i) Static tension and compression tests

When subjected to [tension](https://www.britannica.com/science/tension-physics) (pulling apart), a material [elongates](https://www.britannica.com/science/elongation-physics) and eventually breaks. A simple static tension test determines the breaking point of the material and its elongation, designated as [strain](https://www.britannica.com/science/strain-mechanics) (change in length per unit length). If a 100-millimetre steel bar elongates 1 millimetre under a given load, for example, strain is (101–100)/100 = 1/100 = 1 percent.

A static tension test requires a test piece, usually cylindrical, or with a middle section of smaller diameter than the ends; a test machine that applies, measures, and records various loads; and an appropriate set of grips to grasp the test piece. In the static tension test, the test machine uniformly stretches a small part (the test section) of the test piece. The length of the test section (called the gauge length) is measured at different loads with a device called an extensometer; these measurements are used to compute strain.

Conventional [testing machines](https://www.britannica.com/technology/testing-machine) are of the constant load, constant load-rate, and constant displacement-rate types. Constant load types employ weights directly both to apply load and to measure it. Constant load-rate test machines employ separate load and measurement units; loads are generally applied by means of a hydraulic ram into which oil is pumped at a constant rate. Constant displacement-rate testing machines are generally driven by gear-screws.

Test machine grips are designed to transfer load smoothly into the test piece without producing local stress concentrations. The ends of the test piece are often slightly enlarged so that if slight concentrations of stress are present these will be directed to the gauge section, and failures will occur only where measurements are being taken. Clamps, pins, threading, or bonding are employed to hold the test piece. [Eccentric](https://www.merriam-webster.com/dictionary/Eccentric) (nonuniform) loading causes bending of the sample in addition to tension, which means that stress in the sample will not be uniform. To avoid this, most gripping devices incorporate one or two swivel joints in the linkage that carries the load to the test piece. Air bearings help to correct horizontal misalignment, which can be troublesome with such brittle materials as ceramics.

Static [compression](https://www.britannica.com/science/compression) tests determine a material’s response to [crushing](https://www.britannica.com/science/crushing-strength), or support-type loading (such as in the beams of a house). Testing machines and extensometers for [compression tests](https://www.britannica.com/technology/compressive-strength-test) resemble those used for tension tests. Specimens are generally simpler, however, because gripping is not usually a problem. Furthermore, specimens may have a constant cross-sectional area throughout their full length. The gauge length of a sample in a compression test is its full length. A serious problem in compression testing is the possibility that the sample or load chain may buckle (form bulges or bend) prior to material failure. To prevent this, specimens are kept short and stubby.

Static shear and [bending tests](https://www.britannica.com/technology/bending-test)

Inplane shear tests indicate the [deformation](https://www.britannica.com/science/shear) response of a material to forces applied tangentially. These tests are applied primarily to thin sheet materials, either metals or composites, such as fibreglass reinforced [plastic](https://www.britannica.com/science/plastic).

A [homogeneous](https://www.merriam-webster.com/dictionary/homogeneous) material such as untreated steel casting reacts in a different way under [stress](https://www.britannica.com/science/shear-stress) than does a grained material such as [wood](https://www.britannica.com/science/wood-plant-tissue) or an adhesively bonded joint. These anisotropic materials are said to have preferential planes of weakness; they resist stress better in some planes than in others, and consequently must undergo a different type of shear test.

[Shear strength](https://www.britannica.com/science/shear-strength) of rivets and other fasteners also can be measured. Though the state of stress of such items is generally quite complicated, a simple shear test, providing only limited information, is adequate for most purposes.

Tensile testing is difficult to perform directly upon certain brittle materials such as [glass](https://www.britannica.com/technology/glass) and ceramics. In such cases, a measure of the [tensile strength](https://www.britannica.com/science/tensile-strength) of the material may be obtained by performing a bend test, in which tensile (stretching) stresses develop on one side of the bent member and corresponding compressive stresses develop on the opposite side. If the material is substantially stronger in compression than tension, failure initiates on the tensile side of the member and, hence, provides the required information on the material tensile strength. Because it is necessary to know the exact magnitude of the tensile stress at failure in order to establish the strength of the material, however, the bending test method is applicable to only a very restricted class of materials and conditions.

Measures of [ductility](https://www.britannica.com/science/ductility-physics)

Ductility is the capacity of a material to deform permanently in response to stress. Most common steels, for example, are quite ductile and hence can accommodate local stress concentrations. Brittle materials, such as [glass](https://www.britannica.com/technology/glass), cannot accommodate concentrations of stress because they lack ductility; they, therefore, fracture rather easily.

When a material specimen is stressed, it deforms elastically (i.e., recoverably) at first; thereafter, deformation becomes permanent. A cylinder of steel, for example, may “neck” (assume an hourglass shape) in response to stress. If the material is ductile, this local deformation is permanent, and the test piece does not assume its former shape if the stress is removed. With sufficiently high stress, fracture occurs.

Ductility can be expressed as strain, reduction in area, or toughness. Strain, or change in length per unit length, was explained earlier. Reduction in area (change in area per unit area) may be measured, for example, in the test section of a steel bar that necks when stressed. Toughness measures the amount of energy required to deform a piece of material permanently. Toughness is a desirable material property in that it permits a component to deform plastically, rather than crack and perhaps fracture.

[Hardness](https://www.britannica.com/technology/hardness-tester) testing

Based on the idea that a material’s response to a load placed at one small point is related to its ability to deform permanently (yield), the hardness test is performed by pressing a hardened steel ball ([Brinell test](https://www.britannica.com/science/Brinell-hardness-test)) or a steel or diamond cone ([Rockwell test](https://www.britannica.com/technology/Rockwell-hardness-tester)) into the surface of the test piece. Most hardness tests are performed on commercial machines that register arbitrary values in inverse relation to the depth of penetration of the ball or cone. Similar indentation tests are performed on [wood](https://www.britannica.com/science/wood-plant-tissue). Hardness tests of materials such as rubber or [plastic](https://www.britannica.com/science/plastic) do not have the same [connotation](https://www.merriam-webster.com/dictionary/connotation) as those performed on metals. Penetration is measured, of course, but deformation caused by testing such materials may be entirely temporary.

Some hardness tests, particularly those designed to provide a measure of wear or abrasion, are performed dynamically with a weight of given magnitude that falls from a prescribed height. Sometimes a [hammer](https://www.britannica.com/technology/hammer-tool) is used, falling vertically on the test piece or in a pendulum motion.

