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SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I - NON DESTRUCTIVE TESTING AND TECHNIQUES – SPR1611

UNIT – I
INTRODUCTION TO NDT

Non-destructive Testing is one part of the function of Quality Control and is complementary to other long established methods. By definition non-destructive testing is the testing of materials, for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service. The technique can be applied on a sampling basis for individual investigation or may be used for 100% checking of material in a production quality control system. Whilst being a high technology concept, evolution of the equipment has made it robust enough for application in any industrial environment at any stage of manufacture - from steel making to site inspection of components already in service. A certain degree of skill is required to apply the techniques properly in order to obtain the maximum amount of information concerning the product, with consequent feed back to the production facility. Non-destructive Testing is not just a method for rejecting substandard material; it is also an assurance that the supposedly good is good. The methods covered are: Radiography, Magnetic Particle Crack Detection, Dye Penetrant Testing, Ultrasonic Flaw Detection, Eddy Current and Electro-magnetic Testing

Techniques and capabilities:

1. Visual Inspection
2. Thickness Measurement
3. Defect Detection
4. Other Techniques

1. Visual inspection

The simplest and easiest technique to apply and often called by the generic term 'inspection' on process plant. It is able to detect surface damage and distortion. However, access to the surface is required and the capability relies on the illumination and the eyesight of the inspector. Many aids are available for visual inspection ranging from a magnifying glass through endoscopes and boroscopes which allow viewing of surfaces inaccessible to the eye alone, to fully remote computerised video systems. In the latter case as 'seeing is believing' care needs to be taken to ensure that the signal processing of the image does not hide any defects.

2. Thickness measurement

The commonest damage found on process plant is corrosion and so techniques which allow remaining wall thickness to be measured are widely applied. Ultrasonics (high frequency sound) provides an accurate point measurement of wall thickness. The surface on which the transducer is placed needs to be clean and, as it provides a point measurement, the measurement positions need to be selected with consideration of the type of corrosion damage so that the minimum wall thickness can be detected. When using a grid to survey a large surface area, the pitch of the grid needs to be selected so that it will detect the damage of concern. Care needs to be taken when taking measurements on plant which is painted or coated to ensure that the measurement is just that of the remaining wall. Newer instruments have facilities to assist the operator in this task but older equipment require more care on the part of the operator.

Other thickness techniques include: Flash Radiography, Magnetic Flux Leakage, Pulsed Eddy Currents.

These techniques are more limited in their application by material type, accuracy of measurement, wall thickness or geometry than ultrasonics but offer other advantages such as speed of application or the ability to inspect under insulation.

3. Defect detection

Defect detection techniques fall into two categories:

- those that can only detect defects on or near to the surface of a component (Surface Techniques);
- those which can detect both surface and embedded defects (Volumetric Techniques).

(a). Surface Techniques

- Dye Penetrant Inspection (PT)
- Eddy Currents
- Magnetic Particle Inspection (MPI or MT)

Dye Penetrant inspection (PT)

Dye is drawn into any surface breaking defects which are then highlighted by the application of a developer which draws the dye back out of the defect. This NDT method can only detect defects which are open to the inspection surface. Dye penetrant is the preferred surface technique for non-magnetic materials.

Dye penetrant is better suited to the detection of volumetric defects like pits but is more susceptible to the surface condition than magnetic particle inspection. Detection of tight cracks will require the dye to be left on the surface for a long time. The component surface needs to be cleaned prior to the application of dye penetrant inspection. Mechanical cleaning methods can lead to crack openings being closed, subsequently preventing detection. Care needs to be taken with any technique which requires the application of chemicals to plant to ensure that the chemicals are compatible with the plant material. It is particularly important that only chemicals with low halogen content are applied to stainless steel to avoid the initiation of stress corrosion cracking. Fluorescent dyes are used to increase the contrast of indications making them more visible to the operator and hence increasing the sensitivity of the technique.

Eddy Currents

When an alternating current is passed through a coil close to a component surface, eddy currents are induced and produce a back EMF on the current in the coil. Any defect in the component which restricts the eddy current flow alters the balance between the applied and back EMFs and can be detected. The skin depth, which is a function of the permeability of the material and the frequency, determines the depth of penetration of the eddy currents. In ferro-magnetic material the skin depth is very small and the technique will only detect surface breaking defects. In non-magnetic material it provides some sub-surface capability and can give some indication of the depth of a defect. Eddy current techniques are widely applied in the NDT of heat exchanger tubing.

Magnetic Particle Inspection (MPI or MT)

Defects on the inspection surface interrupt the lines of magnetic flux. Magnetic particles sprayed onto the surface are attracted to these defects identifying their position. This NDT method only detects abrupt changes in the magnetic field and therefore only supplies capability for defects that break the inspection surface. Care needs to be taken to avoid false calls which may arise due to changes in geometry or the presence of residual magnetic fields.

Fluorescent magnetic inks are used to increase the contrast of indications making them more visible to the operator and hence increasing the sensitivity of the technique. Magnetic particle inspection is generally the preferred NDT method for the detection of surface cracks in ferritic material.

(b). Volumetric Techniques

- Radiography
- Ultrasonics

Radiography

Radiography is the detection of material loss by the variation in applied radiation, g or x-ray, passing through a component and impinging on a film. As it is sensitive to material loss, radiography is better suited to the detection of volumetric defects such as slag or porosity. Detection of planar defects or cracks will depend on the gap or opening of these defects and the misorientation of the radiation beam from the axis of the defect. In many cases, cracks will not be detected.Radiography is liked because it produces a hard copy of the results - the film. It is unable to provide depth information regarding defects without additional specialist techniques (eg profile radiography may give depth information on large volume defects). Defects are identified by abrupt changes in the density of the developed film: the film density is related to the exposure it has received from the radiation. The gradient of the curve of density against exposure determines how visible are small changes in exposure. Such changes can arise from the presence of defects and so the ability to detect them through changes in film density is of prime importance. This characteristic of the film is its contrast. Contrast tends to increase with film density and so high densities are beneficial in the detection of defects. However, viewing high density films requires good lighting conditions such as high light intensity, low background light and film masking and there are practical limits on the level to which density can be increased because of the reduction in transmitted light intensity. Density in the range 2.0 - 3.0 is usually regarded as representing the best compromise between contrast and viewing requirements.

Image quality indicators (IQI) are commonly of the wire type, comprising straight wires of differing diameters sealed in a plastic envelope, or ones which use holes or steps in a block of metal. The IQI is placed on the object under test and imaged when the radiograph is taken. The smallest wire diameter, hole diameter or step that is visible on the radiograph then gives a guide to the sensitivity achieved. The IQI type and its position are specified in the appropriate radiographic standard. It should be recognised that the sensitivity established by an IQI relates only to the ability to detect changes in section, wire size etc. This sensitivity is only indirectly related to defect detectability. The quality and sensitivity of a radiograph are measured by the density of the film and the use of an IQI.

Ultrasonics

Ultrasonics is the use of high frequency sound waves in a similar manner to sonar or radar: sound pulses are reflected from interfaces or discontinuities. In thickness checking the reflections from the wall surfaces are measured. In defect detection reflections from cracks, voids and inclusions are detected and assessed. The transfer of sound from the ultrasonic probe to the component requires a coupling medium, which is usually water or gel. The condition of the interface determines how much sound is transferred into the component, how much is scattered and how much noise is produced. Ultrasonics requires a relatively good surface finish.

Manual application over a large area is relatively slow and the technique needs to be tailored to the defects requiring detection. However, ultrasonics is able to provide both length and through wall size information. Some materials such as corrosion-resistant alloys (eg high nickel alloys and austenitic steels) cause additional problems for ultrasonics and require special techniques and appropriately trained personnel. Ultrasonics can be automated and hard copy results produced.

Other techniques:

- AC-FM - Alternating Current Field Measurement
- Acoustic Emission
- Creep waves
- Digital Filmless Radiography
- Flash Radiography
- Leak Testing
- Long Range Ultrasonics
- Magnetic Flux Leakage (MFL)
- Phased Array Inspection
- Pressure Testing
- Pulsed Eddy Currents
- Radioscopy
- Remote Field Eddy Currents
- Replication
- Shearography
- Time of Flight Diffraction. TOFD
- Thermography

CODES AND STANDARDS BODIES INVOLVED IN NDT INDUSTRY

Most countries have one or more organizations (“standards bodies”) that develop and publish technical industrial standards. Some don't, and those usually reference existing codes and standards for their manufacturing, fabrication and construction projects. In the United States, these organizations are usually independent organizations from private industry, but in many countries they are government agencies. The listing below, which is not all-inclusive, provides examples of some of the standards bodies that are commonly used by NDT personnel.

THE AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING, INC. (ASNT)

The American Society for Nondestructive Testing is a member-based, non-profit professional society that provides NDT-related reference materials, technical conferences and the following certification documents. ASNT does not publish standards that describe how to perform NDT tasks; those are published by ASTM International.

ASTM INTERNATIONAL

ASTM International (formerly the American Society for Testing and Materials) is one of the largest voluntary standards development organizations in the world, providing technical standards for materials, products, systems and services. Over 180 ASTM NDT standards are published in the ASTM Annual Book of Standards, Volume 03.03, Nondestructive Testing. ASTM defines three of their document categories as follows:

- A “guide” is a compendium of information or series of options that does not recommend a specific course of action. A guide increases the awareness of information and approaches in a given subject area.
- A “practice” is a definitive set of instructions for performing one or more specific operations or functions that does not produce a test result. Examples of practices include, but are not limited to: application, assessment, cleaning, collection, decontamination, inspection, installation, preparation, sampling, screening and training.
- A "test method" is a definitive procedure that produces a test result. Examples of test methods include, but are not limited to: identification, measurement and evaluation of one or more qualities, characteristics or properties.

Some of the more commonly used ASTM NDT standards are as follows. Additional standards can be found in the ASTM Annual Book of Standards, Volume 03.03.

ASTM E709:	*Standard Guide for Magnetic Particle Testing*
ASTM E1444:	*Standard Practice for Magnetic Particle Testing*
ASTM E165:	*Standard Practice for Liquid Penetrant Examination for General Industry*
ASTM E1417:	*Standard Practice for Liquid Penetrant Testing*
ASTM E1208:	*Standard Practice for Liquid Penetrant Testing using the Lipophilic Post-Emulsifiable Process*
ASTM E1209:	*Standard Practice for Liquid Penetrant Testing using the Water-Washable Process*
ASTM E1210:	*Standard Practice for Liquid Penetrant Testing using the Hydrophilic Post-Emulsifiable Process*
ASTM E1219:	*Standard Practice for Liquid Penetrant Testing using the Solvent-Removable Process*
ASTM E114:	*Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method*
ASTM E164:	*Standard Practice for Contact Ultrasonic Testing of Weldments*
ASTM E1213:	*Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing*
ASTM E2375:	*Standard Practice for Ultrasonic Testing of Wrought Products*
ASTM E94:	*Guide for Radiographic Examination*
ASTM E1742:	*Practice for Radiographic Examination*

ASTM E1000:	*Guide for Radioscopy*
ASTM E1255:	*Practice for Radioscopy*
ASTM E1030:	*Test Method for Radiographic Examination of Metallic Castings*
ASTM E1032:	*Test Method for Radiographic Examination of Weldments*
ASTM E999:	*Guide for Controlling the Quality of Industrial Radiographic Film Processing*
ASTM E142:	*Method for Controlling Quality of Radiographic Testing*
ASTM E2007:	*Standard Guide for Computed Radiography*
ASTM E2738:	*Standard Practice for Digital Imaging and Communication Nondestructive Evaluation (DICONDE) for Computed Radiography (CR) Test methods*
ASTM E268:	*Electromagnetic testing*
ASTM E426:	*Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys*
ASTM E1962:	*Standard Practice for Ultrasonic Surface Testing using Electromagnetic Acoustic Transducer (EMAT) Techniques*

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

The American Society of Mechanical Engineers is a not-for-profit professional organization that enables collaboration, knowledge sharing and skill development across all engineering disciplines, while promoting the vital role of the engineer in society. ASME codes and standards, publications, conferences, continuing education and professional development programs provide a foundation for advancing technical knowledge and a safer world. ASME publishes multiple codes and standards including (but not limited to) the following documents.

