NON DESTRUCTIVE TESTING OF WELDS

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Non destructive testing plays a significant part in maintaining the quality of the products at various stages of manufacture. Raw material stage i.e. before the start of manufacture, intermediate stages. final stage after manufacture all utilise Nondestructive testing techniques. The most commonly used techniques are Liquid Penetrant Inspection (LPI), Magnetic Particle Inspection, Ultrasonic Testing, Radiography Testing. In this article the basics of the testing techniques, equipment, methodologies and their limitations are covered in detail in the subsequent sections.

Liquid Penetrant Inspection

Location of surface flaws and sub-surface flaws is essential for many of the industrial components since the failure to do so may lead to catastrophic situations. For locating gross surface flaws, visual inspection with the aid such as magnifying glasses is adequate. However, location of minute cracks may not be possible even with the aid of magnifying devices. In such cases, Liquid penetrant Inspection and Magnetic Particle Inspection can come to the assistance in the location of defects. For locating only surface flaws, Liquid Penetrant inspection is sufficient while for locating slightly sub-surface flaws and surface faces, magnetic particle inspection can be used.

Penetrant examination is generally considered to be one of the easiest methods of surface inspection to locate discontinuities that are open to the surface. Consequently the need for an accurate application and competent personnel may be under-estimated. To obtain optimum results, the method should be applied with care and accuracy. PI can be used on any rnaterial except when it is extremely porous.

Principle

Surface discontinuities,, such as cracks or other separations, as well as porosity open to the surface can be detected by 'bleeding' after the surface has been treated with a penetrant. A developer is generally used to increase the evaluation efficiency.

Stages of LPI

Following steps are involved in penetrant inspection and illustrated in Fig. 1.

- Surface preparation.
- Application of the penetrant
- Controlling time for penetration.
- Removal of excess penetrant.
- Application of developer.
- Inspection
- Interpretation and Evaluation
- Post cleaning.

Surface Preparation

The effectiveness of liquid penetrant testing is based upon the ability of the penetrant to enter surface discontinuities. The article to be

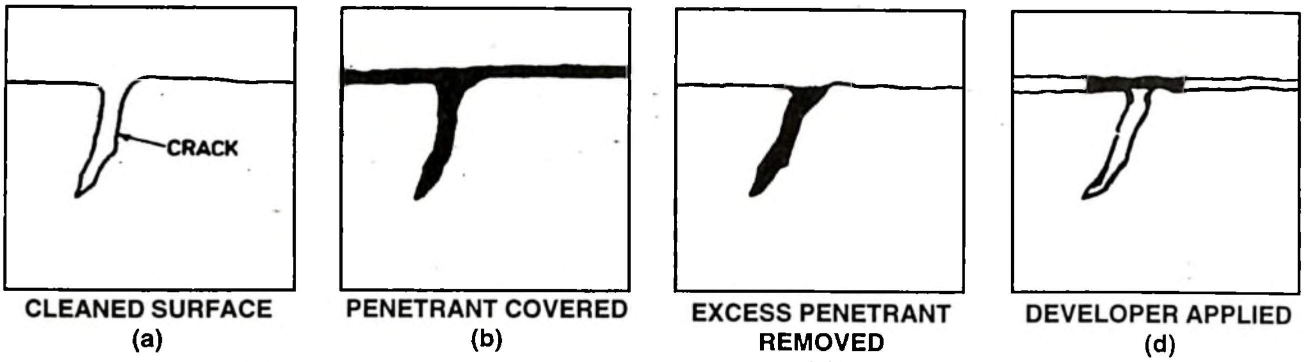

Fig. 1 : Penetrant Inspection Procedure

tested must be clean and dry and free from foreign matter that may cover or fill its discontinuities. All paint, carbon, oil, varnish, oxides, scale, rust etc. must be removed from the article prior to the application of the penetrant. Detergent cleaning, vapour degreasing, steam cleaning, rust removers, pickling solutions etc. are used, depending upon the composition of the article under test and the type of soil to be removed. Any cleaning process used should leave the surface clean and dry and should not harm the article under test. Sand blasting, grinding and similar operations are not suitable since they will close up the surface discontinuities. In case the above operations are done, etching should be done prior to penetrant application.

Types of Penetrant

Since the main feature of penetrant testing is the visibility of the indications, the liquid penetrant contains a coloured dye (usually RED dye) easily seen in white light or a fluorescent dye visible under black or ultra violet light. Hence, the penetrant can be classified as visible dye penetrant or fluorescent dye penetrant

Penetrant Application

Penetrants are applied by spraying, swabbing, brushing and dipping. The method of application depends upon the size of the component, the type of component, the type of equipment etc. The penetrant must be repeatedly applied and the penetrant coating maintained wet. A dried coating will not provide any useful result.

Penetration Time or Dwell Time

The period of time during which the penetrant is permitted to remain on the specimen is a vital part of the test. The minimum time required for the penetrant to enter into the discontinuity is determined by tbe following factors:

- Manufacturer's recommendation.
- Type of material tested.
- Type of discontinuity expected.
- Temperature of the specimen.

It may be pointed out here that tight-crack like discontinuities may require as high as 30 minutes while gross discontinuity may require 3 to 5 minutes.

The temperature of the specimen is most important. Usually at 10 to 45°C the usual liquid penetrants work normally well and at elevated temperature more than 45°C, the normal penetrants will become dry and hence will not penetrate into discontinuities. Similarly, at temperatures below 10°C, the mobility of the particles will be very slow and hence, there will not be any penetrating action. For use at higher temperature, special penetrants have been developed. However, in case of low temperature, the article has to be heated to a temperature of 10°C to 45°C.

Removal of Excess Penetrant

After sufficient dwell time, the excess penetrant on the specimen surface is to be removed. This has to be done without disturbing any penetrant, which has entered into the discontinuity. Complete removal of surface penetrant is effected to ensure against formation of irrelevant indications. The exccess penetrart is first removed by a clean lint -free dry cloth or rag. The cloth is then moistened with the solvent recommended by the penetrant manufacturer and the penetrant is gently wiped off from specimen surface. In any case, the solvent should not be forced on the specimen surface or otherwise it might wash out or dilute the penetrant in the discontinuity. In the case of fluorescent penetrant, the excess penetrant removal is ascertained by viewing the specimen under black light. For visible dye penetrants, traces on the wiping materiat ensures complete penetrant removal.

Developer Application

Since penetrant commences to bleed out of discontinuities immediately following the removal of excess surface penetrant, developer is to be applied to the specimen immediately. The purpose of developer application is two-fold; on one hand by reverse capillary action it seeps out penetrant from the discontinuities and spread it out to a greater area. On the other hand it also serves as a colour contrast background for dye-material. Developers are classified into following categories:

- Wet developer
- Non-aqueous developer
- Dry developer.

Wet Developer

This contains a suspension of absorptive white powder in water. The mixture is prepared as per manufacturer's recommendations and is mildly agitated prior to application. Since the developer itself contains water, water washable penetrants, after washing penetrant need not be dried. The developer is applied either by immersion or by spray method, to form a thin and uniform coating. After application of developer, the specimen is allowed to dry either by natural drying or artificial drying.