[Impact test](https://www.britannica.com/technology/impact-test)

Many materials, sensitive to the presence of flaws, cracks, and notches, fail suddenly under impact. The most common impact tests (Charpy and Izod) employ a swinging [pendulum](https://www.britannica.com/technology/pendulum) to strike a notched bar; heights before and after impact are used to compute the energy required to fracture the bar and, consequently, the bar’s impact strength. In the [Charpy test](https://www.britannica.com/technology/Charpy-impact-test), the test piece is held horizontally between two vertical bars, much like the lintel over a door. In the [Izod test](https://www.britannica.com/technology/Izod-impact-test), the specimen stands erect, like a fence post. Shape and size of the specimen, mode of support, notch shape and geometry, and velocities at impact are all varied to produce specific test conditions. Nonmetals such as wood may be tested as supported beams, similar to the Charpy test. In nonmetal tests, however, the striking hammer falls vertically in a guide column, and the test is repeated from increasing heights until failure occurs.

Some materials vary in impact strength at different temperatures, becoming very [brittle](https://www.britannica.com/science/brittleness-metallurgy) when cold. Tests have shown that the decrease in material strength and elasticity is often quite abrupt at a certain temperature, which is called the transition temperature for that material. Designers always specify a material that possesses a transition temperature well below the range of heat and cold to which the structure or machine is exposed. Thus, even a building in the tropics, which will doubtless never be exposed to freezing weather, employs materials with transition temperatures slightly below freezing.

Fracture toughness tests

The stringent materials-reliability requirements of the space programs undertaken since the early 1960s brought about substantial changes in design philosophy. Designers asked materials engineers to devise quantitative tests capable of measuring the [propensity](https://www.merriam-webster.com/dictionary/propensity) of a material to [propagate](https://www.merriam-webster.com/dictionary/propagate) a [crack](https://www.britannica.com/science/cracking-materials-failure). Conventional methods of stress analysis and materials-property tests were retained, but interpretation of results changed. The [criterion](https://www.merriam-webster.com/dictionary/criterion) for failure became sudden [propagation](https://www.merriam-webster.com/dictionary/propagation) of a crack rather than [fracture](https://www.britannica.com/science/fracture-in-mechanics). Tests have shown that cracks occur by opening, when two pieces of material part in vertical plane, one piece going up, the other down; by edge sliding, where the material splits in horizontal plane, one piece moving left, the other right; and by tearing, where the material splits with one piece moving diagonally upward to the left, the other moving diagonally downward to the right.

Creep test

[Creep](https://www.britannica.com/science/creep-deformation) is the slow change in the dimensions of a material due to prolonged stress; most common metals exhibit creep behaviour. In the creep test, loads below those necessary to cause instantaneous fracture are applied to the material, and the deformation over a period of time (creep strain) under constant load is measured, usually with an extensometer or [strain gauge](https://www.britannica.com/technology/strain-gauge). In the same test, time to failure is also measured against level of stress; the resulting curve is called stress rupture or creep rupture. Once creep strain versus time is plotted, a variety of mathematical techniques is available for [extrapolating](https://www.merriam-webster.com/dictionary/extrapolating) creep behaviour of materials beyond the test times so that designers can utilize thousand-hour test data, for example, to predict ten-thousand-hour behaviour.

A material that yields continually under stress and then returns to its original shape when the stress is released is said to be [viscoelastic](https://www.britannica.com/science/viscoelasticity); this type of response is measured by the [stress-relaxation test](https://www.britannica.com/technology/stress-relaxation-test). A prescribed displacement or strain is induced in the specimen and the load drop-off as a function of time is measured. Various viscoelastic theories are available that permit the translation of stress-relaxation test data into predictions about the creep behaviour of the material.

[Fatigue](https://www.britannica.com/science/fatigue-materials-failure)

Materials that survive a single application of stress frequently fail when stressed repeatedly. This phenomenon, known as fatigue, is measured by mechanical tests that involve repeated application of different stresses varying in a regular cycle from maximum to minimum value. Most fatigue-testing machines employ a rotating [eccentric](https://www.merriam-webster.com/dictionary/eccentric) weight to produce this cyclically varying load. A material is generally considered to suffer from low-cycle fatigue if it fails in 10,000 cycles or less.

The stresses acting upon a material in the real world are usually random in nature rather than cyclic. Consequently, several [cumulative](https://www.merriam-webster.com/dictionary/cumulative) fatigue-damage theories have been developed to enable investigators to [extrapolate](https://www.merriam-webster.com/dictionary/extrapolate) from cyclic test data a prediction of material behaviour under random stresses. Because these theories are not applicable to most materials, a relatively new technique, which involves mechanical application of random fatigue stresses, statistically matched to real-life conditions, is now employed in most materials test laboratories.

Material fatigue involves a number of phenomena, among which are atomic [slip](https://www.britannica.com/science/slip-crystals) (in which the upper plane of a [metal](https://www.britannica.com/science/metal-chemistry) crystal moves or slips in relation to the lower plane, in response to a shearing stress), crack initiation, and crack [propagation](https://www.merriam-webster.com/dictionary/propagation). Thus, a fatigue test may measure the number of cycles required to initiate a crack, as well as the number of cycles to failure.

ii) 1. Pre-cleaning:

The test surface is cleaned to remove any dirt, paint, oil, grease or any loose scale that could either keep penetrant out of a defect or cause irrelevant or false indications. Cleaning methods may include [solvents](https://en.wikipedia.org/wiki/Solvent), alkaline cleaning steps, [vapour degreasing](https://en.wikipedia.org/wiki/Vapour_degreasing), or media blasting. The end goal of this step is a clean surface where any defects present are open to the surface, dry, and free of contamination. Note that if media blasting is used, it may "work over" small discontinuities in the part, and an etching bath is recommended as a post-blasting treatment.

[](https://en.wikipedia.org/wiki/File:KD-Check_Anwendungsbild.jpg)

Application of the penetrant to a part in a ventilated test area.

2. Application of Penetrant:

The penetrant is then applied to the surface of the item being tested. The penetrant is usually a brilliant coloured mobile fluid with high wetting capability.[[1]](https://en.wikipedia.org/wiki/Dye_penetrant_inspection#cite_note-1) The penetrant is allowed "dwell time" to soak into any flaws (generally 5 to 30 minutes). The dwell time mainly depends upon the penetrant being used, the material being tested and the size of flaws sought. As expected, smaller flaws require a longer penetration time. Due to their incompatible nature, one must be careful not to apply solvent-based penetrant to a surface which is to be inspected with a water-washable developer.