The “ASME Boiler & Pressure Vessel Code” (BPVC). The 2010 edition of the BPVC with 2011 addenda was made available in July 2011. This code is made up of 12 sections, or “books,” covering the following subjects:

I.	Power Boilers
II.	Materials
III.	Rules for Construction of Nuclear Facility Components
IV.	Heating Boilers
V.	Nondestructive Examination

VI.	Recommended Rules for the Care and Operation of Heating Boilers
VII.	Recommended Guidelines for the Care of Power Boilers
VIII.	Pressure Vessels
IX.	Welding and Brazing Qualifications
X.	Fiber-Reinforced Plastic Pressure Vessels
XI.	Rules for In-service Inspection of Nuclear Power Plant Components
XII.	Rules for Construction and Continued Service of Transport Tanks

ASME B31.1, *Power Piping*. This code contains requirements for piping systems typically found in electric power-generating stations, industrial institutional plants, geothermal heating systems, and heating and cooling systems.

ASME B31.3, *Process Piping*. This Code contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor and cryogenic plants; and related processing-plant terminals.

AMERICAN PETROLEUM INSTITUTE (API)

The American Petroleum Institute is a national trade association that represents all aspects of America's oil and natural-gas industry, including producers, refiners, suppliers, pipeline operators, marine transporters and service and supply companies. Among the standards that API publishes are the following:

API 510:	*Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration*
API 570:	*Piping Inspection Codes: In-service Inspection, Rating, Repair, and Alteration of Piping Systems*
API 650:	*Welded Tanks for Oil Storage*
API 653:	*Tank Inspection, Repair, Alteration, and Reconstruction*
API 1104:	*Welding of Pipelines and Related Facilities*

AMERICAN WELDING SOCIETY (AWS)

The American Welding Society is a nonprofit organization with the goal of advancing the science, technology and application of welding and related joining disciplines. AWS provides certification programs for welding inspectors, supervisors, educators, etc., and publishes multiple standards, many of which contain procedures for the application of nondestructive testing methods and techniques above and beyond visual inspection. A few of their standards are listed here:

AWS D1.1:	Structural Welding Code - Steel
AWS D1.2:	Structural Welding Code - Aluminum
AWS D1.3:	Structural Welding Code - Sheet Steel
AWS D1.5:	Bridge Welding Code
AWS D1.6:	Structural Welding Code - Stainless Steel

AEROSPACE INDUSTRIES ASSOCIATION (AIA)

The Aerospace Industries Association is a trade association with more than 100 major aerospace and defense member companies. These companies embody every high-technology manufacturing segment of the U.S. aerospace and defense industry from commercial aviation and avionics, to manned and unmanned defense systems, to space technologies and satellite communications.

The AIA publishes multiple aviation and aerospace-related standards, two of which are shown below:

NAS 410, *NAS Certification & Qualification of Nondestructive Test Personnel*. This employer-based certification standard establishes the minimum requirements for the qualification and certification of personnel performing nondestructive testing (NDT), nondestructive inspection (NDI), or nondestructive evaluation (NDE) in the aerospace manufacturing, service, maintenance and overhaul industries. In 2002, NAS 410 was harmonized with European Norm 4179, so that the requirements in both documents are identical.

NAS 999, *Nondestructive Inspection of Advanced Composite Structures*. This specification establishes the requirements for non-destructive inspection (NDI), NDI standards, NDI methods, and NDI acceptance criteria.

NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS (NBBI)

The National Board of Boiler and Pressure Vessel Inspectors is a non-profit organization that promotes greater safety to life and property through uniformity in the construction, installation, repair, maintenance and inspection of pressure equipment. The National Board membership oversees adherence to laws, rules and regulations relating to boilers and pressure vessels. NBBI provides training, and it issues In-service and New Construction commissions for Authorized Inspectors (AIs), Authorized Nuclear Inspectors (ANIs) and Authorized Nuclear In-service Inspectors (ANIIs).

NBBI publishes the “National Boiler Inspection Code” (NBIC), which provides standards for the installation, inspection and repair and/or alteration of boilers, pressure vessels and pressure-relief devices.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

The International Organization for Standardization, the world's largest developer and publisher of International Standards, is a non-governmental organization located in Geneva, Switzerland. ISO is a network of the national standards institutes of 161 countries, one member per country. Many of the ISO member institutes are part of the governmental structure of their countries, or are mandated by their government. Other members have their roots uniquely in the private sector, having been set up by national partnerships of industry associations. Three of the many ISO standards are listed below:

ISO 9712, *Non-destructive testing - Qualification and certification of personnel*. This International standard, which was revised in 2012, provides the requirements for the NDT certification of NDT personnel by an accredited third-party certification body that conforms to the requirements of ISO/IEC 17024, *Conformity assessment — General requirements for bodies operating certification of persons.*

ISO/IEC 17024, *Conformity assessment - General requirements for bodies operating certification of persons*. This international standard was developed with the objective of achieving and promoting a globally accepted benchmark for organizations operating certification of persons.

ISO/IEC 17011, *Conformity assessment - General requirements for accreditation bodies accrediting conformity assessment bodies*. This international standard specifies the general requirements for accreditation bodies. ANSI, the U.S. accreditation body that has accredited ASNT, is accredited under ISO 17011 and is a member of the International Accreditation Forum (IAF), the world association of Conformity Assessment Accreditation Bodies in the fields of management systems, products, services, personnel and other similar programs of conformity assessment.

EUROPEAN COMMITTEE FOR STANDARDIZATION (CEN)

The European Committee for Standardization is a business facilitator in Europe, removing trade barriers for European industry and consumers. Its mission is to foster the European economy in global trading, the welfare of European citizens and the environment. CEN is a major provider of European Standards and technical specifications. It is the only recognized European organization according to Directive 98/34/EC for the planning, drafting and adoption of European Standards in all areas of economic activity with the exception of electro-technology and telecommunication. CEN's 31 National Members work together to develop voluntary European Standards (ENs).

Standards (Norms) developed by CEN are considered "harmonized standards" that are required to be accepted by all member nations in the European Union. The following two ENs are NDT certification standards:

EN 4179, *Aerospace series - Qualification and approval of personnel for non-destructive testing*. This employer-based certification standard is the European version of NAS 410.

EN 473, *Non-destructive testing - Qualification and certification of NDT personnel - General principles*. This European Standard established principles for the third-party ("central") qualification and certification of personnel who perform industrial non-destructive testing (NDT) by an accredited third-party certification body. Under EN 473, certification bodies had to administer procedures for certification according to the requirements of EN 473 and must fulfill the requirements of EN ISO/IEC 17024.

EN ISO 9712, which was approved in June 2012, replaced EN 473 as the European harmonized standard (Norm) for NDT central certification effective 1 January 2012. EN ISO 9712 permits the use of current EN 473 certifications until the certificate holders' next renewal period, at which time they must recertify in accordance with the EN ISO 9712 requirements. EN ISO 9712 and ISO 9712 are identical except that EN ISO 9712 has been approved as a harmonized standard for use under the European Pressure Equipment Directive 97/23/EC.

EUROPEAN PRESSURE EQUIPMENT DIRECTIVE (PED)

The Pressure Equipment Directive (97/23/EC) was adopted by the European Parliament and the European Council in May 1997 and became obligatory throughout the European Union (EU) on 29 November 1999. The purpose of the directive (European law) is to harmonize national laws of the member states of the EU regarding the design, manufacture, testing and conformity assessment of pressure equipment and assemblies of pressure equipment. It applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure greater than 0.5 bar (~7.25 psi).

REGULATORY AGENCIES

In instances where there are extreme issues involving public safety, the U.S. government may create regulations above and beyond those provided by industry codes and standards. Two such examples of this are the control and use of radioactive materials and the transport of hazardous liquids and gasses. The government agencies responsible for oversight on these two subjects are the U.S. Nuclear Regulatory Commission (USNRC) and the U.S. Department of Transportation (USDOT), respectively.

The regulations for both of these organizations can be found in the Code of Federal Regulations (CFR). There are 50 "Titles" in the CFR, with the USNRC regulations being under Title 10, Energy, and the USDOT regulations being under Title 49, Transportation.

The USNRC portion of Title 10 is Parts 1-50. As a minimum, radiographers should be familiar with the following parts:

Title 10, Part 34 (10CFR34): *Licenses for industrial radiography and radiation safety requirements for industrial radiographic operations;*
10CFR20: *Standards for protection against radiation*; and
10CFR21: *Reporting of defects and noncompliance*.

These NRC regulations apply to radioactive materials only; the NRC does not address radiation such as X-radiation, which is generated by electromagnetic means. Electromagnetic radiation is governed by the Suggested State Regulations for Control of Radiation (SSRCR), which is addressed below.

The USDOT portion of Title 49 is under Parts 186-199, and the hazardous liquids and gasses Parts are as follows:

49CFR192: *Transportation of natural and other gas by pipeline: minimum Federal safety standards; and*
49CFR195: *Transportation of hazardous liquids by pipeline*.

These two parts mandate Operator Qualification for "covered tasks," and NDT is considered a covered task.

QUALITY CONTROL AND INSPECTION PROCEDURES IN INDUSTRIAL PRACTICE

Non-destructive testing (NDT) has a number of important roles to play in ensuring the through-life quality and reliability of many important products whose integrity is of paramount importance. The traditional role of NDT in quality control during manufacture - predominantly defect detection - has been complemented in recent years with increasingly important inspections in-service on plant and equipment at varying stages through life. The correct application of NDT can prevent accidents, save lives, protect the environment and avoid economic loss. Non-destructive testing and inspection are vital functions in achieving the goals of efficiency and quality at an acceptable cost. In many cases, these functions are highly critical: painstaking procedures are adopted to provide the necessary degree of quality assurance. The consequences of failure of engineering materials, components and structures are well known and can be disastrous. It is an increasing requirement of quality assurance systems that a company's engineers, technicians and craftsmen are able to demonstrate that they have the required level of knowledge and skill. This is particularly so since NDT and inspection activities are very operator dependent and those in authority have to place great reliance on the skill, experience, judgement and integrity of the personnel involved. Indeed, during fabrication, NDT and inspection provides the last line of defence before the product enters service, whilst once a product or structure enters service, in-service NDT often provides an even more crucial line of defence against failure. Achievement of quality in NDT There are three important factors to achieve the necessary quality and reliability of inspection:-

1. The responsible engineer must specify his requirements very clearly in terms of the regions to be inspected and the types of flaws or deterioration to be looked for (all-encompassing combinations would be prohibitively expensive).