Non - Aqueous Developer

In this type of developer, the white powder is suspended in a solvent vehicle. It is usually applied by spraying from a pressurized spray can or other spraying devices. Prior to application, it is necessary to see the powder is thoroughly mixed with the solvent. It should be applied to form a thin white coating on the specimen, which must be completely dry.

Dry Developer

This type of developer contains a loose, fluffy talcum powder with high absorbent properties. This is applied on the specimen by dusting, blowing or dipping the specimen. This is used only with fluorescent dye penetrants and is usually accomplished in a booth with a blower or fan arrangement

The minimum time for the inspection of discontinuities after the application of developer will vary from the type of developer, type of discontinuities to be detected, and the manufacturer's recommendations. Hovvever, the rule of the thumb is that the minimum time required is one half of the dwell time.

Inspection

An indication in the developer will become visible after a certain lapse of time, depending on the interaction between developer and penetrant liquid and on the size of the imperfections. Very small imperfections may need more time whereas wider and deeper flaws take a few minutes before insignificant imperfections demonstrate themselves.

Interpretation

For interpretation of indications, it is very important to observe their characteristics, at the very moment they appear. As soon as flaws bleed out, the indications may run to larger spots, depending on size and depth, and it is difficult to derive characteristic information from the flaw.

Generally, the blotting out effect is more pronounced for colour penetrants than for the fluorescent types.

The extent to which the developing indications can be realised in practice depends largely on the size and complexity of the surface to be examined as well as on the number of components to be tested.

A supplementary optical examination either by a magnifying glass or a microscope is often necessary for any positive statement to be made about the character of the imperfections. As with all non-destructive testing systems, correct interpretation of the indications require knowledge of the material being tested and its possible imperfections.

After inspection and recordings of findings, the developer should be completely removed from the parts. This can be achieved by wiping or cleaning with water and drying or cleaning with solvents as recommended by the manufacturer depending on the material and its further applications.

Testing Equipment

Depending upon the type of material to be tested, frequency of testing, size of the component and nature of testing, various equipments from test stations to portable kits are available. A certain amount of automation is also involved in test stations and the specimens are usually moved in conveyor system.

But the most common applications are portable kits which will contain cleaners, penetrants, developers, wiping clothes, brushes and some spraying equipments. If fluorescent penetrants are used, a portable black light equipment will also be provided. The unit is usually self contained.

Evaluation of Test Results

Prior to the evaluation of test results, it is necessary to interpret the indications. Indications can be classified as :

- False indications
- Irrelevant indications and
- True indications.

False indications are due to improper penetrant removal and contaminations such as penetrants on the hands of operator, penetrant rubbing of an indication on one specimen to a clean portion of the surface of another specimen, etc. By careful adoption of the technique and re-testing, it is possible to determine whether the indication is false or not. Non-relevant indications are caused by surface discontinuities such as the presence of surface slag or scale or change of section with a groove, etc. These are easily identifiable by an experienced operator and should be noted at the time of evaluation. True indications are those caused by discontinuities in the specimen and only those indications are to be studied while evaluating the results of the examination. While interpreting indications, the following are to be assessed.

Type of Indications

Whether the indication is a continuous line, intermittent line, round or small dots. This ensures to determine the nature of discontinuity present. Continuous line indications are caused by cracks, cold shuts, forging laps, scratches and dye marks. Round indications are caused by gas holes, pin holes etc. Small dots represent fine porosity or micro shrinkage.

Extent of Discontinuity

This has to be viewed on two aspects

(I) how deep the discontinuity goes inside the surface. This can be seen from the brightness of the indication. Deeper the discontinuity, brighter the indication. Once the depth of the discontinuity and other dimensions such as length, width, etc. are noted, the extent of the defect can be got. However the depth is only indicative and depending on the gap in the discontinuity it may vary.

(ii) What effect has the indicated discontinuity on the service life of the specimen? Or in other words, whether the discontinuity can be accepted or not?

This requires the knowledge, on the part of interpreter, of the following:

- The governing code or standard to which the specimen has to satisfy.
- Whether there is any further processing in which the discontinuity may disappear.
- Previous knowledge of similar parts and manufacturing processes.

Application in Welding

Liquid penetrant inspection is widely used for the detection of surface discontinuities such as cracks porosities etc., in welds especially non-magnetic in nature such as Monel, Stainless steel welds etc.

This is also used as an in-process testing of multi-layer welding, used at various stages viz., after root run, after final run, after backchipping and after sealing run. Any defect detected at this stage is rectified and hence, it is possible to produce sound welds. This can be used as a testing method for the detection of heat treatment cracks. Also, it is possible to detect fatigue cracks on components used in service. At site, the testing is widely used for the detection of service discontinuities. Also, liquid penetrant testing is used in the repairing of weldments. When the defects are removed by drilling or gouging, prior to filling up, the area is checked by liquid penetrant inspection to see that the defects are completely removed. Liquid penetrant testing is also widely used for the plate and tube edges before welding for checking the presence of contamination and slag inclusions.

Conducting LPI in Stainless steel components is not a major problem by itself, the residues from the penetrant chemicals may pose problems. The presence of the residual sulfur or halides may pose a problem in stainless components when put into operation especially at high temperature and stresses. The source of the halides or the sulfur may be (1) the cleaning and other penetrant chemicals (2) from other manufacturing operations such as drawing or stamping, and (3) industrial water used in cleaning the components. These chemicals may introduce stress corrosion cracking during the operation of the component. To avoid the presence of these 1 the penetrant chemicals commercial grades of the penetrant chemicals. Additionally during the post cleaning operation after the test is completed, care must be taken to remove the presence of the chemicals in the edges, recesses, keyways, etc. Specific tests may be performed on the components in the typical operation environment using different dyes and developers to confirm the effect on the formation of stress corrosian cracks due to the residues in the chemicals.

Magnetic Particle Inspection

Liquid Penetrant Inspection is sufficient for locating only surface flaws while for locating slightly subsurface and surface flaws, magnetic particle inspection can be used. Magnetic Particle Inspection (MPI) is a technique used for testing ferromagnetic materials. The technique is basically simple and easy to operate. Austenitic stainless steels cannot be tested with this technique. This can be used for detecting discontinuities on surface or subsurface defects at a depth of a maximum of 6mm under favourable conditions.

Principle

The job is suitably magnetised and magnetic lines of force or magnetic flux of enough density is made available. Discontinuities in the path of the magnetic flux create a disturbance in the uniform magnetic field causing flux leakage. The flux leakage set up of magnetic poles attracts iron powder when dusted over the testing zone and forms a pattern of the discontinuity. The flaw is indicated as a pattern on the surface giving the location and to some extent the nature of discontinuity.

Steps in Testing

- Magnetise the job suitably
- Apply the examination medium (i.e. iron powder) over the test surface.
- Interpret and evaluate the indications.