3. Excess Penetrant Removal:

The excess penetrant is then removed from the surface. The removal method is controlled by the type of penetrant used. Water-washable, solvent-removable, [lipophilic](https://en.wikipedia.org/wiki/Lipophilicity) post-emulsifiable, or [hydrophilic](https://en.wikipedia.org/wiki/Hydrophilicity) post-emulsifiable are the common choices. [Emulsifiers](https://en.wikipedia.org/wiki/Emulsifier) represent the highest sensitivity level, and chemically interact with the oily penetrant to make it removable with a water spray. When using solvent remover and lint-free cloth it is important to not spray the solvent on the test surface directly, because this can remove the penetrant from the flaws. If excess penetrant is not properly removed, once the developer is applied, it may leave a background in the developed area that can mask indications or defects. In addition, this may also produce false indications severely hindering the ability to do a proper inspection. Also, the removal of excessive penetrant is done towards one direction either vertically or horizontally as the case may be.

4. Application of Developer:

After excess penetrant has been removed, a white developer is applied to the sample. Several developer types are available, including: [non-aqueous wet developer](https://en.wikipedia.org/w/index.php?title=Non-aqueous_wet_developer&action=edit&redlink=1), dry powder, water-suspendable, and water-soluble. Choice of developer is governed by penetrant compatibility (one can't use water-soluble or -suspendable developer with water-washable penetrant), and by inspection conditions. When using non-aqueous wet developer (NAWD) or dry powder, the sample must be dried prior to application, while soluble and suspendable developers are applied with the part still wet from the previous step. NAWD is commercially available in aerosol spray cans, and may employ [acetone](https://en.wikipedia.org/wiki/Acetone), [isopropyl alcohol](https://en.wikipedia.org/wiki/Isopropyl_alcohol), or a propellant that is a combination of the two. Developer should form a semi-transparent, even coating on the surface.

The developer draws penetrant from defects out onto the surface to form a visible indication, commonly known as bleed-out. Any areas that bleed out can indicate the location, orientation and possible types of defects on the surface. Interpreting the results and characterizing defects from the indications found may require some training and/or experience [the indication size is not the actual size of the defect].

5. Inspection:

The inspector will use visible light with adequate intensity (100 [foot-candles](https://en.wikipedia.org/wiki/Foot-candles) or 1100 [lux](https://en.wikipedia.org/wiki/Lux) is typical) for visible dye penetrant. Ultraviolet (UV-A) radiation of adequate intensity (1,000 micro-watts per centimetre squared is common), along with low ambient light levels (less than 2 foot-candles) for fluorescent penetrant examinations. Inspection of the test surface should take place after 10- to 30-minute development time, and is dependent on the penetrant and developer used. This time delay allows the blotting action to occur. The inspector may observe the sample for indication formation when using visible dye. It is also good practice to observe indications as they form because the characteristics of the bleed out are a significant part of interpretation characterization of flaws.

6. Post Cleaning:

The test surface is often cleaned after inspection and recording of defects, especially if post-inspection coating processes are scheduled.

There are several types of electrical currents used in magnetic particle inspection. For a proper current to be selected one needs to consider the part geometry, material, the type of discontinuity one is seeking, and how far the magnetic field needs to penetrate into the part.

* Alternating current (AC) is commonly used to detect surface discontinuities. Using AC to detect subsurface discontinuities is limited due to what is known as the [skin effect](https://en.wikipedia.org/wiki/Skin_effect), where the current runs along the surface of the part. Because the current alternates in polarity at 50 to 60 cycles per second it does not penetrate much past the surface of the test object. This means the magnetic domains will only be aligned equal to the distance AC current penetration into the part. The frequency of the alternating current determines how deep the penetration.
* Full wave DC[[clarification needed](https://en.wikipedia.org/wiki/Wikipedia:Please_clarify) - [discussion](https://en.wikipedia.org/wiki/Talk:Magnetic_particle_inspection#Rectifier)] (FWDC) is used to detect subsurface discontinuities where AC can not penetrate deep enough to magnetize the part at the depth needed. The amount of magnetic penetration depends on the amount of current through the part DC is also limited on very large cross-sectional parts in terms of how effectively it will magnetize the part.
* [Half wave DC](https://en.wikipedia.org/wiki/Rectifier#Half-wave_rectification) (HWDC, [pulsating DC](https://en.wikipedia.org/wiki/Pulsating_DC)) works similar to full wave DC, but allows for detection of surface breaking indications and has more magnetic penetration into the part than FWDC. HWDC is advantageous for inspection process as it actually helps move the magnetic particles during the bathing of the test object. The aid in particle mobility is caused by the half-wave pulsating current waveform. In a typical mag pulse of 0.5 seconds there are 15 pulses of current using HWDC. This gives the particle more of an opportunity to come in contact with areas of magnetic flux leakage.

An AC electromagnet is the preferred method for find surface breaking indication. The use of an electromagnet to find subsurface indications is difficult. An AC electromagnet is a better means to detect a surface indication than HWDC, DC, or permanent magnet, while some form of DC is better for subsurface defects.

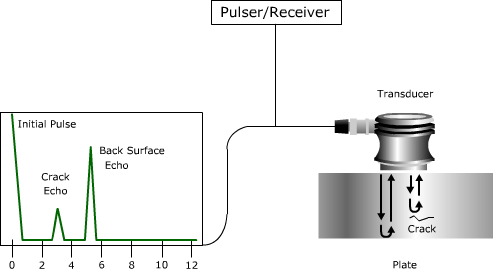
iii)

Ultrasonic Testing (UT) uses high frequency sound waves (typically in the range between 0.5 and 15 MHz) to conduct examinations and make measurements. Besides its wide use in engineering applications (such as flaw detection/evaluation, dimensional measurements, material characterization, etc.), ultrasonics are also used in the medical field (such as sonography, therapeutic ultrasound, etc.).

In general, ultrasonic testing is based on the capture and quantification of either the reflected waves (pulse-echo) or the transmitted waves (through-transmission). Each of the two types is used in certain applications, but generally, pulse echo systems

are more useful since they require one-sided access to the object being inspected.

## Basic Principles

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

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

## Advantages and Disadvantages

The primary advantages and disadvantages when compared to other NDT methods are:

Advantages

* It is sensitive to both surface and subsurface discontinuities.
* The depth of penetration for flaw detection or measurement is superior to other NDT methods.
* Only single-sided access is needed when the pulse-echo technique is used.
* It is highly accurate in determining the reflector position and estimating its size and shape.
* Minimal part preparation is required.
* It provides instantaneous results.
* Detailed images can be produced with automated systems.
* It is nonhazardous to operators or nearby personnel and does not affect the material being tested.
* It has other uses, such as thickness measurement, in addition to flaw detection.
* Its equipment can be highly portable or highly automated.