2. The NDT methods, equipment and personnel must be capable of the purpose for which they are being employed.

3. The selected NDT process must be implemented thoroughly. Many of the necessary controls are available through the “NDT infrastructure” which has been established in many countries.

These infrastructures are quite sophisticated and most complete in the manufacturing quality control sphere of NDT, particularly in those geographical areas where ISO 9001 certification of quality assurance demands comprehensive systems to be in place. For the newer applications of NDT or in-service inspection, some of the infrastructure is being developed. As world trade rapidly becomes more liberalised, and equipment is sourced more widely, the NDT infrastructures which were originally national in their coverage, need to become international. Quality in execution of NDT operations demands attention to a series of interlinked aspects extending from research and development, codes and standards, equipment, personnel training and certification to the effects of human reliability and the influence of auditing and surveillance. These aspects can be represented as links in a chain as shown in Figure.

Figure. NDT Quality Chain

The chain will only be as strong as its weakest link. Extra attention to one link in the chain cannot compensate for lack of attention to another - just as a strong link in a chain cannot compensate for a weak link. National and international standards for quality systems such as ISO 9001 require management to establish systems to control all activities which affect quality including NDT. The quality system must address each of the links in the NDT quality chain - to ensure that all the links are in place and properly joined. Other legislation, codes and practice, and good professional conduct all oblige users of NDT and suppliers of NDT to address how to achieve reliability

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UNIT – II
COMMON NDT METHODS

VISUAL TESTING (VT)

Visual testing is the first NDT method that should be considered before applying more sophisticated and expensive methods. In this method direct visual and optically aided inspection is applied to the surface of object to detect flaws and anomalies. If significant flaws are detected during visual inspection then the part being inspected can be rejected on that basis. There is then hardly any need or justification for applying the other NDT methods.

Tools for visual inspection

The human eye is the most frequently used tool for visual inspection. It can be aided by lenses and magnifiers. At places where direct vision is not possible boroscopes can be used. The images can be observed under visible light or ultraviolet light may be used for fluorescent materials. Video and film cameras have also been employed for remote visual inspection, hi fact liquid penetrant testing and magnetic particle testing are only more advanced forms of visual inspection.

Applications of visual inspection

Visual inspection can be applied to all sorts of materials for the detection of surface cracks, voids, pores, inclusions and for the assessment of surface roughness. It can be applied for metrology and dimensional measurements using mechanical gauges. Process control applications of visual inspection include both on-line and off-line monitoring control. As mentioned earlier it can be applied to all sorts of materials such as metallic and non-metallic, ferromagnetic and non-magnetic, conductors and non conductors, machined parts, components, assemblies and systems. However, the application of the technique is limited by the visual access which is needed and the specialized aids which are usually required. The sensitivity of the method depends upon the degree of magnification that may be achievable. For accurate flaw discrimination, detection and measurement, the information obtained by visual inspection may need to be supplemented by other NDT methods.

Liquid Penetrant Testing

Liquid penetrant testing is one of the oldest and simplists NDT methods where its earliest versions (*using kerosene and oil mixture*) dates back to the 19th century. This method is used to reveal surface discontinuities by bleedout of a colored or fluorescent dye from the flaw. The technique is based on the ability of a liquid to be drawn into a "clean" surface discontinuity by capillary action. After a period of time called the "dwell time", excess surface penetrant is removed and a developer applied. This acts as a blotter that draws the penetrant from the discontinuity to reveal its presence.

The advantage that a liquid penetrant inspection offers over an unaided visual inspection is that it makes defects easier to see for the inspector where that is done in two ways:

1. It produces a flaw indication that is much larger and easier for the eye to detect than the flaw itself. Many flaws are so small or narrow that they are undetectable by the unaided eye (*a person with a perfect vision can not resolve features smaller than 0.08 mm*).
2. It improves the detectability of a flaw due to the high level of contrast between the indication and the background which helps to make the indication more easily seen (*such*

as a red indication on a white background for visable penetrant or a penetrant that glows under ultraviolate light for flourecent penetrant).

Liquid penetrant testing is one of the most widely used NDT methods. Its popularity can be attributed to two main factors: its relative ease of use and its flexibility. It can be used to inspect almost any material provided that its surface is not extremely rough or porous. Materials that are commonly inspected using this method include; metals, glass, many ceramic materials, rubber and plastics.

However, liquid penetrant testing can only be used to inspect for flaws that break the surface of the sample (*such as surface cracks, porosity, laps, seams, lack of fusion, etc*.).

Steps of Liquid Penetrant Testing

The exact procedure for liquid penetrant testing can vary from case to case depending on several factors such as the penetrant system being used, the size and material of the component being inspected, the type of discontinuities being expected in the component and the condition and environment under which the inspection is performed. However, the general steps can be summarized as follows:

1. *Surface Preparation*: One of the most critical steps of a liquid penetrant testing is the surface preparation. The surface must be free of oil, grease, water, or other contaminants that may prevent penetrant from entering flaws. The sample may also require etching if mechanical operations such as machining, sanding, or grit blasting have been performed. These and other mechanical operations can smear metal over the flaw opening and prevent the penetrant from entering.

2. *Penetrant Application*: Once the surface has been thoroughly cleaned and dried, the penetrant material is applied by spraying, brushing, or immersing the part in a penetrant bath.

3. *Penetrant Dwell*: The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn from or to seep into a defect. Penetrant dwell time is the total time that the penetrant is in contact with the part surface. Dwell times are usually recommended by the penetrant producers or required by the specification being followed. The times vary depending on the application, penetrant materials used, the material, the form of the material being inspected, and the type of discontinuity being inspected for. Minimum dwell times typically range from five to 60 minutes. Generally, there is no harm in using a longer penetrant dwell time as long as the penetrant is not allowed to dry. The ideal dwell time is often determined by experimentation and may be very specific to a particular application.

4. *Excess Penetrant Removal*: This is the most delicate part of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects. Depending on the penetrant system used, this step may involve cleaning with a solvent, direct rinsing with water, or first treating the part with an emulsifier and then rinsing with water.

5. *Developer Application*: A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. Developers come in a

variety of forms that may be applied by dusting (*dry powders*), dipping, or spraying (*wet developers*).

6. *Indication Development*: The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws. This development time is usually a minimum of 10 minutes. Significantly longer times may be necessary for tight cracks.

7. *Inspection*: Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

8. *Clean Surface*: The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.

Advantages and Disadvantages

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

Advantages

1. High sensitivity (*small discontinuities can be detected*).

2. Few material limitations (*metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected*).
3. Rapid inspection of large areas and volumes.
4. Suitable for parts with complex shapes.
5. Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
6. Portable (materials are available in aerosol spray cans)
7. Low cost (materials and associated equipment are relatively inexpensive)

Disadvantages
1. Only surface breaking defects can be detected.
2. Only materials with a relatively nonporous surface can be inspected.
3. Pre-cleaning is critical since contaminants can mask defects.
4. Metal smearing from machining, grinding, and grit or vapor blasting must be removed.
5. The inspector must have direct access to the surface being inspected.
6. Surface finish and roughness can affect inspection sensitivity.
7. Multiple process operations must be performed and controlled.
8. Post cleaning of acceptable parts or materials is required.
9. Chemical handling and proper disposal is required.

Penetrants
Penetrants are carefully formulated to produce the level of sensitivity desired by the inspector. The penetrant must possess a number of important characteristics:
- spread easily over the surface of the material being inspected to provide complete and even coverage.
- be drawn into surface breaking defects by capillary action.
- remain in the defect but remove easily from the surface of the part.
- remain fluid so it can be drawn back to the surface of the part through the drying and developing steps.
- be highly visible or fluoresce brightly to produce easy to see indications.
- not be harmful to the material being tested or the inspector.

Penetrant materials are not designed to perform the same. Penetrant manufactures have developed different formulations to address a variety of inspection applications. Some applications call for the detection of the smallest defects possible while in other Introduction to applications, the rejectable defect size may be larger. The penetrants that are used to detect the smallest defect will also produce the largest amount of irrelevant indications.
Standard specifications classify penetrant materials according to their physical characteristics and their performance.

Penetrant materials come in two basic types:

Type 1 - Fluorescent Penetrants: they contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation.
Type 2 - Visible Penetrants: they contain a red dye that provides high contrast against the white developer background.

Fluorescent penetrant systems are more sensitive than visible penetrant systems because the eye is drawn to the glow of the fluorescing indication. However, visible penetrants do not require a darkened area and an ultraviolet light in order to make an inspection.

Penetrants are then classified by the method used to remove the excess penetrant from the part. The four methods are:

Method A - Water Washable: penetrants can be removed from the part by rinsing with water alone. These penetrants contain an emulsifying agent (detergent) that makes it possible to wash the penetrant from the part surface with water alone. Water washable penetrants are sometimes referred to as self-emulsifying systems.
Method B - Post-Emulsifiable, Lipophilic: the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible.
Method C - Solvent Removable: they require the use of a solvent to remove the penetrant from the part.
Method D - Post-Emulsifiable, Hydrophilic: they use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash.

Penetrants are then classified based on the strength or detectability of the indication that is produced for a number of very small and tight fatigue cracks. The five sensitivity levels are:

Level ½ - Ultra Low Sensitivity
Level 1 - Low Sensitivity
Level 2 - Medium Sensitivity
Level 3 - High Sensitivity
Level 4 - Ultra-High Sensitivity
The procedure for classifying penetrants into one of the five sensitivity levels uses specimens with small surface fatigue cracks. The brightness of the indication produced is measured using a photometer.

Developers
The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector. Developers used with visible penetrants create a white background so there is a greater degree of contrast between the indication and the surrounding background. On the other hand, developers used with fluorescent penetrants both reflect and refract the incident ultraviolet light, allowing more of it to interact with the penetrant, causing more efficient fluorescence.
According to standards, developers are classified based on the method that the developer is applied (*as a dry powder, or dissolved or suspended in a liquid carrier*). The six standard forms of developers are:
Form a - Dry Powder
Form b - Water Soluble
Form c - Water Suspendable
Form d - Nonaqueous Type 1: Fluorescent (Solvent Based)
Form e - Nonaqueous Type 2: Visible Dye (Solvent Based)
Form f - Special Applications

Dry Powder

Dry powder developers are generally considered to be the least sensitive but they are inexpensive to use and easy to apply. Dry developers are white, fluffy powders that can be applied to a thoroughly dry surface in a number of ways; by dipping parts in a container of developer, by using a puffer to dust parts with the developer, or placing parts in a dust cabinet where the developer is blown around. Since the powder only sticks to areas of indications since they are wet, powder developers are seldom used for visible inspections.

Water Soluble

As the name implies, water soluble developers consist of a group of chemicals that are dissolved in water and form a developer layer when the water is evaporated away. The best method for applying water soluble developers is by spraying it on the part. The part can be wet or dry. Dipping, pouring, or brushing the solution on to the surface is sometimes used but these methods are less desirable. Drying is achieved by placing the wet but well drained part in a recirculating, warm air dryer with the temperature 21°C. Properly developed parts will have an even, pale white coating over the entire surface.