Kinds of Magnetisation

Magnetisation of the material as shown in Fig 2, can be carried out principally in two ways, viz.,

- Longitudinal magnetisation - wherein the magnetisation is parallel to the long axis of the component, the flux path, completiuig itsetf through the air outside the material. Longitudinal magnetisation is obtained in yoke method and coil method.
- Circular magnetisation wherein the magnetic field is transverse to the length of the component and the flux path is contained within the article. Circular magnetisation is obtained in Head shot method, central conductor method and prod method.

Methods of Magnetisation

Yoke Magnetisation : A Permanent Magnet or an electromagnet can be used for the yoke magnetisation. Only longitudinal magnetisation is produced in this type of magnetisation. The field strength is fixed and cannot be varied. This is mostly suitable for surface detection only. Electromagnetic yokes also can be used in place of permanent magnet and handling is easy in that case.

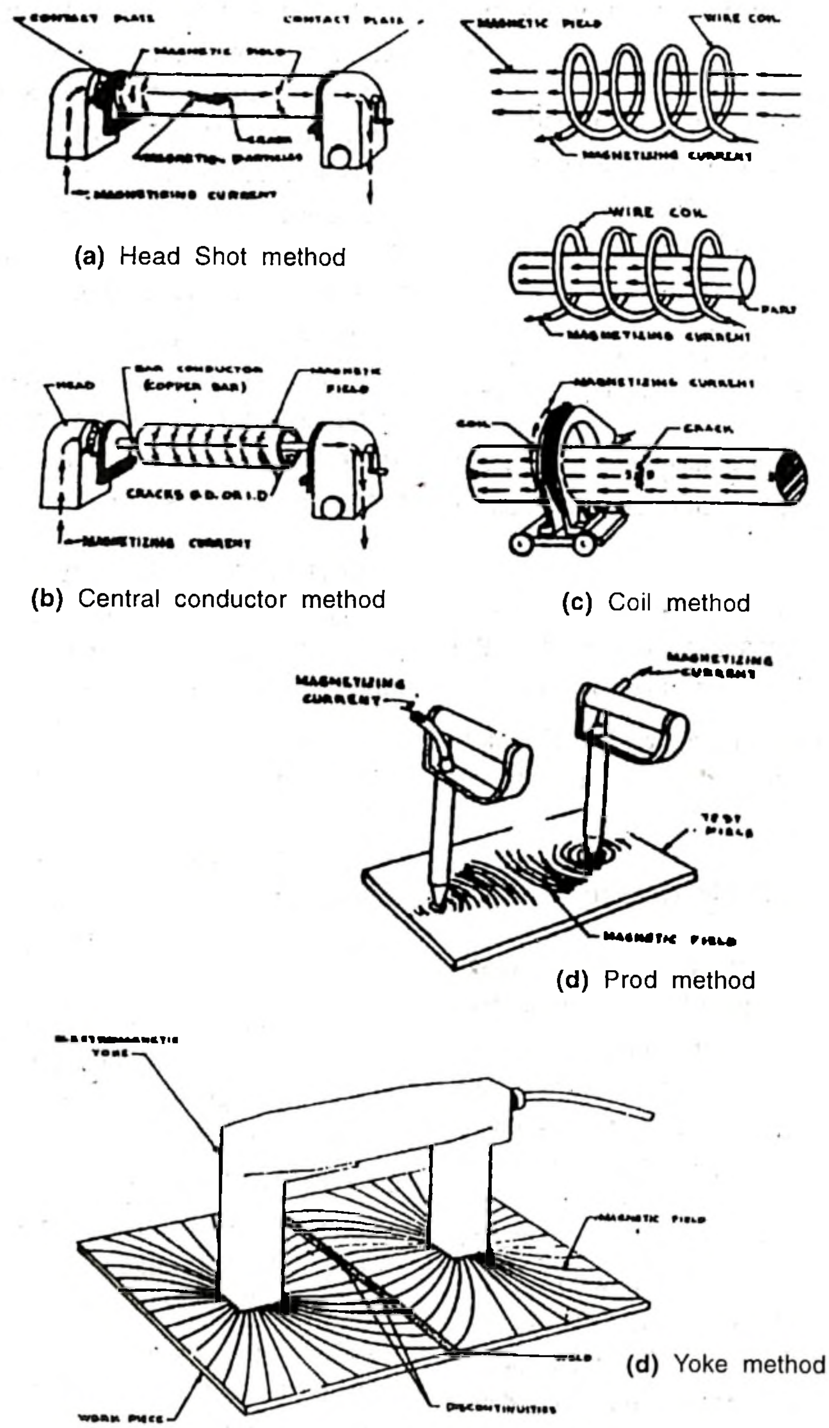

Fig. 2 : Methods of Magnetisation

Coil Magnetisation : The component is placed inside a coil, which is carrying the magnetising current and magnetised in a direction parallel to the axis of the coil. Hence the discontinuities transverse to the axis of the coil are detected. All the three types of current, namely AC, DC or HWDC can be used in combination with dry or wet powder method suiting the job.

The current is calculated as
NI = 45000 D/L
Where L is the inspection length (< 50 mm)
D is diameter of the component
N is the number of turns
I is the current in amperes.

Prod Magnetisation : In this method, current carrying prods are used for producing circular magnetisation in local areas. Current used is AC, DC or HWDC as per the job requirement. Normally a current of 100 to 120 Amps per inch spacing between the prods is used. The spacing of 6"-8" gap is used as maximum. Care must be taken to avoid burning of the part under the prod contact points.

Head Shot Method : Current is passed through the test material and this induces directly a circular field. This can be used for detecting cracks along the axis of the part or the current path. This is mostly used for circular components.

Central Conductor Method : This is used for hollow components. A circular field is generated and induced indirectly into the components and can be used for detecting discontinuities that are parallel to the axis of the component or current path.

Examination Media

The examination media i.e: the iron particles may be in the form of a dry powder (Dry Method) or they may be suspended in a liquid carrier (Wet Method).

The size of the dry powder particle is about 60 microns and a mixture of elongated and spherical particle is used to obtain good sensitivity and mobility. Dry powders are available in different colours for better contrast against any background. In Wet Method, the iron oxide is suspended preferably in kerosene or in any other carrier liquid. The size should be between 40 and 60 microns.

Testing

Pre-inspection Procedure: Normally as welded, as-cast and as-forged surfaces are suitable for testing. However, excess scales. ripples, slag etc. may interfere with the interpretation of the indication and are to be dressed properly. Flakes, heavy build-up of paints, rust and grease are to be cleaned.

If prods are to be used, the contact points for the prods should be cleaned locally to ensure proper electrical contact.

After the pre-inspection procedure is completed, the testing can be undertaken.

Inlerpretation : Crack-like flaws are the ones most easily detected and are shown as crisp sharply defined lines. Inclusions and slag stringers give more diffuse indications. It is difficult to draw any conclusions on the depth or width of a crack from the magnetic indications. Normally surface discontinuities appear sharp and distinct. Sub-surface discontinuities appear wide and fuzzy.

False indication can occur where there is a section change or a change in magnetic properties or because of tool marks or scratches, which hold the magnetic powder. Magnetic writing caused by two specimens rubbing over one another can also cause spurious marks in certain steels. These false indications can be verified by visual inspection using low magnification.