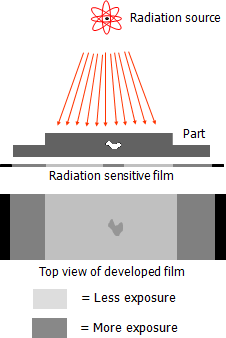
Disadvantages

* Surface must be accessible to transmit ultrasound.
* Skill and training is more extensive than with some other methods.
* It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
* Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
* Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
* Linear defects oriented parallel to the sound beam may go undetected.
* Reference standards are required for both equipment calibration and the characterization of flaws.

Radiographic Testing

Radiography is used in a very wide range of aplications including medicine, engineering, forensics, security, etc. In NDT, radiography is one of the most important and widely used methods. Radiographic testing (RT) offers a number of advantages over other NDT methods, however, one of its major disadvantages is the health risk associated with the radiation.

In general, RT is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by a radiation sensitive film (Film Radiography) or by a planer array of radiation sensitive sensors (Real-time Radiography). Film radiography is the oldest approach, yet it is still the most widely used in NDT.



## Basic Principles

In radiographic testing, the part to be inspected is placed between the radiation source and a piece of radiation sensitive film. The radiation source can either be an X-ray machine or a radioactive source (Ir-192, Co-60, or in rare cases Cs-137). The part will stop some of the radiation where thicker and more dense areas will stop more of the radiation. The radiation that passes through the part will expose the film and forms a shadowgraph of the part. The film darkness (density) 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 can be used to determine thickness or composition of material and would also reveal the presence of any flaws or discontinuities inside the material.

## Advantages and Disadvantages

The primary advantages and disadvantages as compared to other NDT methods are:

Advantages

* Both surface and internal discontinuities can be detected.
* Significant variations in composition can be detected.
* It has a very few material limitations.
* Can be used for inspecting hidden areas (direct access to surface is not required)
* Very minimal or no part preparation is required.
* Permanent test record is obtained.
* Good portability especially for gamma-ray sources.

Disadvantages

* Hazardous to operators and other nearby personnel.
* High degree of skill and experience is required for exposure and interpretation.
* The equipment is relatively expensive (especially for x-ray sources).
* The process is generally slow.
* Highly directional (sensitive to flaw orientation).
* Depth of discontinuity is not indicated.
* It requires a two-sided access to the component.

iii **Dye Penetrant**

PT can detect discontinuities open to the surface in all materials except porous ones. It is commonly used on nonmagnetic materials such as austenitic stainless steel where MT is not possible. A typical colour contrast technique would be carried out as follow

Diagram

Description automatically generated

The test surface is thoroughly cleaned and degreased.

The liquid penetrant is applied to the area of concern,

The penetrant is left for a dwell time as recommended by the manufacturer or code (see ASME V requirements later) to give it time to enter any surface-breaking indications by capillary action.

Excess penetrant is removed from the component surface taking care to prevent the penetrant being washed out of any defects.

A light coating of the white developer is sprayed on to the component. The penetrant is drawn out of any discontinuities (by a reverse capillary action coupled with a blotting effect from the developer) and stains the developer. An indication of the depth of the discontinuity can be determined from the amount of bleed-out of penetrant from the discontinuity.

**Colour contrast PT** uses a red penetrant against a white background and requires viewing to take place under good lighting conditions (1000 lux is required under ASME V).

**Fluorescent PT** uses a dye visible under ultraviolet light and has to be viewed in a darkened area. This technique is actually the more sensitive and will therefore detect finer linear-type indications than will the colour contrast technique.

Dye penetrant testing is an effective method of testing for surface-breaking defects such as cracks or porosity. The process involves spraying the surface to be tested with a penetrating liquid, often with a colored or fluorescent dye. After allowing the penetrant to work for a few minutes, the surface is washed and then either left or coated with a dye-absorbing material. After a time the liquid in any crack seeps out and either can be seen as a [discoloration](https://www.sciencedirect.com/topics/materials-science/discoloration) of the dye-absorbing coating, or can be seen under [ultraviolet light](https://www.sciencedirect.com/topics/engineering/ultraviolet-light). The technique can be used on as-cast or machined surfaces. An example of the type of results obtained

A picture containing indoor, pan, disk brake, metal

Description automatically generated

Magnetic Particles

Magnetic particle inspection is an NDT method used to reveal surface and near surface discontinuities in magnetic materials. This inspection method can only be used on materials that can be magnetized (known as ferrous). The MPI process, when properly performed, establishes a field leakage site on the surface of the part below which the flaw lies. This chapter presents theory and practical guidance for the performance of magnetic particle inspection MPI is the method of choice on ferrous materials instead of liquid penetrant because it is faster, requires less surface preparation, and in some instances is able to locate subsurface flaws. MPI relies on the principle of magnetism (paragraph 3.2.1). Very small ferrous particles, which are suspended in a bath of oil or water, are attracted to magnetic field leakage sites, just as iron filings are attracted to the poles of a magnet. Cracks and similar types of discontinuities cause disruptions in the magnetic field of magnetized parts, in turn attracting these ferrous particles to the leakage site. This allows the inspector to visualize where the discontinuities are located in the part. The keys to a successful magnetic particle inspection are the correct amount of magnetization of the part, in an optimum direction with respect to flaws, and adequate contrast between the part’s surface and the particles used to identify the flaw. The particles used are precipitated soft iron, and are stained or dyed in various colors, usually with a fluorescent dye or a red dye. Fluorescent dyes on particles in a liquid suspension are used to find very tight surface flaws. Visible dyes on dry particles are less sensitive to tiny surface defects, but are better for finding subsurface flaws. The type of flaw and/or the inspection environment determines selection of the color or type of particles.

When parts made of ferrous materials, such as iron, are placed in a strong magnetic field or have electric current flowing through them, they will become ''magnetized.'' The degree of magnetization is affected by the strength of the magnetizing field or the amount of current flow. How strongly the ferrous part will be magnetized after the magnetizing force is removed is called ''retentivity.'' Permanent magnets have high retentivity and conductors normally have low retentivity. When a surface or near-surface discontinuity interrupts the magnetic field in a magnetized part, some of the field is forced into the air above the discontinuity resulting in a leakage field. The size and strength of the leakage field depends on the size and proximity of the discontinuity to the magnetic field. The discontinuity is detected by the use of finely divided iron particles applied to a part’s surface and attracted to the leakage field. This collection of particles indicates the presence and location of the discontinuity.