Water Suspendable

Water suspendable developers consist of insoluble developer particles suspended in water. Water suspendable developers require frequent stirring or agitation to keep the particles from settling out of suspension. Water suspendable developers are applied to parts in the same manner as water soluble developers then the parts are dried using warm air.

Nonaqueous

Nonaqueous developers suspend the developer in a volatile solvent and are typically applied with a spray gun. Nonaqueous developers are commonly distributed in aerosol spray cans for portability. The solvent tends to pull penetrant from the indications by solvent action. Since the solvent is highly volatile, forced drying is not required.

Special Applications

Plastic or lacquer developers are special developers that are primarily used when a permanent record of the inspection is required.

Preparation of Part

One of the most critical steps in the penetrant inspection process is preparing the part for inspection. All coatings, such as paints, varnishes, plating, and heavy oxides must be removed to ensure that defects are open to the surface of the part. If the parts have been machined, sanded, or blasted prior to the penetrant inspection, it is possible that a thin layer of metal may have smeared across the surface and closed off defects. Also, some cleaning operations, such as steam cleaning, can cause metal smearing in softer materials. This layer of metal smearing must be removed before inspection.

Penetrant Application and Dwell Time

The penetrant material can be applied in a number of different ways, including spraying, brushing, or immersing the parts in a penetrant bath. Once the part is covered in penetrant it must be allowed to dwell so the penetrant has time to enter any defect that is present.

There are basically two dwell mode options:

- *Immersion-dwell*: keeping the part immersed in the penetrant during the dwell period.
- *Drain-dwell*: letting the part drain during the dwell period (*this method gives better sensitivity*).

Penetrant Dwell Time

Penetrant dwell time is the total time that the penetrant is in contact with the part surface. The dwell time is important because it allows the penetrant the time necessary to seep or be drawn into a defect. Dwell times are usually recommended by the penetrant producers or required by the specification being followed. The time required to fill a flaw depends on a number of variables which include:

- The surface tension of the penetrant.
- The contact angle of the penetrant.
- The dynamic shear viscosity of the penetrant.
- The atmospheric pressure at the flaw opening.
- The capillary pressure at the flaw opening.
- The pressure of the gas trapped in the flaw by the penetrant.
- The radius of the flaw or the distance between the flaw walls.
- The density or specific gravity of the penetrant.
- Microstructural properties of the penetrant.

The ideal dwell time is often determined by experimentation and is often very specific to a particular application. For example, the table shows the dwell time requirements for steel parts according to some of the commonly used specifications.

Penetrant Removal Process

The penetrant removal procedure must effectively remove the penetrant from the surface of the part without removing an appreciable amount of entrapped penetrant from the discontinuity. If the removal process extracts penetrant from the flaw, the flaw indication will be reduced by a proportional amount. If the penetrant is not effectively removed from the part surface, the contrast between the indication and the background will be reduced.

Removal Method

As mentioned previously, penetrant systems are classified into four types according to the method used for excess penetrant removal.

- *Method A: Water-Washable*
- *Method B: Post-Emulsifiable, Lipophilic*
- *Method C: Solvent Removable*
- *Method D: Post-Emulsifiable, Hydrophilic*

Method C, Solvent Removable, is used primarily for inspecting small localized areas. This method requires hand wiping the surface with a cloth moistened with the solvent remover, and is, therefore, too labor intensive for most production situations.

Method A, Water-Washable, is the most economical to apply of the different methods and it is easy to use. Water-washable or self-emulsifiable penetrants contain an emulsifier as an integral part of the formulation. The excess penetrant may be removed from the object surface with a simple water rinse.

When removal of the penetrant from the defect due to over-washing of the part is a concern, a post-emulsifiable penetrant system can be used. The post-emulsifiable methods are generally only used when very high sensitivity is needed. Post-emulsifiable penetrants require a separate emulsifier to breakdown the penetrant and make it water washable. The part is usually immersed in the emulsifier but hydrophilic emulsifiers may also be sprayed on the object. Brushing the emulsifier on to the part is not recommended either because the bristles of the brush may force emulsifier into discontinuities, causing the entrapped penetrant to be removed. The emulsifier is allowed sufficient time to react with the penetrant on the surface of the part but not given time to make its way into defects to react with the trapped penetrant. Controlling the reaction time is of essential importance when using a post-emulsifiable system. If the emulsification time is too short, an excessive amount of penetrant will be left on the surface, leading to high background levels. If the emulsification time is too long, the emulsifier will react with the penetrant entrapped in discontinuities, making it possible to deplete the amount needed to form an indication.

The hydrophilic post-emulsifiable method (*Method D*) is more sensitive than the lipophilic post-emulsifiable method (*Method B*). The major advantage of hydrophilic emulsifiers is that they are less sensitive to variation in the contact and removal time.

When using an emulsifiable penetrant is used, the penetrant inspection process includes the following steps (*extra steps are underlined*): **1**. pre-clean part, **2**. apply penetrant and allow to dwell, **3**. *pre-rinse to remove first layer of penetrant*, **4**. *apply hydrophilic emulsifier and allow contact for specified time*, **5**. rinse to remove excess penetrant, **6**. dry part, **7**. apply developer and allow part to develop, and **8**. inspect.

Rinse Method and Time for Water-Washable Penetrants

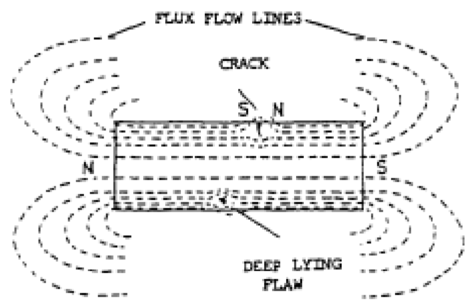
The method used to rinse the excess penetrant from the object surface and the time of the rinse should be controlled so as to prevent over-washing. It is generally recommended that a coarse spray rinse or an air-agitated, immersion wash tank be used. When a spray is being used, it should be directed at a 45° angle to the part surface so as to not force water directly into any discontinuities that may be present. The spray or immersion time should be kept to a minimum through frequent inspections of the remaining background level.

Hand Wiping of Solvent Removable Penetrants

When a solvent removable penetrant is used, care must also be taken to carefully remove the penetrant from the part surface while removing as little as possible from the flaw. The first step in this cleaning procedure is to dry wipe the surface of the part in one direction using a white, lint-free, cotton rag. One dry pass in one direction is all that should be used to remove as much penetrant as possible. Next, the surface should be wiped with one pass in one direction with a rag moistened with cleaner. One dry pass followed by one damp pass is all that is recommended. Additional wiping may sometimes be necessary; but keep in mind that with every additional wipe, some of the entrapped penetrant will be removed and inspection sensitivity will be reduced.

MAGNETIC PARTICLE TESTING

Magnetic particle testing is used for the testing of materials which can be easily magnetized. This method is capable of detecting open-to-surface and just below-the-surface flaws, hi this method the test specimen is first magnetized either by using a permanent magnet or an electric current through or around the specimen. The magnetic field thus introduced into the specimen is composed of magnetic lines of force. Whenever there is a flaw which interrupts the flow of magnetic lines of force, some of these lines must exit and re-enter the specimen. These points of exit and re-entry form opposite magnetic poles and whenever minute magnetic particles are sprinkled onto the surface of the specimen, these particles are attracted by these magnetic poles to create a visual indication approximating the size and shape of the flaw.



Methods of magnetization

Electric currents are used to create or induce magnetic fields in magnetic materials. Several types of magnetization are in use for magnetic particle inspection. Some of the types are DC magnetization, half wave rectified current magnetization and AC magnetic particle inspection. Direct current obtained from storage batteries was first believed to be the most desirable current to use, since it penetrates more deeply into test specimens than any other current. The big disadvantage of the current obtained from storage batteries is that there is a specific limit to the magnitude and duration of current, which can be drawn from the battery before recharging. Battery maintenance is costly and can become a source of trouble. Battery current can be replaced by the current obtained through dry plate rectifiers from AC power lines. This has the advantage of permitting an almost unlimited supply of DC. Half wave rectified current is the most effective current to use for detection of surface and sub-surface defects using dry magnetic particles. It gives mobility to magnetic particles and aids in the formation of indications. Alternating current is also used for detection of surface cracks like fatigue cracks. AC inspection units should be equipped with proper current controls. An advantage of using AC is that the parts being inspected with this current can be easily demagnetized.

Some of the commonly used methods of magnetizing the test specimens of different configurations are given below:

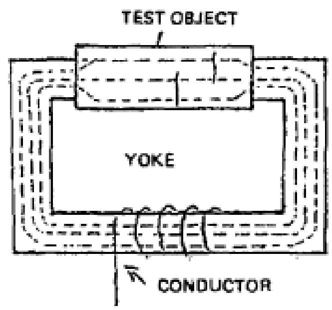
(a) Circular magnetization

Electric current passing through any straight conductor such as wire or bar creates a
circular magnetic field around that conductor For inspection of axial cracks in a solid or hollow part, the part can be magnetized circularly. For a solid part the current is passed through the test piece and a circular field is developed inside and around the piece. In the case of hollow or tube like objects, a central conductor is used to carry the magnetizing current. The central conductor is always a copper rod. The conductor is placed inside the hollow piece and current is then

applied to it. This induces a circular magnetic field on the inside and outside surface of the hollow piece.

(b) Longitudinal magnetization

Parts can be magnetized longitudinally using a permanent magnet or by using an electromagnet. Parts can also be magnetized longitudinally by the application of electric current in a coil. When electric current is passed through a coil of several turns, a magnetic field is established lengthwise or longitudinally within the coil. The nature and direction of this field is the result of the field around the conductor which forms due to the number of turns in the current carrying coil. A crack at right angles or tangential to this field can be revealed. Longitudinal magnetization may be achieved by surrounding the test specimen with helical coils and passing current through them.



(c) Magnetization of **irregular parts**

Parts of irregular shape sometimes have to be tested. They can be tested using the magnetic particle inspection method. Local magnetization is created by applying prods to the area to be tested. The area is magnetized circularly and any defect in the path of the magnetic lines of force can be indicated. The inspection of irregular parts by this method is time consuming since a magnetizing current has to be applied many times to achieve thorough inspection of a component. However the testing time is not a large problem, due to the quick testing capability of the magnetic particle inspection method.