Demagnetisation : Steel articles which have been exposed to the effects of very strong magnetic fields often remain magnetised for a considerable time after testing. This is a problem when the component is built into a machinery because local poles attract ferrous particles which may cause excessive wear. During heat treatment, demagnetisation takes place automatically but the majority of the components are tested in the final machined condition, demagnetisation methods have to be used. This amount of residual magnetism depends on the magnetising current, used for magnetic particle testing its strength and nature (AC or DC) and the permeability of the material.

With DC demagnetisation. the current is repeatedly reversed while being progressively reduced. With AC' demagnetisation, which is the most common method, the component is subjected to a gradually diminishing field by either withdrawing it along the axis of a solenoid or reducing the current in the solenoid. It is better to rotate the part when it is passed through the coil. A special technique to demagnetise large structures is to pass a special low frequency current through the part: however, only DC is suitable for very thick section parts since AC will demagnetise only the skin. The components should be checked for freedom from magnetism after treatment.

Post Cleaning

After completion of testing, the components have to be cleaned by air, water or solvent and wiping off.

Magnetising Currents

The three types of currents used are

- Direct current
- Alternating current
- Half wave D.C.

The magnetic field produced by Direct current (D.C.) penetrates the cross-section of the component and is good for detecting sub-surface discontinuities.

The magnetic field created by AC is the maximum at the surface of the component and the penetrating capability is relatively less. This is good for locating surface discontinuities.

Ultrasonic Testing

Mechanical vibrations which have frequency higher than the audible range of human ear viz. 20 Hz to 20 KHz are called ultrasonic waves. Unlike electromagnetic radiation, these waves require a medium and velocity of propagation depends on the elasticity of the medium. Most common modes of propagation of ultrasonic waves are:

- Longitudinal waves
- Transverse waves
- Surface or Rayleigh waves.

Longitudinal Waves

These waves shown in Fig. 3 travel through the medium as a series of alternate compressions and rarefactions in which the particles transmitting the wave vibrate back and forth in the direction of travel of the waves. Longitudinal ultrasonic waves are readily propagated in liquids and gases as well as in elastic solids. The velocity of longitudinal waves is about 5920m/ sec. in steel.

Transverse Waves

In transverse or shear waves, shown in Fig. 4 each particle vibrates up and down in a plane perpendicular to the direction of propagation. The

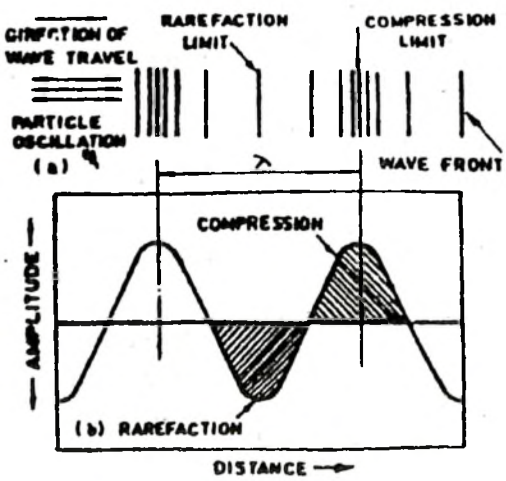

Fig. 3 : Longitudinal Wave

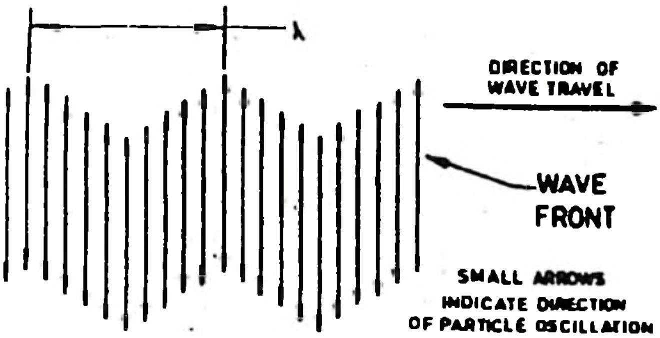

Fig. 4 : Transverse Wave

velocity of tansverse waves is about 50% of the longitudinal wave velocity for the same material.

Surface or Rayleigh waves and Plate or Lamb Waves

These are another type of waves used in the inspection of surface soundness of metals. These waves travel along with flat or curved surface of relatively thick solid parts. Lamb waves, also known as plate waves are another type of ultrasonic waves used in the non-destructive inspection of metals. These are propagated in metals that are only few wave lengths in thickness.

MAJOR VARIABLES

Sensitivity or the ability to detect a very small discontinuity is generally increased by using relatively high frequencies (short wave lengths). Resolution is the ability of the system to give simultaneous, separate indications from discontinuities that are close together in depth. Resolution is directly proportional to probe band width and inversely related to pulse length but is not affected by frequency.

Penetration, or maximum depth (range) in a material from which useful indications can be detected is reduced by the use of high frequencies. This effect is most pronounced in the inspection of metal that has coarse grain structure or minute inhomogenities, because of the scattering of the ultrasonic waves. With the decrease in frequency, the shape of an ultrasonic beam increasingly departs from the ideal of zero beams spread.

Acoustic-impedanoe : The acoustic impedance is Z = P x V where V - Velocity and P - density of the material.

ˬaws of Ultrasound

At any angle other than normal the angle of incidence is equal to the angle of reflection. The Snell's law is

Sin A/ Sin B = V1 / V2

A - Angle of incidence,
B - angle of refraction,
VI - velocity of sound in the Medium 1
V2 - velocity of sound in Medium 2

Additionally mode conversion takes place at the interface when the longitudinal wave is refracted as longitudinal and transverse waves and shown in Fig. 5

Attenuation

The intensity of an ultrasonic beam that is received by a transducer is considerably less than the intensity of the initial transmission. There is