Horseshoe Magnet. A familiar type of magnet is the horseshoe magnet. Like a bar magnet, this is a permanent magnet and possesses residual magnetism. It will attract iron filings to its ends where a leakage field occurs. By convention, these ends are commonly called ''north'' and ''south'' poles, indicated by N and S on the diagram. Continuous magnetic flux lines, or lines of force in leakage fields, flow from the north to the south pole. In an ideal horseshoe magnet, the flux lines leave only at the poles and consequently an external magnetic force capable of attracting magnetic materials exists only at the poles. This action provides an example of a longitudinal magnetic field. In a real horseshoe magnet very small discontinuities are distributed throughout creating small, weak, localized leakage fields distributed over the surface of the magnet.

A picture containing text, clipart

Description automatically generated

A typical stationary horizontal wet magnetic particle inspection unit has two contact heads (headstock and tailstock) for either direct contact or central conductor, circular magnetization using a copper rod between the heads, or a cable connected to a contact block between the heads. Many of the units contain a coil used for longitudinal magnetization. The coil and one contact head are movable on rails. The other contact head is fixed; the contact plate on it being air cylinder operated, provides a means for clamping the part. The unit has a self-contained power supply with all the necessary electrical controls. Magnetizing currents are usually three-phase full-wave DC or AC depending upon usage requirements. The units are made in several different sizes to accommodate different length parts and with various maximum output currents. A fulllength tank with pump, agitation and circulation system for wet inspection media is located beneath the head and coil mounting rails. A hand hose with nozzle is provided for applying the bath. On special units, automatic bath application facilities are provided

The distinguishing feature of mobile equipment is the wheels the unit is mounted on. Mobile units can be easily moved to any inspection site where suitable line input voltages and current capacity are available. Mobile inspection units are available in several sizes ranging from 3000 to 6000-amperes of AC and half-wave DC outputs. The units may have remote current output, ON/OFF and MAG/DEMAG controls that permit one-man operation at the site of inspection. The units can be used with either rigid or cable-wrapped coils for longitudinal magnetization and demagnetization. Cables connected to a part or passing through it are used for circular magnetization or demagnetization. This type of equipment is sturdy and well suited for both fabrication and overhaul inspections. CAUTION Contact prods SHALL NOT be used on aerospace components or parts

Portable MPI equipment is manufactured in a variety of sizes, shapes, voltages, and current outputs. Portable equipment operates on the same principle as stationary and mobile equipment; however, the compactness allows areas to be inspected where larger equipment may prohibit access. Portable equipment is usually operated on 110 or 220 volt AC and is rated between 200 and 2 000-amperes. Portable equipment can be either AC, or a combination of AC and half wave DC. They can be used wherever an adequate 115-volt AC power source exists.

Portable power packs are high Amp output devices. Examples of this equipment are the Magnaflux P-1500 or DA-1500, which are capable of putting out 1500-Amps AC or HWDC fields. These power packs weigh in at 93-pounds and have a duty cycle of 2-minutes on and 2-minutes off. Field selection is determined by using the appropriate field cable connector. Current output is indefinitely variable from zero to maximum by use of the current control located on the front panel meter. The actual current output is determined by cable size and length. These units can also be found mounted to carts

The term probe and yoke are virtually interchangeable in this discussion. Probes and yokes (e.g., Magnaflux DA-200 or Y-7) are versatile, lightweight (approximately 8-pounds) hand-held devices used for inspection of small parts and localized inspections of large parts. Probes and yokes are easily used and often provide adequate inspections. They are essentially U-shaped laminated cores of soft iron with a coil wound around the base of the U. Probes and yokes are capable of putting a strong magnetic field into that portion of the part that lay between the poles of the probe or yoke. When electrical current is passing through the coil, the two ends of the core are magnetized with opposite polarity and the combination is an electromagnet similar to a permanent horseshoe magnet. They are capable of putting out constant AC or pulsed DC fields with the flip of a switch. A probe or yoke may be used to induce only a longitudinal field in a part. No electrical current passes through the part. They also have a duty cycle that will be defined in the operating instructions for the specific yoke. As an example, for the DA-200, duty cycle is 2 minutes on and 2 minutes off.

Alternating current, which is single phase when used directly for magnetizing purposes, usually has a frequency of 50 or 60-hertz. The AC longitudinal magnetizing field induced in the part is restricted to the surface due to its skin effect. AC provides a very desirable field for maintenance and overhaul inspection work due to its high sensitivity to surface defects. The peak AC current produces a surge peak in the magnetic field well above the average DC current required to develop a field of equivalent strength.

AC magnetic fields form eddy currents that tend to guide or restrict the magnetic lines of flux into a narrow pattern between the poles. Alternating magnetic fields cause surface vibration that adds mobility to the inspection particles to form larger and more distinct build-up of particles at the defect. An AC magnetic field can be used when it is necessary to discriminate between surface indications and subsurface defects that might be revealed with a DC magnetizing field. Yokes utilizing AC magnetization also have the additional advantage of being readily used for demagnetization.

An electro-magnet powered by DC provides a very strong magnetic field. However, being a constant field and lacking any vibratory action, it is sometimes difficult to gather enough particles at the defect to form a visible indication. To overcome this difficulty, full-wave or half-wave rectified single-phase alternating current is used. This adds mobility to the magnetic inspection particles comparable to that produced by AC.

Permanent magnets can also be used to magnetize parts in MPI. This method of magnetization has severe limitations and is properly used only when these limitations do not prevent the formation of satisfactory leakage fields at discontinuities. Permanent magnet yokes create longitudinal fields. The poles created on the parts may result in confusing particle indications. Control of field direction is possible only over a limited area. If you stand a permanent bar magnet on end on a steel plate, it will create a radial field in the plate around the pole in contact with the plate. The flux produced by this radial field travels a distance from this point of contact until it leaves the surface of the plate, only to return to the pole at the opposite end of the magnet. Cracks crossing such a field pattern may be seen provided the field produced in the plate is sufficiently strong and properly oriented. The flux generally follows along a straight line drawn between the poles, and is strongest near the poles of the yoke and weakest at the point midway between the poles. The magnetic field strength within the part depends on the strength of the yoke magnetization and the distance between the poles. Outside this limited area, the field spreads out, and cracks favorably located with respect to field direction may or may not be shown. This method of magnetization SHALL NOT be used unless the inspector is aware of, and understands the limitations of this technique.

Diagram

Description automatically generated

For longitudinal magnetization of shafts, spindles, rear axles, and similar small parts, the handheld AC coil offers a simple and convenient method of inspecting for transverse cracks. Parts are magnetized and demagnetized with the same coil. The most common type of demagnetizing equipment consists of an open, tunnel-like coil through which AC is passed at the line frequency, usually 60-Hertz. The larger type of equipment is frequently placed on its own stand, incorporating a track or carriage to facilitate moving large and heavy parts through the demagnetizing equipment. The demagnetizing equipment can also include tabletop units, yokes, or plug-in coils more suited for the demagnetization of small parts. However, the large stationary type of equipment is preferable when geometrically complex parts are involved.