General procedure for magnetic testing

The steps and sequence involved in the magnetic method are as follows:

(a) Preparation of the test specimen

Loose rust and scale should be removed from the component. Machined parts should be degreased using appropriate solvents. In painted parts the paint should be removed locally to provide adequate contact areas for the current flow tests. Parts with paint in the test area will only require degreasing unless the colour of the paint is the same as that of the particles in the ink to be used and is likely, therefore, to provide poor contrast. In the latter case a contrast aid may be applied. This is normally a thin white coating. The application of a white emulsion paint is an alternative procedure. Components which have been in a magnetic field may be carrying residual magnetism. It is advisable to remove this residual magnetism to avoid false indications.

b) Magnetization of the test specimen

The test specimen may be magnetized depending on its shape and configuration. It is advisable to devise and write down the technique to be used listing the operations required with all details of directions of tests and jigs needed. Many components may not have simple geometric shapes but instead may have what can be considered to be combinations of simple shapes. In such cases more than one magnetizing technique may be necessary to be able to test the whole specimen. When multi-diameter or multi thickness specimens are to be tested in the same direction, testing of the larger diameter/thickness portion will over-saturate the smaller diameter/thickness portion, therefore the lower value tests should be made first. The sensitivity of defect detection improves with the level of magnetization. Theoretically a level just below saturation would give the most sensitive results but this is impractical owing to the variety of non-regular shapes encountered and therefore, in practice lower levels are quite adequate. For most critical work about 40% of saturation is sufficient. With this level of magnetization large defects of 2.5 mm depth below the surface can always be found and up to about 1.5 mm deep all defects of a serious nature can be detected. Practically the saturation flux value for the test specimen may be found by increasing the flux level until background is formed. Variables affecting the flux for permanent magnets and electromagnets include the cross section and length of the test specimen and the total length of the flux path including the machine poles. For the current flow method a value of 9 A/mm of perimeter of the test specimen is the recommended level of magnetization for critical work. For basically round components this can be expressed as 28 A/mm of diameter. While testing using a coil, the factors that influence the magnetic flux are number of ampere turns of the coil, fill factor of the coil, length over diameter ratio of the test specimen and the coil shape. To obtain a suitable test value in this case, the current in the coil is increased with the component in position until saturation is obtained and the suggested standard would then be 40% of the saturation value. Alternatively for rigid coils and provided that the component is placed near the coil perimeter and has a cross-sectional area not more than 10% of the coil cross-sectional area, the test current may be calculated using the equation $A = 9000/CT$ where A is the current in amperes, C is the coil diameter in millimetres and T is the number of coil turns.

(c) Application of the magnetic powder

Magnetic particles are available in red or black colours. The red material improves visibility on dark surfaces. There are also fluorescent materials available. Thesemagnetic particles may be applied to the test specimen either in dry or in wet form. If a dry powder is used it should be applied to the magnetized component such as to achieve an even distribution. Tapping the test specimen with a rubber hammer is often helpful. For the wet magnetic particles it is best that these are applied during magnetization. They should cease flowing just before excitation ceases. They can be applied to the test specimen by brush, ladle or hose. Whichever method is used, care should be taken to avoid violent flow over the test specimen, otherwise faint indications from flaws are disturbed. Such faint indications will also be washed away if the magnetic particles are reapplied after the current has ceased to flow. The application of magnetic particles may also be made by immersing the test specimen in a suspension of particles. As the particles in the wet method are generally finer than those in the dry method the wet method is more sensitive for the detection of fine surface defects. On the other hand it is not as sensitive as the dry method for the detection of subsurface discontinuities. Greatest sensitivity is achieved through the use of fluorescent magnetic particles.

(d) Viewing and recording of indications

The whole of the surface under test should be viewed. Viewing of under surfaces may need a mirror. Bores may need special lighting and viewing of end faces may necessitate removing the test specimen from between the contacts. Doubtful indications are often more evident if the component is allowed to drain for a few minutes. Any indications found can be marked with a grease pencil after allowing the ink to drain. It is frequently desirable to record not only the appearance of indications on a part but also their locations. For a permanent record the indication can be lifted from the test specimen and transferred to white paper using adhesive tape.

(e) Demagnetization

For many industrial applications the tested specimens are required to be free from magnetism. Demagnetization may be achieved by inserting the part in the field of an alternating current solenoid and gradually withdrawing it from the field. Larger parts may be demagnetized by subjecting them to an alternating current field that is gradually reduced in intensity by means of a current controller. When large masses of steel or iron are involved, alternating current has insufficient penetration to demagnetize such pieces thoroughly. In such cases direct current should be used. Hammering or rotating in the field will sometimes assist demagnetization. Heat treating or stress relief will demagnetize weldments and total demagnetization is always accomplished when the work piece is heated above the curie temperature of the metal. The efficiency of demagnetization should be checked by using a compass or a commercial magnetic field indicator.

Equipment for **magnetic particle inspection**

It is emphasized that magnetic particle testing is an important process in the production of steel components which are not checked at any subsequent manufacturing stage. The provision of adequate equipment for use by a reliable operator will more than justify the initial cost and will ensure that the tests are correctly carried out. Equipment is available in the range of from small hand tools to big universal type testing equipment. In both categories, i.e. portable and nonportable, more than hundred types are used in industry. Portable equipment can be taken to the site for the inspection of large castings, weldments, assembles or welded structures or parts of assemblies tested without disassembly. Small parts, on the other hand can be brought to a fixed inspection station. In industry, inspection is a part of the production line. Therefore inspection of in-process parts can be done by sampling or on a 100% basis at one or more locations along the production line. Sometimes inspection is needed where mass production of a single piece is done. For this purpose specialized testing equipment may be best for minimum testing cost per piece. At other places inspection of various types of parts may be required in a very high volume. Here there is need for an equipment where eight, ten or twenty different parts can be inspected on a single piece of equipment in lots of several thousand per hour. In many industries various types of parts are produced on a low production basis. For this a single piece of test equipment can be used with greater efficiency. Other factors which need to be kept in view when selecting equipment are the types of defects of interest, the required sensitivity and whether the whole or a localized area of the test specimen is to be inspected. Different types of equipment available in the market are briefly reviewed here. Hand operated small fixed or stationary units are widely used for small manufactured parts. These units normally contain a built-in tank with pump which agitates the wet particle bath and pumps inspection fluid through a hand held hose for application to test objects. A part is clamped within the magnetizing coil between the copper contact faces. At the operator's option, the parts can be magnetized circularly with current between the head, or longitudinally with current through the coil, or both if desired, while the part is magnetized, the operator applies the liquid inspection medium, and then views the surface for indications. Most units are provided with inspection hoods and black lights, so that fluorescent magnetic particles can be used. This increases the rate of inspection and reduces the possibility of missing an indication. This type probably accounts for about 75% of magnetic particle inspection. For bulkier work upto say 1.5 m long and 0.3 m in diameter, more power is needed to maintain the desired flux level. Such units have a magnetizing current upto 5000 amp. a.c. and a magnetic field of about 1500 oersteds (120 K A/m). A demagnetizer which is built in can accommodate a part of 360 x 250 mm. Sensitivity may be controlled to reveal only surface cracks with a.c or surface and subsurface cracks with half wave current. For site testing, equipment must be capable of being handled manually up ladders and to be located remote from mains supply. Many standard sizes of portable magnetic particle inspection equipment are in use. They vary from small hand held yokes made from permanent magnets to electromagnets. Several types of completely automatic equipments are used for magnetic particle inspection in hundreds of plant locations. Inspection is carried out automatically on parts carried by a continuous conveyer. Loading and unloading may be manual or automatic. The inspector is required to view the parts as they pass on the conveyer and must only see and react to readily visible indications. Parts bearing indications are diverted for later evaluation and salvage or rejection. Accepted parts remain on the conveyer and pass through an automatic demagnetizer before being discharged from the unit. Such equipment permits a rapid and low-cost inspection where slower inspection may not be worth its cost. Special purpose equipment for checking automatically a large number of identical parts of simple form can be designed in such a way that a current flow test and a coil test are applied at the same time, thus enabling both longitudinal and transverse defects to be found.

Applications of the magnetic method of testing

In general engineering practice, a large proportion of components are made of steel or iron which are capable of being magnetized. This is fortunate because this testing method is not expensive and it can reveal all the surface faults in parts which are subjected to light stresses and fatigue and in those which have been cast, welded or heat treated during fabrication. Many inspection specifications for aerospace, atomic and other critical work specially call for this type of test. When non metallic inclusions occur in areas of high stress or in certain special locations, they may be a cause for rejection. A subsurface condition which is much more likely to be dangerous is the presence of inclusions which were not plastic at the time of rolling or forging e.g. refractory materials. Usually the inclusions are very fine and are revealed with magnetic particle inspection only when they occur near the surface. They are most likely to be shown on highly finished surface by applying the wet method with high magnetization levels. Inspection before machining is not helpful, and if inclusions are considered a cause for rejection, parts should be inspected after surface finishing. Surface seams in rolled bars result from cracks or other defects (surface) in the billets from which they are rolled or from some defects introduced by the rolling operation itself. The great elongation of the metal draws out such surface defects, into long, straight seams, usually parallel to the direction of rolling. Cooling cracks which occur in rolled bars are similar to seams but usually differ in appearance in some respects. When magnetic particles are applied to such a surface for inspection, the indications are sharp and well defined, but deviate some what from the rolling direction. Porosity in castings caused by gases trapped during the solidification of the molten metal can sometimes be located with magnetic particle inspection. Subsurface blow holes and thermal cracks in castings can also be revealed with magnetic particle inspection. Magnetic particle inspection is used extensively on welds. It is possible to findporosity, slag inclusion shrink cracks, inadequate penetration and incomplete fusion. With d.c. magnetization a subsurface discontinuity like lack of penetration at a root can be revealed. Cracks caused by faulty heat treatment processing are readily found with magnetic particle inspection. Such cracks may occur during either the heating or quenching cycle and may be enlargements of conditions existing in the part from some previous operation. Heat treatment cracks which are created by the quench cycle and which are also called quench cracks, are usually found at sharp changes of section, which cause unequal cooling rates, or at fillets or notches which act as stress concentration points. Fatigue cracks are produced in service under repeated stress reversals or stress variation. A crack almost invariably starts at a highly stressed surface and propagates through the section until failure results. A fatigue crack will start more readily where design or surface condition provides a point of stress concentration. Sharp fillets, poor surface finish, seams, grinding cracks, and other such defects act as stress raisers and assist in the start of fatigue cracking. All magnetic particle inspection to eliminate seams, inclusions, cooling cracks, laps, porosity, heat treatment cracks and grinding cracks is for the purpose of preventing fatigue or service failure after the part goes into service. Consistent use of magnetic particle inspection as well as other non-destructive tests in a well planned preventive maintenance programme can in many cases reduce service failure from fatigue to practically zero.

Range and limitations of magnetic particle inspection

Magnetic particle testing is a method of finding surface and near surface defects in any steel or iron sample capable of being magnetized. It is essential that the flux path crosses the flaw and ideally should be at right angles to it. Fortunately, with an adequate level of magnetization, defects oriented by as much as 50 degrees with respect to the direction of the flux will show up and any object can be tested completely provided at least two tests are made. The flux direction in the object for the second test should be at right angles to the flux direction for the first. To ensure an adequate test, the factors that need to be considered include the shape of the component, the dimensions of the component, the magnetic permeability, surface finish, possible defects and their orientation, suitable flux direction and strength and a suitable testing stage during manufacturing. Unless due consideration is given to all these factors, the test is unreliable, although it may reveal some defects, but it is quite possible that serious defects may not be revealed. Because every component differs and at least two tests are required to find all defects it is good to establish a proper technique for each. For components having complex shapes, this technique may consist of as many as a dozen tests at varying field strengths and using different methods to ensure 100 percent coverage. Provided that adequate equipment is available, it is feasible to test any type and size of magnetic object. The size of defects which can be detected will depend upon surface finish and other factors. Magnetic particle inspection is not expensive. The test can be performed in the presence of an overlay of paint or non-magnetic plating. The inspection can be undertaken by semi-skilled labour without requiring elaborate protection such as that needed for radiography. The presence of non-conducting surface coatings, such as paint, may preclude the use of contact current flow tests. The material must be capable of being magnetized which precludes the testing of austenitic steels and other non-magnetic materials. Since every test requires at least two directions of flux, components of complex shapes may need numerous tests which becomes cumbersome and time-consuming. Demagnetization is another of the shortcomings. The ink particles can clog fine passages and their removal is sometimes laborious.