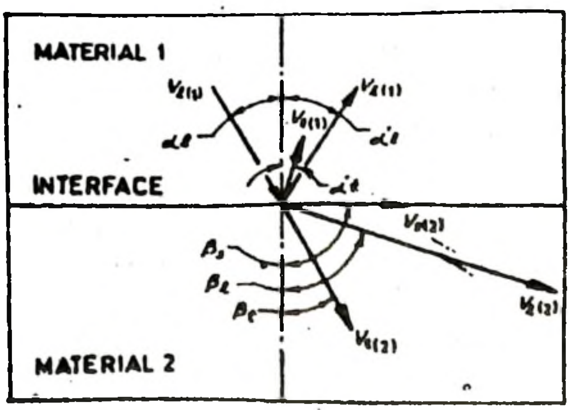

Fig. 5 : Reflection, Refraction mode Conversion

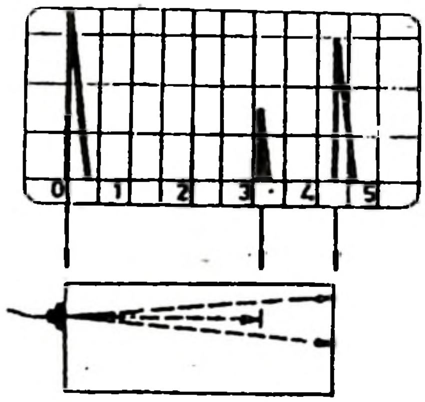

Fig. 6 : Pulse Echo Testing

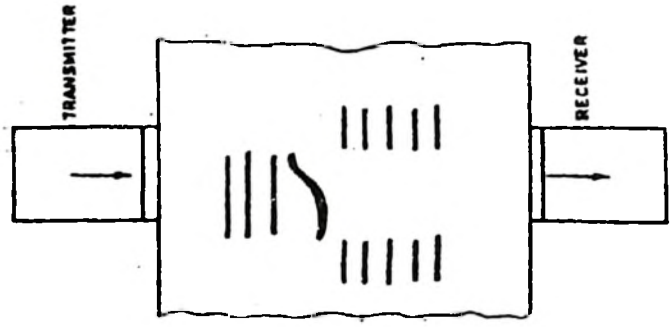

Fig. 7 : Through Transmission System

a loss in the energy due to absorption of sound in the material. This loss is known as attenuation.

Probes

Generation as well as detection of ultrasonic waves for inspection is accomplished by means of a transducer element which is contained with a device most often referred to as a search unit or a probe. The active element in a search unit is a piezoelectric crystal. This crystal works on the principle of piezoelectric effect. The crystal develops an electrical charge when pressure is applied to it. Conversely, when an electrical field is applied, the crystal mechanically deforms. The most common types of piezoelectric materials used for ultrasonic search units are quartz, lithium sulphate, polarized ceramics such as barium titanate, lead zirconate titanate and lead metaniobate.

Probe Types

Search units are of many types and shapes. Variation in search unit construction includes transducer element material, transducer element thickness, surface area and shape and type of backing material and degree of loading. The basic types are normal beam, angle beam, and Transmitter and receiver probes.

Reference Blocks

Ultrasonic inspection is basically a comparison process and requires the use of reference blocks for calibration of the equipment and probe set up before put to use on the actual job. The calibration is done with standard reference blocks. The most widely used reference block is Suizer's block, ASTM block, IIW block, miniature angle beam block, etc. shown in Fig. 8. The calibration of the set up is done to check the following:

Time base, Linearity, Resolution, Sensitivity, Beam spread, Beam angle, Dead zone, Probe index and Penetration Power. This is illustrated in Fig. 9.

Inspection Methods

Ultrasonic inspection can be performed by

a. Pulse Echo Method
b. Through Transmission Method.

Ultrasonic technique in which flaws are detected by measuring intensity and time of flight of reflected sound waves having single frequency is called pulse echo method of ultrasonic testing which is most widely used.

Pulse Echo Method

In pulse echo method flaws are detected and their sizes estimated by comparing the intensity of reflected sound from an interface (either within the test piece or at the back surface) with the intensity of sound reflected from a reference interface of known size or from the

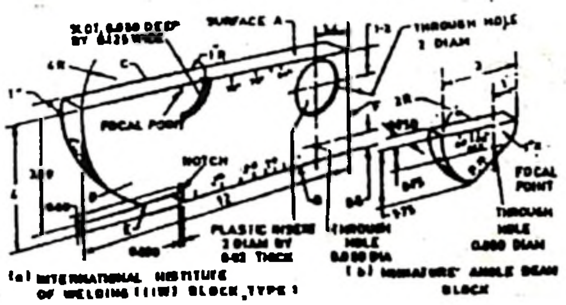

Fig. 8 : Calibration Block - IIW V1 Block, V2 Block

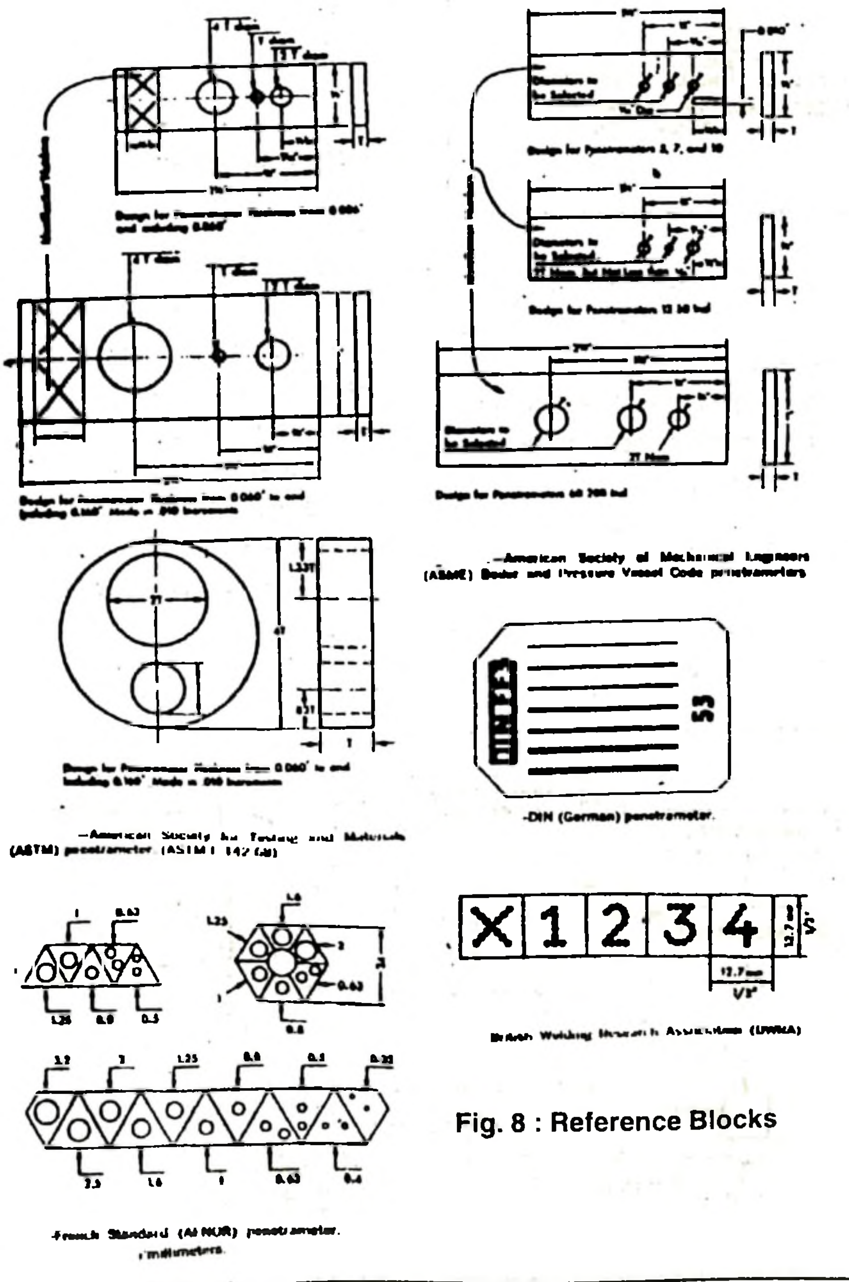

Fig. 8 : Reference Blocks

back surface (back reflection) serves as a reference point for time of flight measurements that enable the depth of some internal flaws to be measured. It is necessary that an internal flaw reflect at least part of the sound energy on to the receiving transducer for such depth measurements to be made.

