ii) Low inherent contrast of the image.
(iii) Selenium layer is quite easily scratched.

Applications of Xerography Testing

The xerography testing is widely used for:

(i) Inspection of welding.
(ii) Casting defects.
(iii) Detecting flaws in aerospace components.

COMPUTED RADIOGRAPHY

What is Computed Radiography?

Computed radiography (CR) uses a cassette similar to a film cassette. Instead of film, the cassette holds an imaging plate.

A computed radiography system consists of an image reader/digitizer, cassettes containing imaging plates (photo stimulable-phosphor plates), a computer console with analysing software, monitors and a printer.

Arrangement and Working Principle

Figure shows the arrangement of equipment and working principle of computed radiography.

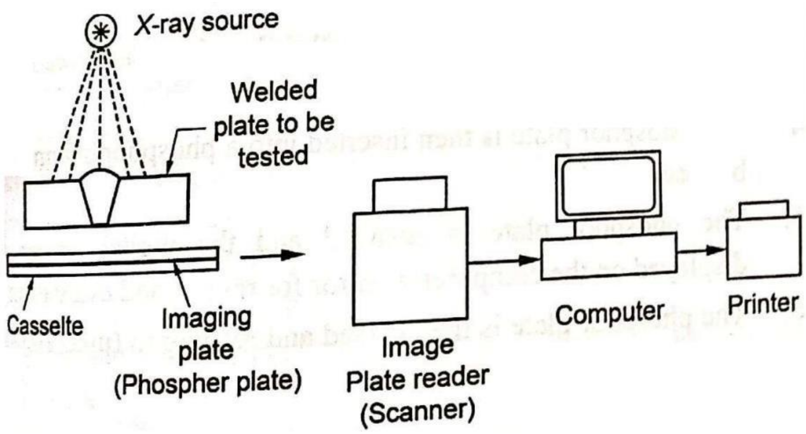


Figure. Working principle of computed radiography

Imaging plates are inserted in a radiographic table's cassette holder and images are acquired using the X-ray system. When exposed to X-rays, electrons in the phosphor plate are excited into a higher energy state, forming a latent image. Then it is inserted in the image reader.

An image reader scans the phosphor plate with laser spot. When the trapped electrons absorb the laser energy, they emit as they return to their ground state.

This light is collected by a light guide and transmitted to a signal, then it is amplified and converted into a digital signal, multiplier tube, which produces an analog electrical and digitally stored. The plate can be reused after it is exposed to an erasing light that removes residual radiation.

Steps involved in Computed Radiography

The various steps involved in computed radiography are given below:

1. The phosphor plate is inserted into a cassette.
2. Placing and exposing the phosphor plate by the X-ray source with the part to be inspected.
3. A radiation pattern is exposed on the phosphor plate creating a latent image.
4. The phosphor plate is then inserted into a phosphor scanner to be read.
5. The phosphor plate is scanned and the digital image is displayed on the computer monitor for review and evaluation.
6. The phosphor plate is then erased and reading to (upto 10,000 times reusable).

Difference between Computed Radiography and Film Radiography

Below table presents the comparison between computed radiography and film radiography.

Table. Computed radiography Vs Film radiography

S.No.	Computed Radiography	Film Radiography
1	Phosphor plate inserted in the cassette.	Film is inserted in the cassette
2	Light tight dark room is not required for imaging	Light tight dark room is required for imaging
3	No chemical processing is required to develop image.	Chemical processing is required to develop image
4	Less time consuming to read the image (1 to 2 minutes)	More time consuming to read the image (8 to 10 minutes).
5	Derived digital image can be enhanced for review	Film image cannot be enhanced

Advantages of Computed Radiography

The main advantages of the computed radiography over the film radiography are as follows:

(i) Shorter exposure time (only 10-50% of film).
(ii) Higher dynamic range (less retakes and different thickness in one shot).
(ii) Phosphor plates can be reused (consumable cost saving).
(iv) No chemicals and dark room is required.
(v) Lower doses (more safety).

(vi) Easier and faster analysis of defects.
(vii) Flexible imaging plates are possible (phosphor plates can be bent).
(viii) Ability to copy and duplicate without loss of image quality (no image degradation).

Limitations of Computed Radiography

Some of the limitations of computed radiography are as follows:

(i) High initial cost on equipment.
(ii) Image plates are sensitive to fogging (need to be erased daily).
(iii) Wider latitude (degradation of contrast is possible).