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UNIT – III - N O N D E S T R U C T I V E T E S T I N G AND T E C H N I Q U E S – SPR1611

UNIT - III

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 Xray 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 shadow graph 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 liter areas indicate less exposure (*higher 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 in comparison 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.

Nature of Penetrating Radiation

Both X-rays and gamma rays are electromagnetic waves and on the electromagnetic spectrum they ocupy frequency ranges that are higher than ultraviolate radiation. In terms of frequency, gamma rays generaly have higher frequencies than X-rays as seen in the figure . The major distenction between X-rays and gamma rays is the origion where X-rays are usually artificially produced using an X-ray generator and gamma radiation is the product of radioactive materials. Both X-rays and gamma rays are waveforms, as are light rays, microwaves, and radio waves. X-rays and gamma rays cannot been seen, felt, or heard. They possess no charge and no mass and, therefore, are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light. Electromagentic radiation act somewhat like a particle at times in that they occur as small “packets” of energy and are referred to as “*photons*”. Each photon contains a certain amount (*or bundle*) of energy, and all electromagnetic radiation consists of these photons. The only difference between the various types of electromagneticradiation is the amount of energy found in the photons. Due to the short wavelength of X-rays and gamma rays, they have more energy to pass through matter than do the other forms of energy in the electromagnetic spectrum. As they pass through matter, they are scattered and absorbed and the degree of penetration depends on the kind of matter and the energy of the rays.

Properties of X-Rays and Gamma Rays
 They are not detected by human senses (cannot be seen, heard, felt, etc.).
 They travel in straight lines at the speed of light.
 Their paths cannot be changed by electrical or magnetic fields.
 They can be diffracted, refracted to a small degree at interfaces between two different materials, and in some cases be reflected.
 They pass through matter until they have a chance to encounter with an atomic particle.
 Their degree of penetration depends on their energy and the matter they are traveling through.

- They have enough energy to ionize matter and can damage or destroy living cells.

Radiation Energy, Intensity and Exposure

Different radioactive materials and X-ray generators produce radiation at different energy levels and at different rates. It is important to understand the terms used to describe the energy and intensity of the radiation.

Radiation Energy

The energy of the radiation is responsible for its ability to penetrate matter. Higher energy radiation can penetrate more and higher density matter than low energy radiation. The energy of ionizing radiation is measured in *electronvolts* (***eV***). One electronvolt is an extremely small amount of energy so it is common to use kiloelectronvolts (***keV***) and megaelectronvolt (***MeV***). An electronvolt is a measure of energy, which is different from a volt which is a measure of the electrical potential between two positions. Specifically, an electronvolt is the kinetic energy gained by an electron passing through a potential difference of one volt. X-ray generators have a control to adjust the radiation energy, *keV* (or *kV*).

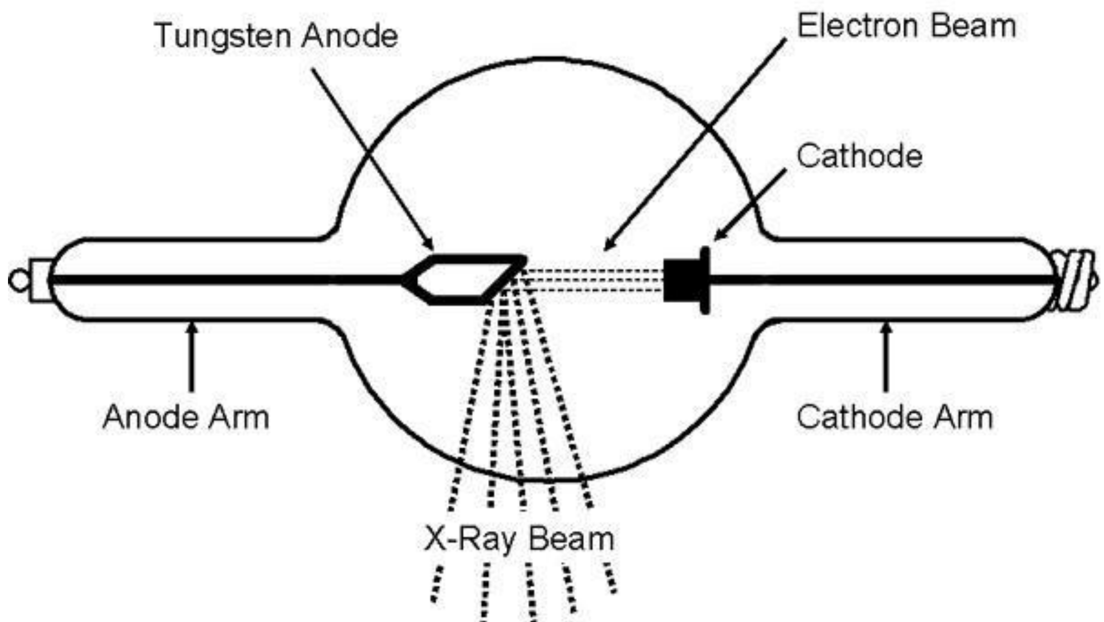
Interaction between Penetrating Radiation and Matter (*Attenuation*)

When X-rays or gamma rays are directed into an object, some of the photons interact with the particles of the matter and their energy can be absorbed or scattered. This absorption and scattering is called "*Attenuation*". Other photons travel completely through the object without interacting with any of the material's particles. The number of photons transmitted through a material depends on the thickness, density and atomic number of the material, and the energy of the individual photons. Even when they have the same energy, photons travel different distances within a material simply based on the probability of their encounter with one or more of the particles of the matter and the type of encounter that occurs. Since the probability of an encounter increases with the distance traveled, the number of photons reaching a specific point within the matter decreases exponentially with distance traveled.

X-ray Generators

The major components of an X-ray generator are the tube, the high voltage generator, the control console, and the cooling system. As discussed earlier in this material, X-rays are generated by directing a stream of high speed electrons at a target material such as tungsten, which has a high atomic number. When the electrons are slowed or stopped by the interaction with the atomic particles of the target, X-radiation is produced. This is accomplished in an X-ray tube.

The tube cathode (*filament*) is heated with a low-voltage current of a few amps. The filament heats up and the electrons in the wire become loosely held. A large electrical potential is created between the cathode and the anode by the high-voltage generator. Electrons that break free of the cathode are strongly attracted to the anode target. The stream of electrons between the cathode and the anode is the tube current. The tube current is measured in milliamps and is controlled by regulating the low-voltage heating current applied to the cathode. The higher the temperature of the filament, the larger the number of electrons that leave the cathode and travel to the anode. The milliamp or current setting on the control console regulates the filament temperature, which relates to the intensity of the X-ray output.



The high-voltage between the cathode and the anode affects the speed at which the electrons travel and strike the anode. The higher the kilovoltage, the more speed and, therefore, energy the electrons have when they strike the anode. Electrons striking with more energy results in X-rays with more penetrating power. The high-voltage potential is measured in kilovolts, and this is controlled with the voltage or kilovoltage control on the control console. An increase in the kilovoltage will also result in an increase in the intensity of the radiation. The figure shows the spectrum of the radiated X-rays associated with the voltage and current settings.

Radiographic Film

X-ray films for general radiography basically consist of an emulsion-gelatin containing radiation-sensitive silver halide crystals (*such as silver bromide or silver chloride*). The emulsion is usually coated on both sides of a flexible, transparent, blue-tinted base in layers about *0.012 mm* thick. An adhesive undercoat fastens the emulsion to the film base and a very thin but tough coating covers the emulsion to protect it against minor abrasion. The typical total thickness of the X-ray film is approximately *0.23 mm*. Though films are made to be sensitive for X-ray or gamma-ray, yet they are also sensitive to visible light. When X-rays, gamma-rays, or light strike the film, some of the halogen atoms are liberated from the silver halide crystal and thus leaving the silver atoms alone. This change is of such a small nature that it cannot be detected by ordinary physical methods and is called a "*latent (hidden) image*". When the film is exposed to a chemical solution (*developer*) the reaction results in the formation of black, metallic silver.

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 Contrast

The 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.

Controlling Radiographic Quality

One of the methods of controlling the quality of a radiograph is through the use of image quality indicators (IQIs), which are also referred to as *penetrameters*. IQIs provide means of visually informing the film interpreter of the contrast sensitivity and definition of the radiograph. The IQI indicates that a specified amount of change in material thickness will be detectable in the radiograph, and that the radiograph has a certain level of definition so that the density changes are not lost due to unsharpness. Without such a reference point, consistency and quality could not be maintained and defects could go undetected. IQIs should be placed on the source side of the part over a section with a material thickness equivalent to the region of interest. If this is not possible, the IQI may be placed on a block of similar material and thickness to the region of interest. When a block is used, the IQI should be the same distance from the film as it would be if placed directly on the part in the region of interest. The IQI should also be placed slightly away from the edge of the part so that at least three of its edges are visible in the radiograph.

Image quality indicators take many shapes and forms due to the various codes or standards that invoke their use. The two most commonly used IQI types are: the hole type and the wire IQIs. IQIs come in a variety of material types so that one with radiation absorption characteristics similar to the material being radiographed can be used.

Radiation Health Risks

As mentioned previously, the health risks associated with the radiation is considered to be one the major disadvantages of radiogaphy. The amount of risk depends on the amount of radiation dose received, the time over which the dose is received, and the body parts exposed. The fact that X-ray and gamma-ray radiation are not detectable by the human senses complicates matters further. However, the risks can be minimized and controlled when the radiation is handled and managed properly in accordance to the radiation safety rules. The active laws all over the world require that individuals working in the field of radiography receive training on the safe handling and use of radioactive materials and radiation producing devices. Today, it can be said that radiation ranks among the most thoroughly investigated (and somehow understood) causes of disease. The primary risk from occupational radiation exposure is an increased risk of cancer. Although scientists assume low-level radiation exposure increases one's risk of cancer, medical studies have not demonstrated adverse health effects in individuals exposed to small chronic radiation doses. The occurrence of particular health effects from exposure to ionizing radiation is a complicated function of numerous factors including:

- *Type of radiation involved*. All kinds of ionizing radiation can produce health effects. The main difference in the ability of alpha and beta particles and gamma and X-rays to cause health effects is the amount of energy they have. Their energy determines how far they can penetrate into tissue and how much energy they are able to transmit directly or indirectly to tissues.
- *Size of dose received*. The higher the dose of radiation received, the higher the likelihood of health effects.