**Ultrasonic Testing**

Ultrasonic inspection is a non-destructive method in which high frequency sound waves are introduced into the material being inspected. Most ultrasonic inspection is done at frequencies between 0.5 and 25 MHz - well above the range of human hearing, which is about 20 Ha to 20 KHz. The sound waves travel through the material with some attendant loss of energy (attenuation) due to material characteristics or are measured after reflection at interfaces (pulse echo) or flaws or are measured at the opposite surface (pulse transmission). The reflected beam is detected and analysed to define the presence and location of flaws. The degree of reflection depends largely on the physical state of matter on the opposite side of the interface, and to a lesser extent on specific physical properties of that matter, for instance, sound waves are almost completely reflected at metal-gas interfaces. Partial reflection accords at metal-liquid or metal-solid interfaces. Ultrasonic testing has a superior penetrating power to radiography and can detect flaws deep in the test specimen (say up to about 6 to 7 meters of steel). It is quite sensitive to small flaws and allows the precise determination of the location and size of the flaws.

ultrasonic waves arriving at an interface between two media are partially reflected in to the medium from which they are incident and partially transmitted in to the other medium. The method of ultrasonic testing which utilizes the transmitted part of the ultrasonic waves is the through transmission method while that which make use of the reflected portion of the waves is classified as the pulse echo test method. An other method which is used for the ultrasonic testing of materials is the resonance method.

In this method two ultrasonic probes are used. One is the transmitter probe and the other is the receiver probe. These probes are situated on opposite side of the specimen

In this method the presence of an internal defect is indicated by a reduction in signal amplitude, or in the case of gross defects, complete loss of the transmitted signal. The appearance of the CRT screen

**Text, letter

Description automatically generated**

Position of transmitter and receiver probes in the through transmission method of ultrasonic testing.

This method is used for the inspection of large ingots and castings particularly when the attenuation is high and gross defects are present. The method does not give the size and location of the defect. In addition good mechanical coupling and alignment of the two probes is essential.

**Diagram

Description automatically generated**

(a) , (b), (c)CR.T screen appearance for defects of varying sizes in the through transmission method. (a) Defect free specimen.

This is the method most commonly utilized in the ultrasonic testing of materials. The transmitter and receiver probes are on the same side of the specimen and the presence of a defect is indicated by the reception of an echo before that of the back wall echo. The CRT screen is calibrated to show the separation in distance between the time of arrival of a defect echo as against that of the back wall echo of the specimen, therefore, the location of a defect can be assessed accurately. The principle of the pulse echo method

**Diagram

Description automatically generated with medium confidence**

Principle of pulse echo method of ultrasonic testing. (a) Defect free specimen. (b) Specimen with small defect and (c) Specimen with large defect.

A condition of resonance exists whenever the thickness of a material equals half the wavelength of sound or any multiple thereof in that material. Control of wavelength in ultrasonics is achieved by control of frequency. If we have a transmitter with variable frequency control, it can be tuned to create a condition of resonance for the thickness of plate under test. This condition of resonance is easily recognized by the increase of received pulse amplitude. Knowing the resonance or fundamental frequency f and velocity V of ultrasound in the specimen the thickness lt' of the specimen under test can be calculated from the equation :

t = V / 2f

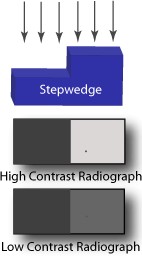
Since it is difficult to recognize the fundamental mode of vibration, the fundamental frequency is usually calculated from the difference of two adjacent harmonics which are depicted by two adjacent rises in the pulse amplitude. Therefore

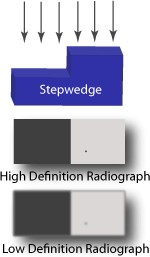
t = V/2 (f - n f )

Where = frequency at nth harmonic. n f = frequency at (n-1)th harmonic. n-1 The resonance method of ultrasonics was at one time specially suited to the measurement of thickness of thin specimens such as the cladding tubes for reactor fuel elements. The method has now be largely superseded by the pulse echo method because of improved transducer design.

## Radiographic Sensitivity

The usual objective in radiography is to produce an image showing the highest amount of detail possible. This requires careful control of a number of different variables that can affect image quality. Radiographic sensitivity is a measure of the quality of an image in terms of the smallest detail or discontinuity that may be detected. Radiographic sensitivity is dependant on the contrast and the definition of the image.

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

*Radiographic definition* is the abruptness of change in going from one area of a given radiographic density to another. Like contrast, definition also makes it easier to see features of interest, such as defects, but in a totally different

way. In the image to the right, the upper radiograph has a high level of definition and the lower radiograph has a lower level of definition. In the high definition radiograph it can be seen that a change in the thickness of the stepwedge translates to an abrupt change in radiographic density. It can be seen that the details, particularly the small dot, are much easier to see in the high definition radiograph. It can be said that a faithful visual reproduction of the stepwedge was produced. In the lower image, the radiographic setup did not produce a faithful visual reproduction. The edge line between the steps is blurred. This is evidenced by the gradual transition between the high and low density areas on the radiograph.

## Radiographic “Image” Density

After taking a radiographic image of a part and processing the film, the resulting darkness of the film will vary according to the amount of radiation that has reached the film through the test object. As mentioned earlier, the darker areas indicate more exposure and lighter areas indicate less exposure. The processed film (*or image*) is usually viewed by placing it in front of a screen providing white light illumination of uniform intensity such that the light is transmitted through the film such that the image can be clearly seen. The term “radiographic density” is a measure of the degree of film darkening (*darkness of the image*). Technically it should be called “transmitted density” when associated with transparent-base film since it is a measure of the light transmitted through the film. Radiographic density is the logarithm of two measurements: the intensity of light incident on the film (𝐼𝑜) and the intensity of light transmitted through the film (𝐼𝑡). This ratio is the inverse of transmittance.