Applications of Computed Radiography

Typical applications of computed radiography include:

(i) On-site inspection of pipes in processing industry for leaking, wall thickness and corrosion measurement.
(ii) Inspection of composite materials used in aerospace applications.
(iii) On-site scanning of circumferential and longitudinal welds.
(iv) Inspection of casting with different thickness in one image.

COMPUTED TOMOGRAPHY IN NON-DESTRUCTIVE TESTING

What is Computed Tomography?

Computed tomography (CT) is a newer method of non- destructive evaluation by producing 2D and 3D images of an object from X-ray sources.

From CT images, the following characteristics of the internal structure of an object can be obtained:

(i) Internal defects (cracks, voids, inclusions, porosity and delamination).
(ii) Dimensional measurements (thickness, diameter, shape of the in homogeneity and three dimensional geometry).
(iii) Physical and mechanical properties (density, crack growth, phase identification and impurities).

Arrangement and Working Principle

Figure shows the principle of computed tomography used in non-destructive evaluation of components.

The test component is placed on a computer controlled turntable which is located between a radiation source and the imaging system. The turntable and the imaging systems are connected to a computer so that X-ray images collected can be correlated to the position of the component.

The principal components like X-rays tube, an X-ray detector and a turn table are enclosed within a radiation shielding cabinet to meet the safety concerns.

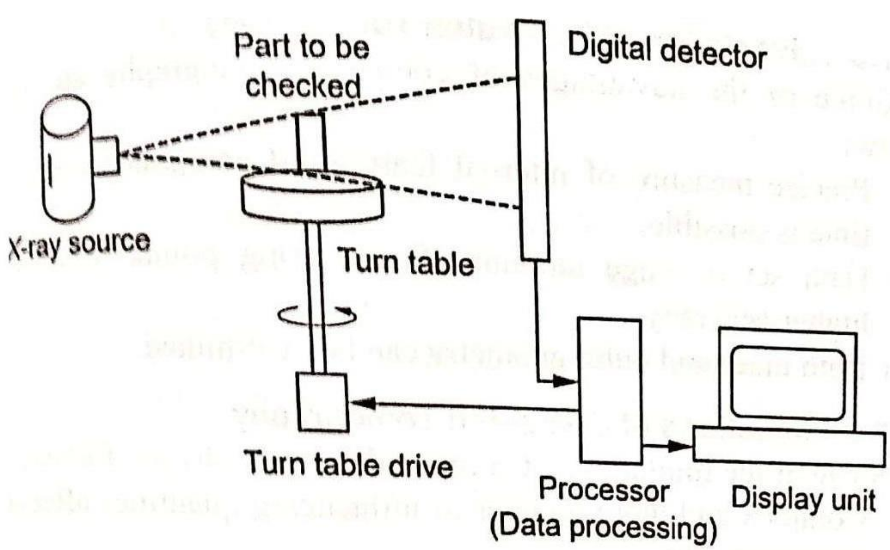


Figure. Principle of computed tomography

During computed tomography scanning, several 2D X-ray images were taken around the object, preferably covering 360 degrees.

CT systems typically acquire images according to the desired final resolution. For example:

- ✓ One image every degree – 360 images
- ✓ One image every 0.1 degree - 3600 images

The 2D digital images taken 'are saved directly into a single folder for further processing.

CT calibration and CT reconstruction algorithms are used to reconstruct the 3D CT volume. These 3D images are made of 3 dimensional pixels (voxels). With the help of visualization software, the 3D images can be visualized in real time, Because of this facility, it is possible to slice through anywhere in the object, to check for defects and to take accurate measurement is possible.

Advantages of Computed Tomography

Some of the advantages of computed tomography are given below:

(i) Precise measure of internal features of components in short time is possible.

(ii) Data set of huge amount of measuring points resulted in higher accuracy.

(iii) Both inner and outer geometry can be determined.

Limitations of Computed Tomography

Some of the limitations of computed tomography are follows:

(i) Complex and more number of influencing quantities affecting measurements.

(ii) No standard test procedures are available.

(iii) Scanning multiple materials within one product may encounter problem in data acquisition.

(iv) High equipment cost.

Applications of Computed Tomography

Typical applications of computed tomography include:

(i) Crack detection and measurement of aero-space structures.

(ii) Defect analysis like porosity and voids present in castings.

(iii) Density analysis of materials.

(iv) Failure analysis of components (V)Non-destructive internal measurements.