- *Rate at which the dose is received*. Tissue can receive larger dosages over a period of time. If the dosage occurs over a number of days or weeks, the results are often not as serious if a similar dose was received in a matter of minutes.
- *Part of the body exposed*. Extremities such as the hands or feet are able to receive a greater amount of radiation with less resulting damage than blood forming organs housed in the upper body.
- *The age of the individual*. As a person ages, cell division slows and the body is less sensitive to the effects of ionizing radiation. Once cell division has slowed, the effects of radiation are somewhat less damaging than when cells were rapidly dividing.
- *Biological differences*. Some individuals are more sensitive to radiation than others. Studies have not been able to conclusively determine the cause of such differences.

Radiation Detectors

Instruments used for radiation measurement fall into two broad categories:

- Rate measuring instruments.
- Personal dose measuring instruments.

Rate measuring instruments measure the rate at which exposure is received (*more commonly called the radiation intensity*). Survey meters, audible alarms and area monitors fall into this category. These instruments present a radiation intensity reading relative to time, such as *R/hr* or *mR/hr*. An analogy can be made between these instruments and the speedometer of a car because both are measuring units relative to time. Dose measuring instruments are those that measure the total amount of exposure received during a measuring period. The dose measuring instruments, or dosimeters, that are commonly used in industrial radiography are small devices which are designed to be worn by an individual to measure the exposure received by the individual. An analogy can be made between these instruments and the odometer of a car because both are measuring accumulated units.

Survey Meters

The survey meter is the most important resource a radiographer has to determine the presence and intensity of radiation. There are many different models of survey meters available to measure radiation in the field. They all basically consist of a detector and a readout display. Analog and digital displays are available. Most of the survey meters used for industrial radiography use a gas filled detector. Gas filled detectors consists of a gas filled cylinder with two electrodes having a voltage applied to them. Whenever the device is brought near radioactive substances, the gas becomes ionized. The electric field created by the potential difference between the anode and cathode causes the electrons of each ion pair to move to the anode while the positively charged gas atom is drawn to the cathode. This results in an electrical signal that is amplified, correlated to exposure and displayed as a value.

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UNIT – IV - N O N D E S T R U C T I V E T E S T I N G AND T E C H N I Q U E S – SPR1611

UNIT - IV

Ultrasonic Testing Methods

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 reflector position and estimating 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.

PHYSICS OF ULTRASOUND

Wave Propagation

Ultrasonic testing is based on the vibration in materials which is generally referred to as acoustics. All material substances are comprised of atoms, which may be forced into vibrational motion about their equilibrium positions. Many different patterns of vibrational motion exist at the atomic level; however, most are irrelevant to acoustics and ultrasonic testing. Acoustics is focused on particles that contain many atoms that move in harmony to produce a mechanical wave. When a material is not stressed in tension or compression beyond its elastic limit, its individual particles perform elastic oscillations. When the particles of a medium are displaced from their equilibrium positions, internal restoration forces arise. These elastic restoring forces between particles, combined with inertia of the particles, lead to the oscillatory motions of the medium. In solids, sound waves can propagate in four principal modes that are based on the way the particles oscillate. Sound can propagate as longitudinal waves, shear waves, surface waves, and in thin materials as plate waves. Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. The particle movement responsible for the propagation of longitudinal and shear.
 In *longitudinal waves*, the oscillations occur in the longitudinal direction or the direction of wave propagation. Since compression and expansion forces are active in these waves, they are also called pressure or compression waves. They are
also sometimes called density waves because material density fluctuates as the wave moves. Compression waves can be generated in gases, liquids, as well as solids because the energy travels through the atomic structure by a series of

compressions and expansion movements.

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

Modes of Sound Wave Propagation

In air, sound travels by the compression and rarefaction of air molecules in the direction of travel. However, in solids, molecules can support vibrations in other directions. Hence, a number of different types of sound waves are possible. Waves can be characterized by oscillatory patterns that are capable of maintaining their shape and propagating in a stable manner. The propagation of waves is often described in terms of what are called "*wave modes*".

As mentioned previously, longitudinal and transverse (shear) waves are most often used in ultrasonic inspection. However, at surfaces and interfaces, various types of elliptical or complex vibrations of the particles make other waves possible. Some of these wave modes such as Rayleigh and Lamb waves are also useful for ultrasonic inspection.

Though there are many different modes of wave propagation, the table summarizes the four types of waves that are commonly used in NDT.

Wave Type	Particle Vibration
Longitudinal (Compression)	Parallel to wave direction
Transverse (Shear)	Perpendicular to wave direction
Surface - Rayleigh	Elliptical orbit - symmetrical mode
Plate Wave - Lamb	Component perpendicular to surface

Since longitudinal and transverse waves were discussed previously, surface and plate waves are introduced here.

 Surface (or Rayleigh) waves travel at the surface of a relatively thick solid material penetrating to a depth of one wavelength. A surface wave is a combination of both a longitudinal and transverse motion which results in an elliptical motion. The major axis of the ellipse is perpendicular to the surface of the solid. As the depth of an individual atom from the surface increases, the width of its elliptical motion decreases. Surface waves are generated when a longitudinal wave intersects a surface slightly larger than the second critical angle and they travel at a velocity between .87 and .95 of a shear wave.

Rayleigh waves are useful because they are very sensitive to surface defects (*and other surface features*) and they follow the surface around curves. Because of this, Rayleigh waves can be used to inspect areas that other waves might have difficulty reaching.

 Plate (or Lamb) waves are similar to surface waves except they can only be generated in materials a few wavelengths thick (*thin plates*). Lamb waves are complex vibrational waves that propagate parallel to the test surface throughout the thickness of the material. They are influenced a great deal by the test wave frequency and material thickness. Lamb waves are generated when a wave hits a surface at an incident angle such that the parallel component of the velocity of the wave (in the source) is equal to the velocity of the wave in the test material. Lamb waves will travel several meters in steel and so are useful to scan plate, wire, and tubes.

o With Lamb waves, a number of modes of particle vibration are possible, but the two most common are symmetrical and asymmetrical. The complex motion of the particles is similar to the elliptical orbits for surface waves. Symmetrical Lamb waves move in a symmetrical fashion about the median plane of the plate. This is sometimes called the "*extensional mode*" because the wave is stretching and compressing the plate in the wave motion direction. The asymmetrical Lamb wave mode is often called the "*flexural mode*" because a large portion of the motion is in a normal direction to the plate, and a little motion occurs in the direction parallel to the plate. In this mode, the body of the plate bends as the two surfaces move in the same direction.

Properties of Acoustic Waves

Among the properties of waves propagating in isotropic solid materials are wavelength, frequency, and velocity. The wavelength is directly proportional to the velocity of the wave and inversely proportional to the frequency of the wave. The velocity of sound waves in a certain medium is fixed where it is a characteristic of that medium. As can be noted from the equation, an increase in frequency will result in a decrease in wavelength. For instance, the velocity of longitudinal waves in steel is *5850 m/s* and that results in a wavelength of *5.85 mm* when the frequency is *1 MHz*.

Wavelength and Defect Detection

In ultrasonic testing, the inspector must make a decision about the frequency of the transducer that will be used in order to control the wavelength. The wavelength of the ultrasound used has a significant effect on the probability of detecting a discontinuity. A general rule of thumb is that a discontinuity must be larger than one-half the wavelength to stand a reasonable chance of being detected.

Sensitivity and ***resolution*** are two terms that are often used in ultrasonic inspection to describe a technique's ability to locate flaws. *Sensitivity* is the ability to locate small discontinuities. Sensitivity generally increases with higher frequency (*shorter wavelengths*). *Resolution* is the ability of the system to locate discontinuities that are close together within the material or located near the part surface. Resolution also generally increases as the frequency increases.

The wave frequency can also affect the capability of an inspection in adverse ways. Therefore, selecting the optimal inspection frequency often involves maintaining a balance between the favorable and unfavorable results of the selection. Before selecting an inspection frequency, the material's grain structure and thickness, and the discontinuity's type, size, and probable location should be considered. As frequency increases, sound tends to scatter from large or course grain structure and from small imperfections within a material. Cast materials often have coarse grains and thus require lower frequencies to be used for evaluations of these products. Wrought and forged products with directional and refined grain structure can usually be inspected with higher frequency transducers.

Since more things in a material are likely to scatter a portion of the sound energy at higher frequencies, the ***penetration depth*** (*the maximum depth in a material that flaws can be located*) is also reduced. Frequency also has an effect on the shape of the ultrasonic beam. Beam spread, or the divergence of the beam from the center axis of the transducer, and how it is affected by frequency will be discussed later.

It should be mentioned, so as not to be misleading, that a number of other variables will also affect the ability of ultrasound to locate defects. These include the pulse length, type and voltage applied to the crystal, properties of the crystal, backing material, transducer diameter, and the receiver circuitry of the instrument.

Sound Propagation in Elastic Materials

It was mentioned previously that sound waves propagate due to the vibrations or oscillatory motions of particles within a material. An ultrasonic wave may be visualized as an infinite number of oscillating masses or particles connected by means of elastic springs. Each individual particle is influenced by the motion of its nearest neighbor and both inertial and elastic restoring forces act upon each particle.

A mass on a spring has a single resonant frequency (*natural frequency*) determined by its spring constant ***k*** and its mass ***m***. Within the elastic limit of any material, there is a linear relationship between the displacement of a particle and the force attempting to restore the particle to its equilibrium position. This linear dependency is described by *Hooke's Law*. In terms of the spring model, the relation between force and displacement is written as $\boldsymbol{F = k\, x}$.

The Speed of Sound

Hooke's Law, when used along with Newton's Second Law, can explain a few things about the speed of sound. The speed of sound within a material is a function of the properties of the material and is independent of the amplitude of the sound wave. Newton's Second Law says that the force applied to a particle will be balanced by the particle's mass and the acceleration of the particle. Mathematically, Newton's Second Law is written as $\boldsymbol{F = m\, a}$. Hooke's Law then says that this force will be balanced by a force in the opposite direction that is dependent on the amount of displacement and the spring constant. Therefore, since the applied force and the restoring force are equal, $\boldsymbol{m\, a = k\, x}$ can be written.

Since the mass $\boldsymbol{m}$ and the spring constant $\boldsymbol{k}$ are constants for any given material, it can be seen that the acceleration $\boldsymbol{a}$ and the displacement $\boldsymbol{x}$ are the only variables. It can also be seen that they are directly proportional. For instance, if the displacement of the particle increases, so does its acceleration. It turns out that the time that it takes a particle to move and return to its equilibrium position is independent of the force applied. So, within a given material, sound always travels at the same speed no matter how much force is applied when other variables, such as temperature, are held constant.

Material Properties Affecting the Speed of Sound

Of course, sound does travel at different speeds in different materials. This is because the mass of the atomic particles and the spring constants are different for different materials. The mass of the particles is related to the density of the material, and the spring constant is related to the elastic constants of a material.

Attenuation of Sound Waves

When sound travels through a medium, its intensity diminishes with distance. In idealized materials, sound pressure (*signal amplitude*) is reduced due to the spreading of the wave. In natural materials, however, the sound amplitude is further weakened due to the scattering and absorption. Scattering is the reflection of the sound in directions other than its original direction of propagation. Absorption is the conversion of the sound energy to other forms of energy. The combined effect of scattering and absorption is called attenuation. Attenuation is generally proportional to the square of sound frequency.