Most pulse echo systems consist of electronic clock, electronic signal generator or pulser, a sending transducer, a receiving transducer, an echo signal amplifier, and a display device. Shown in Fig. 10

Through Transmission Method

In Through Transmission method flaws are detected by comparing the intensity of ultrasound transmitted through the test piece with the intensity transmitted through a reference standard made of the same material. Transmission testing requires two search units, one to transmit the ultrasonic waves and one to receive them. The main application of transmission method is the inspection of plate for cracks or laminations that have relatively large dimensions compared to the size of the search units.

Testing of Welds

Before actually commencing the examination of welds it is necessary that aspects like visual conditions of the weld surface, couplants & the parent metal in the scanning zone be considered.

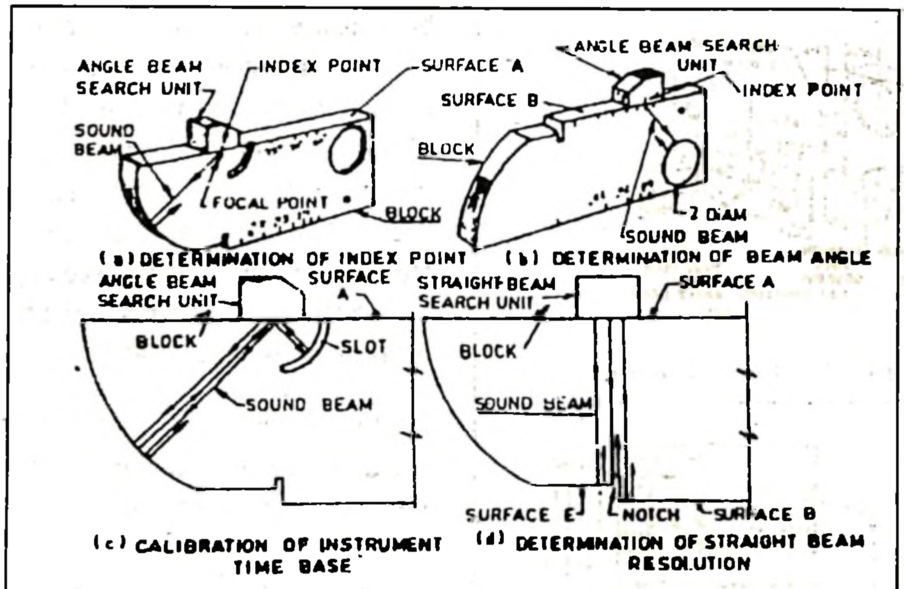

Fig. 9 : Calibration of time base and Resolution

The visual appearanoe of the weld should be checked for shape of the weld, e.g. surface curvature, degree of root penetration, backing ring, different parent metal thicknesses, extent of the reinforcement, presence of undercuts, weld finish and alignment of parts.

Couplants

A couplant, usually a liquid or semi-liquid is required between the face of the probe and the test surface to permit transmission of the acoustic energy from the transducer to the material under test. Typical couplants include water, oil, grease and glycerin.

Defect Detection

To detect all possible defects, the weld is to be examined over its entire cross-section and along the length specified. For the detection of longitudinal defects the shear wave probe is placed on the contact surface and kept perpendicular to the weld centre line. To examine the entire weld, the probe is moved over the scanning zone.

Defect Location

The accurate determination of the position of a defect in a welded joint is important not only when repairs have to be made but in an ultrasonic examination it can give, together with defect orientation useful information for the determination of the type of defect. The position of a defect is determined by the distance (Projected path length between probe index and reflector) and depth from the surface. The distance and the depth can be easily calculated from the path length, probe angle and thickness.

Defect Identification

Important indication with regard to the shape and orientation of a defect can be obtained from the appearance of the signal and its behaviour when the defect is scanned from various directions. The echo signals obtained from the planar defects, such as cracks and lack of sidewall fusion will mostly appear as sharp and narrow indications. They are characterised by the directionality to the incident

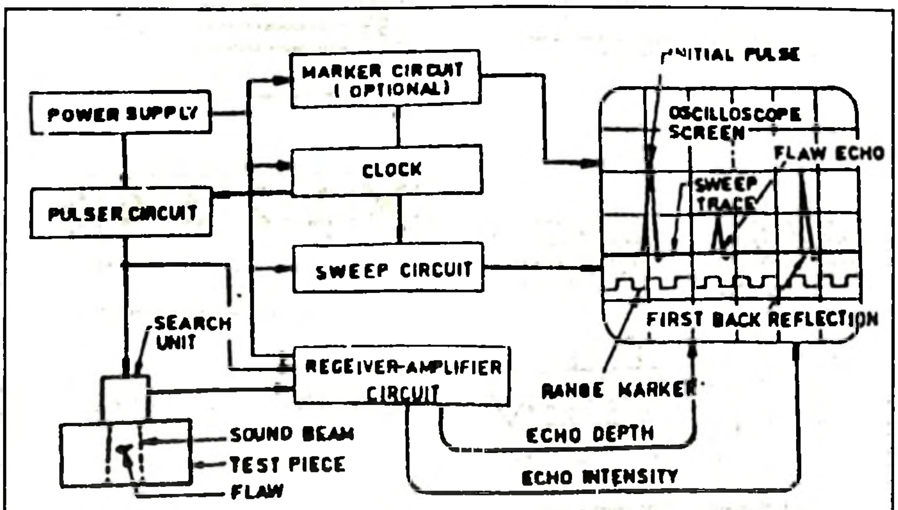

Fig. 10 : Pulse Echo Testing System

beam in both directions perpendicular to their main dimension. Orbiting the probe from the position which ensures maximum echo height will result in a sudden amplitude drop. Noticeable difference in echo height may be obtained by successive use of different probe angles. When the defect orientation is perpendicular to the plate surface about the same echo height will be noticed with scanning from both sides of the weld. An inclined orientation may result in an echo height difference.

The echo height obtained from stag inclusions does not necessarily differ from those received from cracks or lack of fusion, but may be distinguished by different echo shapes and directional sensitivity. Because of the rough surface of this type of discontinuity the defect intercepts successive relations in the beam and gives rise to a succession of echo signals. An orbital movement with the probe will cause little change in this echo appearance. The individual signals of which the echo is composed however will change and consequently there will be a variation of echo height. A scan from the opposite side of the weld is likely to give a similar echo appearance.

Spherically shaped discontinuities such as gas pores reflect only a small part of the incident beam in the direction of the receiver. Moreover, the dimensions of this type of defect are small. Low amplitude signals with narrow echo shape characterise this type of defect. The echo will remain almost constant when the probe is moved around the defect and when scanning from the opposite side. In the event of porosity a number of these small echoes may appear close together depending on the number and distribution of the pores.