𝐷𝑒𝑛𝑠𝑖𝑡𝑦 = log 𝐼𝑜

𝐼𝑡

Similar to the decibel, using the log of the ratio allows ratios of significantly different sizes to be described using easy to work with numbers. The following table shows numeric examples of the relationship between the amount of transmitted light and the calculated film density.

|  |  |  |  |
| --- | --- | --- | --- |
| **Transmittance** | **Transmittance** (%) | **Inverse of Transmittance** | **Density** |
| **(It/I0)** |  | **(I0/It)** | **(Log(I0/It))** |
| 1.0 | 100% | 1 | 0 |
| 0.1 | 10% | 10 | 1 |
| 0.01 | 1% | 100 | 2 |
| 0.001 | 0.1% | 1000 | 3 |
| 0.0001 | 0.01% | 10000 | 4 |

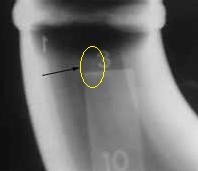
From the table, it can be seen that a density reading of *2.0* is the result of only one percent of the incident light making it through the film. At a density of *4.0* only *0.01%* of transmitted light reaches the far side of the film. Industrial codes and standards typically require a radiograph to have a density between *2.0* and *4.0* for acceptable viewing with common film viewers. Above 4.0, extremely bright viewing lights is necessary for evaluation.

Film density is measured with a “*densitometer*” which simply measures the amount of light transmitted through a piece of film using a photovoltic sensor.

## Secondary (Scatter) Radiation Control

Secondary or scatter radiation must often be taken into consideration when producing a radiograph. The scattered photons create a loss of contrast and definition. Often, secondary radiation is thought of as radiation striking the film reflected from an object in the immediate area, such as a wall, or from the table or floor where the part is resting.

Control of side scatter can be achieved by moving objects in the room away from the film, moving the X-ray tube to the center of the vault, or placing a collimator at the exit port, thus reducing the diverging radiation surrounding the central beam.

When scarered radiation comes from objects behind the film, it is often called “backscatter”. Industry codes and standards often require

that a lead letter “*B*” be placed on the back of the cassette to verify the control of backscatter. If the letter “*B*” shows as a “*ghost*” image on the film, a significant amount of backscatter radiation is reaching the film. The image of the “*B*” is often very nondistinct as shown in the image to the right. The arrow points to the area of backscatter radiation from the lead “*B*” located on the back side of the film.

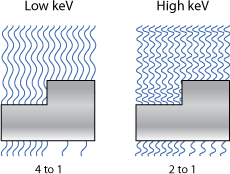
The control of backscatter radiation is achieved by backing the film in the cassette with a sheet of lead that is at least *0.25 mm* thick such that the sheet will be behind the film when it is exposed. It is a common practice in industry to place thin sheets of lead (*called “lead screens”*) in front and behind the film (*0.125 mm thick in front and 0.25 mm thick behind*).

## Radiographic Contrast

As mentioned previously, radiographic contrast describes the differences in photographic density in a radiograph. The contrast between different parts of the image is what forms the image and the greater the contrast, the more visible features become. Radiographic contrast has two main contributors; subject contrast and film (*or detector*) contrast.

### *Subject Contrast*

Subject contrast is the ratio of radiation intensities transmitted through different areas of the component being evaluated. It is dependant on the absorption differences in the component, the wavelength of the primary radiation, and intensity and distribution of secondary radiation due to scattering.

It should be no surprise that absorption differences within the subject will affect the level of contrast in a radiograph. The larger the difference in thickness or density between two areas of the subject, the larger the difference in radiographic density or contrast. However, it is also possible to radiograph a

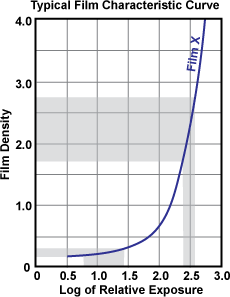
particular subject and produce two radiographs having entirely different contrast levels. Generating X-rays using a low kilovoltage will generally result in a radiograph with high contrast. This occurs because low energy radiation is more easily attenuated. Therefore, the ratio of photons that are transmitted through a thick and thin area will be greater with low energy radiation.

There is a tradeoff, however. Generally, as contrast sensitivity increases, the latitude of the radiograph decreases. Radiographic latitude refers to the range of material thickness that can be imaged. This means that more areas of different thicknesses will be visible in the image. Therefore, the goal is to balance radiographic contrast and latitude so that there is enough contrast to identify the features of interest but also to make sure the latitude is great enough so that all areas of interest can be inspected with one radiograph. In thick parts with a large range of thicknesses, multiple radiographs will likely be necessary to get the necessary density levels in all areas.

### *Film Contrast*

Film contrast refers to density differences that result due to the type of film being used, how it was exposed, and how it was processed. Since there are other detectors besides film, this could be called detector contrast, but the focus here will be on film. Exposing a film to produce higher film densities will generally increase the contrast in the radiograph.

A typical film characteristic curve, which shows how a film responds to different amounts of radiation exposure, is shown in the figure. From the shape of the curves, it can be seen that when the film has not seen many photon interactions (*which will*

*result in a low film density*) the slope of the curve is low. In this region of the curve, it takes a large change in exposure to produce a small change in film density. Therefore, the sensitivity of the film is relatively low. It can be

seen that changing the log of the relative exposure from *0.75* to *1.4* only changes the film density from

*0.20* to about *0.30*. However, at film densities above *2.0*, the slope of the characteristic curve for most films is at its maximum. In this region of the curve, a relatively small change in exposure will result in a relatively large change in film density. For example, changing the log of relative exposure from *2.4* to *2.6* would change the film density from *1.75* to *2.75*. Therefore, the sensitivity of the film is high in this region of the curve. In general, the highest overall film density that can be conveniently viewed or digitized will have the highest level of contrast and contain the most useful information.

As mentioned previously, thin lead sheets (*called “lead screens”*) are typically placed on both sides of the radiographic film during the exposure (*the film is placed between the lead screens and inserted inside the cassette*). Lead screens in the thickness range of *0.1 to 0.4 mm* typically reduce the scattered radiation at energy levels below *150 kV*. Above this energy level, they will emit electrons to provide more exposure of the film, thus increasing the density and contrast of the radiograph.

Other type of screens called “fluorescent screens” can alternatively be used where they produce visible light when exposed to radiation and this light further exposes the film and increases density and contrast.