UT of Austenitic Stainless Steel Welds

Generally speaking the austenitic stainless steel welds cannot be tested using transverse waves whatever their frequency. Either the signal strength is not very high compared to the strength of the noise which is due to the reflection from grain boundaries. The transverse waves can be used in the checking of root flaws and lack of sidewall fusion defects where the waves do not travel in the weld. It is possible to test austenitic welds by using short pulses of longitudinal waves. Testing should be done by scanning directly and not by the bounced mode. Longitudinal TR probes also can be used for detecting the defects in the direct scanning method. However, for thick welds this may require more number of probes with different ranges.

Radiographic Testing

Radiography employs the penetrating capacity of ionising radiation like X or Gamma rays to produce a shadow of the internal condition of a job on a recording medium. The record in a film is known as Radiograph.

X-Rays and Gammarays

X-rays are produced in a high voltage electron tube and Gamma rays are the products of nuclear disintegration, the latter obtained from either natural or artificial radioactive isotopes. Except for the sources Gamma rays and X-rays are similar to one another.

X-rays and Gamma rays are waves which cannot be perceived by our natural senses. They can cause serious damage to life if received beyond certain limits. X rays and Gamma Rays are a part of the electromagnetic spectrum with the shortest wave length in the entire spectrum.

X-rays and Gamma rays have no electrical charge and hence cannot be affected by electrical field. They travel in straight lines and travel with the speed of light (3x1010 cm/sec). X-rays and Gamma rays include a wide range of energies capable of varying penetration through different materials. Radiation suffers absorption, scatter and diffraction when they penetrate solid matter.

X-Ray Tube

A Tungsten filament fixed in a cup shaped cathode is heated by means of a low voltage current. Electrons are liberated and they are accelerated by increasing the potential difference between the cathode and a slanting edged anode. The place of impingement is made of tungsten to stand the heat as well as to provide a metal target of high atomic number. Heat produced is dissipatod through the anode and removed by forced or natural cooling. The assembly is enclosed in a vacuum glass envelope. X-rays produced leave the tube through a thinner glass window. Fig.11 shows a setup for making an industrial radiograph using X-rays.

A KV control increases or decreases the applied voltage and the penetration is controlled by KV Higher the KV, greater the penetration.

A current control knob and meter is used to increase or decrease current supplied to filament. Increase of milliamperage results in the hotter filament, more electron emission and hence larger quantity of Xrays. This decides the duration of exposure. A timer controlled switch to control the exposure is provided in the control panel.

Film is used as the recording medium in radiography. Resembling a photographic film. The differences are due to the penetrating nature of the energy involved and service conditions.

The base is made of polyesters and provides a transparent medium over which the sensitive emulsion may be coated. The industrial radiographic film has a thicker and tougher base than the photographic film since they are subjected to lot of handling during exposure.

Density

The function of emulsion coating is to produce opaque deposits when exposed to light or radiation. The extent of deposit is expressed as density.

Density D = Log (Ii / h)
Ii = Intensity of Incident light
It = Intensity of the emergent light
Optimum density for an industrial radiograph is 2 to 4.

Exposure

It is the product of intensity of radiation and duration for which the energy was acting on the film. To express radiographic exposure, one has to give Kilovoltage, Milliamperes and time in case of X-rays and type of source, its strength in curies and exposure time in minutes for an isotope source.

Speed

Speed of the film is measured in terms of the log of exposure needed to produce a density of 1.0 in Medical and 2.0 in Industrial radiographic film above the base density. The grain size of the Silver Halide Crystals embedded in the emulsion controls the speed. The larger the grain, the faster is the film. Sensitivity decreases with the increase in grain size.

Radiographic Processing

Processing involves reduction of exposed silver halides in the emulsion to silver metal by a controlled chemical action. The process involves immersion and agitation of the exposed film in different solutions in the following order.

1. Water 2. Developer 3. Stop bath 4. Fixer 5. Rinsing in flowing water.

The main chemical action occurs in the Developer and the fixer solution and rest of them play secondary roles. The temperature of processing should be maintained at 20°C.

The film is agitated in a bath of developer for a period of 5 to 10 minutes. The exposed Grains of Silver Halide get preferentially reduced to metallic Silver and latent image is formed. The alkalinity of developer is maintained, between pH values 9.5 to 11.5 for successful preferential reduction. Stop bath is a 3% solution of Acetic Acid used to neutralize the developer alkalies and to stop the developing action. The film after 10 seconds of agitation 'in this bath is ready for fixing.

Fixer is used to dissolve away the unreduced Silver Halides and render the radiograph permanent. Among fixers Ammonium Thio-Sulphate and Sodium Thio-Sulphate are the two chemicals popularly used. Hardening agents are added to harden the gelatin which is very soft until this treatment.

Thorough washing in flowing water removes the chemicals embedded in the gelatin. The films are dried in a dust free chamber at 50°C and they are ready for evaluation.

Image Quality Indicators (IQI)

As a check on the adequacy of the radiographic technique, a standard test piece, called a penetrameter, is placed on the source side of the specimen.. The penetrameter is of a simple geometric shape, made of a material radiographically similar to the specimen itself, and usually contains some simple structure such as strips wires etc. Its thickness is a definite proportion (e.g.2%) of the specimen thickness. The radiographic technique may be considered satisfactory if the penetrameter and its structures are shown clearly in the radiograph. If the radiographic procedure has been able to demonstrate a 2% difference in specimen thickness, (i.e. it shows the structure of a 2% penetrameter) the penetrameter sensitivity is considered satisfactory. Wire type, step wedge and plate hole are the widely used types of penetrameters and are covered by different codes.

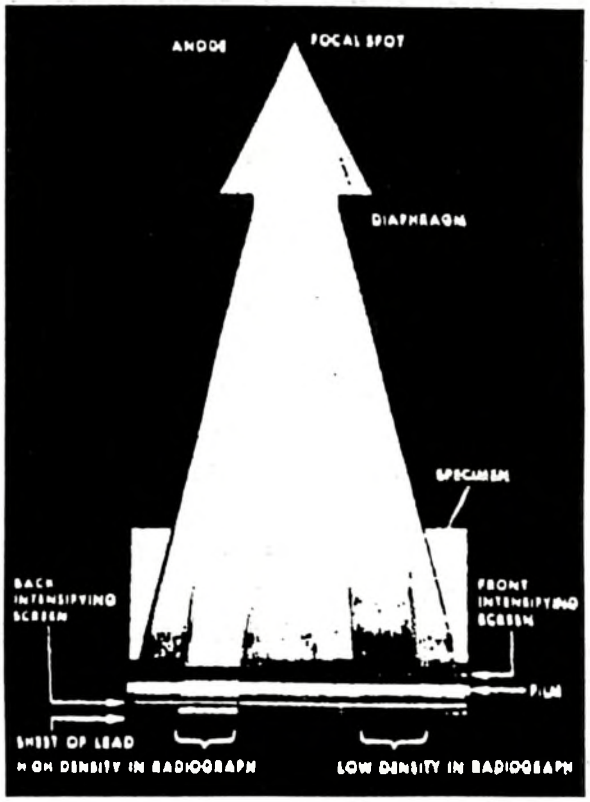

Fig. 11 : Diagram of setup for making an industrial radiograph with x-rays.