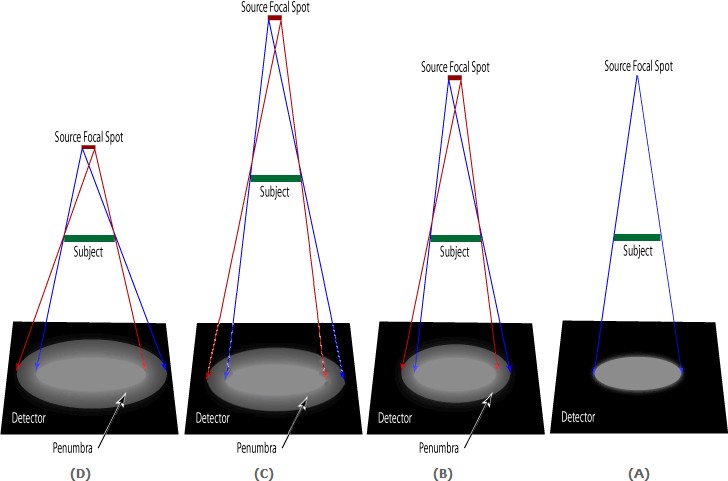
## Radiographic Definition

As mentioned previously, radiographic definition is the abruptness of change from one density to another. Both geometric factors of the equipment and the radiographic setup, and film and screen factors have an effect on definition.

### *Geometric Factors*

The loss of definition resulting from geometric factors of the radiographic equipment and setup is refered to as “*geometric unsharpness*”. It occurs because the radiation

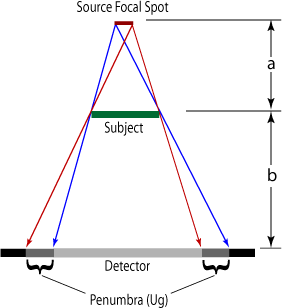
does not originate from a single point but rather over an area. The three factors controlling unsharpness are source size, source to object distance, and object to detector (film) distance. The effects of these three factors on image defenetion is illustrated by the images below (*source size effect; compare* ***A*** *&* ***B****, source to object distance; compare* ***B*** *&* ***D****, and object to detector distance; compare* ***B*** *&* ***C***).



The source size is obtained by referencing manufacturers specifications for a given X- ray or gamma ray source. Industrial X-ray tubes often have focal spot sizes of *1.5 mm* squared but microfocus systems have spot sizes in the *30 micron* range. As the source size decreases, the geometric unsharpness also decreases. For a given size source, the unsharpness can also be decreased by increasing the source to object distance, but this comes with a reduction in radiation intensity. The object to detector distance is usually kept as small as possible to help minimize unsharpness. However, there are situations, such as when using geometric enlargement, when the object is separated from the detector, which will reduce the definition.

In general, in order to produce the highest level of definition, the focal-spot or source size should be as close to a point source as possible, the source-to-object distance

should be as large as practical, and the object-to-detector distance should be a small as practical.

Codes and standards used in industrial radiography require that geometric unsharpness be limited. In general, the allowable amount is *1/100* of the material thickness up to a maximum of *1 mm*. These values refer to the width of penumbra shadow in a radiographic image.

The amount of geometric unsharpness (𝑈𝑔) can be calculated using the following geometric formula:

𝑈 = 𝑑

𝑔

𝑏

𝑠 𝑎

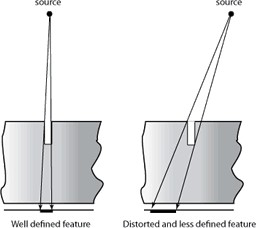
Where;

𝑑𝑠 : source focal-spot size

𝑎 : distance from the source to the front surface of the object

𝑏 : distance from the front surface of the object to the detector (*or the thickness of*

*the object if a thick object is placed immediately on top of the detector*)

The angle between the radiation and some features will also have an effect on definition. If the radiation is parallel to an edge or linear discontinuity, a sharp distinct boundary will be seen in the image. However, if the radiation is not parallel with the discontinuity, the feature will appear distorted, out of position and less defined in the image.

Abrupt changes in thickness and/or density will appear more defined in a radiograph than will areas of gradual change. For example, consider a circle. Its largest dimension will be a cord that passes through its centerline. As the cord is moved away from the centerline, the thickness gradually decreases. It is sometimes difficult to locate the edge of a void due to this gradual change in thickness.

Lastly, any movement of the specimen, source or detector during the exposure will reduce definition. Similar to photography, any movement will result in blurring of the image. Vibration from nearby equipment may be an issue in some inspection situations.

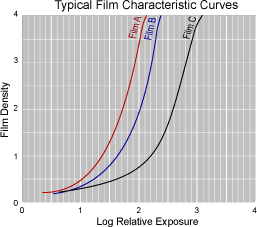
### *Film and Screen Factors*

The last set of factors concern the film and the use of fluorescent screens. A fine grain film is capable of producing an image with a higher level of definition than is a coarse grain film. Wavelength of the radiation will influence apparent graininess. As the wavelength shortens and penetration increases, the apparent graininess of the film will increase. Also, increased development of the film will increase the apparent graininess of the radiograph.

The use of fluorescent screens also results in lower definition. This occurs for a couple of different reasons. The reason that fluorescent screens are sometimes used is because incident radiation causes them to give off light that helps to expose the film. However, the light they produce spreads in all directions, exposing the film in adjacent areas, as well as in the areas which are in direct contact with the incident radiation. Fluorescent screens also produce screen mottle on radiographs. Screen mottle is associated with the statistical variation in the numbers of photons that interact with the screen from one area to the next.

## Film Characteristic Curves

In film radiography, the number of photons reaching the film determines how dense the film will become when other factors such as the developing time are held constant. The number of photons reaching the film is a function of the intensity of the radiation and the time that the film is exposed to the radiation. The term used to describe the control of the number of photons reaching the film is “exposure”.

Different types of radiographic films respond differently to a given amount of exposure. Film manufacturers commonly characterize their film to determine the relationship between the applied exposure and the

resulting film density. This relationship commonly varies over a range of film densities, so the data is presented in the form of a curve such as the one for *Kodak AA400* shown to the right. This plot is usually called a film characteristic curve or density curve. A log scale is sometimes used for the *x*-axis or it is more common that the values are reported in log units on a linear scale as seen in the figure. Also, relative exposure values (*unitless*) are often used. Relative exposure is the ratio of two exposures. For

example, if one film is exposed at *100 kV* for *6 mA.min* and a second film is exposed at the same energy for *3 mA.min*, then the relative exposure would be *2*.

The location of the characteristic curves of different films along the *x*-axis relates to the speed of the film. The farther to the right that a curve is on the chart, the slower the film speed (*Film A has the highest speed while film C has the lowest speed*). The shape of the characteristic curve is largely independent of the wavelength of the X-ray or gamma ray, but the location of the curve along the *x*-axis, with respect to the curve of another film, does depend on radiation quality.

Film characteristic curves can be used to adjust the exposure used to produce a radiograph with a certain density to an exposure that will produce a second radiograph of higher or lower film density. The curves can also be used to relate the exposure produced with one type of film to exposure needed to produce a radiograph of the same density with a second type of film.