It should be remembered that even if a certain hole in a penetrameter is visible in a radiograph, the cavity of the same diameter and thickness in the specimen may not be visible, the penetrameter holes having sharp boundaries, gives an abrupt though small change in metal thickness, while a natural cavity with more or less rounded sides gives a gradual change. Therefore, the image of the hole will be sharper and more easily seen in the radiograph than the image of the cavity. Similarly, a fine crack may be of considerable extent, but if the Xrays happen to pass from tube to film normal to the plane of the crack, its image on the film may not be visible because of the very gradual transition in photographic density. Thus a penetrameter is used to indicate the quality of the radiographic technique and not as a measure of the sizes of the cavity which can be shown. A thin stock or a uniform block may be used to keep the penetrameter on, when the object to be radiographed is not suitable to keep the IQI directly over it.

Radiographic Interpretation

The interpretation of a radiograph involves the following three distinct stages:

- Verification that the pattern of the radiographic image in conformity with the shape of the part and that it is related to the particular specimen under consideration.
- Recognition of any spurious effects in the radiograph arising from faulty exposure, handling of processing methods, and

- Identification of any internal flaws in the specimen by their characteristic appearance in the radiograph. A fourth and culminating stage exists that it is concerned with the assessment of the probable effect of any defect upon the serviceability of the specimen.

The interpreter should have in mind the fundamental principles of the formation of radiographic images. Useful indications are provided by

a. The shape of the image

b. The distribution of density of the image

c. The direction of the incident rays upon the test object and upon the film.

To fulfill this task, the interpreter should know the fundamental characteristics of radiation with respect to the test material. He should also know the fundamentals of the manufacturing process for the products he is inspecting. in the case of weldments, he should know the different welding methods, their peculiarities, their possible and most probable defects etc. Wherever possible, he should know in advance the specific welding method employed. Only under these conditions can the test method give the best results. Properly applied, radiograph is not restricted to a mere Go - No - Go' test for detecting voids or defects. Its function is enlarged to that of providing useful information to the production shop which can lead to possible improvements in manufacturing technique.

Radiographic Images

Single slag or inclusions oxides whose average atomic number is lower than that of iron, are less opaque to X-rays and produce dark indications on the radiograph. Slag inclusions generally have irregular shapes whose sizes follow no definite rules. Small slag inclusions appear radiographically as dark spots with irregular borders and sharp pointed ends. Often the image density is variable and sometimes even approaching that of the sound metal.

Lack of Penetration

In butt welding, a root opening is usually left at the bottom of the groove (in one-side welding) or at the centre of the weld (in two side welding). If the opening between the two plates is too narrow in relation to the diameter of weld rod employed and the current used, it is difficult to attain complete penetration and fusion at the root of the weld. A gap remains in the root area of the weld and will produce an indication on the radiograph. Such discontinuities can arise from poor bevelling preparation of the weld groove. The typical radiographic appearance of lack of penetration at the root of a weld is that of continuous or an intermittent dark line at the centre of the weld seam

Cracks

If the welding parameters or materials (either parent metal or electrode) are inadequate, then the internal stresses caused by shrinkage upon cooling of the weld maybe so high as to produce cracks. In accordance with their origin, cracks are classified as hot cracks, cold cracks, etc. These discontinuities can be either parallel or perpendicular to the axis of the weld seams. In general, cracks are never straight lines but often have zig-zag shapes. Since cracks are the most dangerous among weld defects particular attention must be paid to their indications in checking weld radiographs.

Lack of Fusion

As a consequence of insufficient heat or the presence of scale on the fusion face of a weld the deposited metal may remain separated from the base metal by a very thin layer of oxide. This defect is called lack of fusion. Radiographic indication of a lack of fusion is a very narrow, straight dark line, parallel to and displaced to one side of the weld image.

Tungsten Inclusions

Tungsten inclusions are characteristics of the inert atmosphere welding methods. If the tungsten electrodes which support the electric arc come into contact with the weldmetal, some tungsten

The following Table lists some frequently used radio isotopes and their important charecterstics :

SL. NO.	SOURCE	SYMBOL	HALFLIFE	ENERGY Me v	PENETRATION mm STEEL
1.	Radium 226	Ra 226	1600 Yrs	22, 1.8, 1.1, 0.6, 0.35	75-200
2.	Cobalt 60	Co 60	5.3 Yrs	1.3, 1.17	50-200
3.	Conium 137	Cs 137	33 Yrs	0.662	10-75
4.	Indium 192	Lr 192	74 days	0.61; 0.60-59; 0-48 0-46; 0-32. 0-31; 0-29	5 to 75
5.	Thulium	Tm 170	127 days	0.084	0.25 of Al

particles are trapped in the deposited metal. This may be in the form of small splinters or even as pieces of the tungsten wire. Because of its high melting point, no fusion of the tungsten occurs. Since it has higher atomic number than iron, the radiographic indications take the form of very light marks in the weld image.

Hazards of Ionising Radiation

Most of the effects of radiation on the human body are known and predictable. Radiation safety practices are based on these effects and the characteristics of radiation. Since radiation cannot be detected by any of the human senses and its damaging effects do not become immediately apparent, personnel protection is dependent upon detection devices and shielding. The Division of Radiological Protection of BARC enforces safety regulations covering the handling and use of radioisotopes. These regulations are designed to limit radiation exposure to safe levels and to afford protection for general public. The radiographer must have sufficient knowledge and comply with all pertinent regulations, Radiography is safe but it is only as safe as those working with it permit it to be.

Radiographic Techniques

SINGLE WALL SINGLE IMAGE : This is the technique when the radiation beam penetrates through the thickness of the specimen once and produces the image on the film. This is also called direct technique. This technique is employed for plate welds, drum welds and castings of larger sizes.

DOUBLE WALL, DOUBLE IMAGE : The technique is adopted when either the source or film cannot be positioned directly in contact with the other side of plate as in smaller diameter tubes or castings of smaller sizes. in this case the radiation beam penetrates twice the wall thickness before it falls on the film. As the diameter of the tube is smaller, it is possible to get the image of both upper and lower wall in the same film, without any appreciable loss of geometric unsharpness or sensitivity. The technique is employed while radiographing tubular butt welds with diameter less than 100 mm.

DOUBLE - WALL SINGLE IMAGE : When the diameter is increased beyond 100 mm, the double wall double image technique becomes unsuitable as the image of the upper wall undergoes certain magnification causing unsharpness in the radiograph. Hence, the double wall, single image technique is employed..

In this case, the radiation beam penetrates twice the wall thickness and produces useful image of the lower wall only in the film. Equal number of segments (say 4 or more) are made for a circumferential weld and are individually exposed.

Panoramic Radiography

By a single exposure the entire circumference of a weld can be radiographed by keeping the source at the centre of the pipe. Similarly, a number of castings can be radiographed by arranging them in the periphery of a circle and keeping the source at the centre.

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