Acoustic Impedance

Sound travels through materials under the influence of sound pressure. Because molecules or atoms of a solid are bound elastically to one another, the excess pressure results in a wave propagating through the solid. The *acoustic impedance* of a material is defined as the product of its density and the velocity of sound in that material.

Where;

: acoustic impedance (*kg/m2s*) or (*N s/m3*)

: density (*kg/m3*)

: sound velocity (*m/s*)

Reflection and Transmission Coefficients

Ultrasonic waves are reflected at boundaries where there is a difference in acoustic impedances of the materials on each side of the boundary. This difference in is commonly referred to as the impedance mismatch. The greater the impedance mismatch, the greater the percentage of energy that will be reflected at the interface or boundary between one medium and another.

The fraction of the incident wave intensity that is reflected can be derived based on the fact that particle velocity and local particle pressures must be continuous across the boundary. When the acoustic impedances of the materials on both sides of the boundary are known, the fraction of the incident wave intensity that is reflected

TRANSDUCERS

Piezoelectric Transducers

The conversion of electrical pulses to mechanical vibrations and the conversion of returned mechanical vibrations back into electrical energy is the basis for ultrasonic testing. This conversion is done by the transducer using a piece of piezoelectric material (*a polarized material having some parts of the molecule positively charged, while other parts of the molecule are negatively charged*) with electrodes attached to two of its opposite faces. When an electric field is applied across the material, the polarized molecules will align themselves with the electric field causing the material to change dimensions. In addition, a permanently-polarized material such as quartz (SiO_2) or barium titanate ($BaTiO_3$) will produce an electric field when the material changes dimensions as a result of an imposed mechanical force. This phenomenon is known as the piezoelectric effect.

The most commonly employed ceramic for making transducers is lead zirconate titanate. The thickness of the active element is determined by the desired frequency of the transducer.

Characteristics of Piezoelectric Transducers

The function of the transducer is to convert electrical signals into mechanical vibrations (*transmit mode*) and mechanical vibrations into electrical signals (*receive mode*). Many factors, including material, mechanical and electrical construction, and the external mechanical and electrical load conditions, influence the behavior of a transducer.

Transducer Types

Ultrasonic transducers are manufactured for a variety of applications and can be custom fabricated when necessary. Careful attention must be paid to selecting the proper transducer for the application. It is important to choose transducers that have the desired frequency, bandwidth, and focusing to optimize inspection capability. Most often the transducer is chosen either to enhance the sensitivity or resolution of the system.

Transducers are classified into two major groups according to the application.

Contact transducers are used for direct contact inspections, and are generally hand manipulated. They have elements protected in a rugged casing to withstand sliding contact with a variety of materials. These transducers have an ergonomic design so that they are easy to grip and move along a surface. They often have replaceable wear plates to lengthen their useful life. Coupling materials of water, grease, oils, or commercial materials are used to remove the air gap between the transducer and the component being inspected.

Immersion transducers do not contact the component. These transducers are designed to operate in a liquid environment and all connections are watertight. Immersion transducers usually have an impedance matching layer that helps to get more sound energy into the water and, in turn, into the component being inspected. Immersion transducers can be purchased with a planer, cylindrically focused or spherically focused lens. A focused transducer can improve the sensitivity and axial resolution by concentrating the sound energy to a smaller area. Immersion transducers are typically used inside a water tank or as part of a squirter or bubbler system in scanning applications.

Ultrasonic thickness measurement (**UTM**) is a method of performing non-destructive measurement (gauging) of the local thickness of a solid element (typically made of metal, if using ultrasound testing for industrial purposes) basing on the time taken by the ultrasound wave to return to the surface. This type of measurement is typically performed with an ultrasonic thickness gauge.

Ultrasonic waves have been observed to travel through metals at a constant speed characteristic to a given alloy with minor variations due to other factors like temperature. Thus, given this information, called celerity, one can calculate the length of the path traversed by the wave using this simple formula:

$$l_m = ct/2$$

where l_m is the thickness of the sample

c is the celerity of sound in the given sample
t is the traverse time

The formula features division by two because usually the instrumentation emits and records the ultrasound wave on the same side of the sample using the fact that it is reflected on the boundary of the element. Thus, the time corresponds to traversing the sample twice.

Ultra Sonic Technique is frequently used to monitor metal thickness or weld quality in industrial settings. NDE Technicians equipped with portable ultra sonic probes reach steel plating in sides, tanks, decks and the superstructure. They can read its thickness by simply touching the steel with the measurement head (transducer). Contact is usually assured by first removing visible corrosion scale and then applying petroleum jelly or another couplant before pressing the probe against metal. However, when UTM is used with an Electromagnetic Acoustic Transducer (EMAT) the use of couplant is not required. These testing methods are used to inspect metal to determine quality and safety without destroying or compromising its integrity.

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UNIT – V - N O N D E S T R U C T I V E T E S T I N G AND T E C H N I Q U E S – SPR1611

UNIT – V

EDDY CURRENT INSPECTION AND OTHER APPLICATIONS OF NDT

EDDY CURRENT TESTING (ET)

This method is widely used to detect surface flaws, to sort materials, to measure thin walls from one surface only, to measure thin coatings and in some applications to measure case depth. This method is applicable to electrically conductive materials only. In the method eddy currents are produced in the product by bringing it close to an alternating current carrying coil. The alternating magnetic field of the coil is modified by the magnetic fields of the eddy currents. This modification, which depends on the condition of the part near to the coil, is then shown as a meter reading or cathode ray tube presentation. The figure 1 gives the basic principles of eddy current testing.

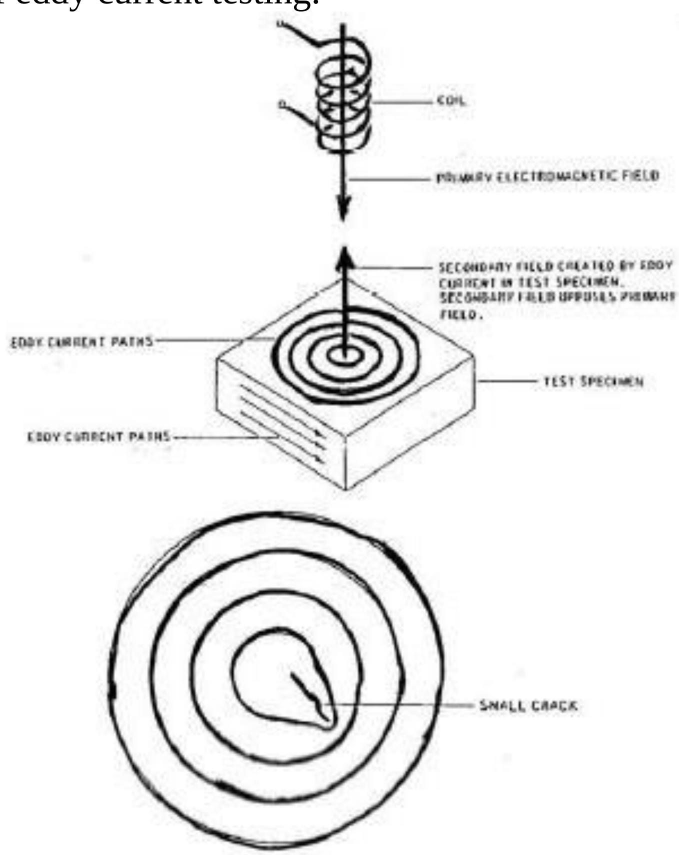


FIG. 1(a) Generation of eddy currents in the test specimen. (b) Distortion of eddy currents due to defect.

There are three types of probes used in eddy current testing. Internal probes are usually used for the in-service testing of heat exchanger tubes. Encircling probes are commonly used for the testing of rods and tubes during manufacturing. The

uses of surface probes include the location of cracks, sorting of materials, measurement of wall and coating thickness, and case depth measurement.
This method may be used for:
(a) For the detection of defects in tubings.
(b) For sorting materials.
(c) For measurement of thin wall thickness from one surface only.
(d) For measuring thin coatings.
(e) For measuring case depth.

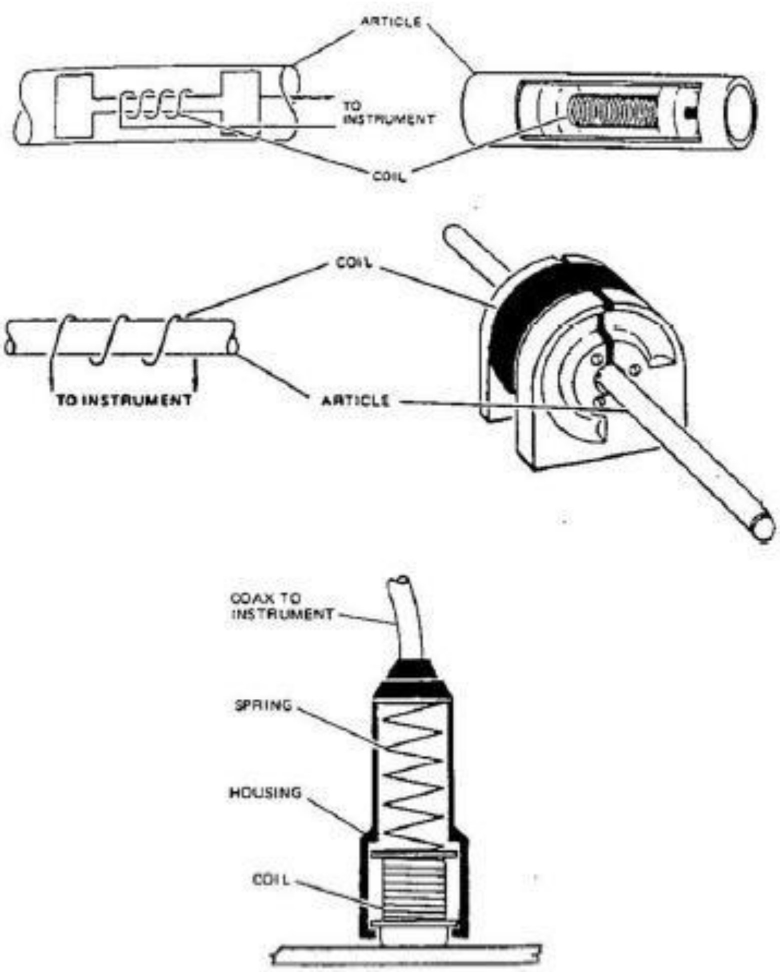


FIG. 2. Types of probes used in eddy current testing. (a) internal coil) encircling coil (c)
surface probe.

Some of the advantages of eddy current testing include:
(a) Does not require couplant.
(b) It gives instantaneous response.
(c) Has uncomplicated steps during set-up.

(d) Is extremely sensitive to flaws.
(e) Is very repeatable.
(f) High scanning speeds can be used.
(g) Is very accurate for dimensional analysis of flaws or coating thickness.
Some of the limitations of eddy current testing include the following:
(a) The theory requires a good academic background in electrical principles and in mathematics.
(b) Extremely sensitive to surface variations and therefore requires a good surface.
(c) It is applicable to conductor materials only.
(d) Can be used on non-magnetic and magnetic material but is not reliable on carbon steel for the detection of subsurface flaws.
(e) Its depth of penetration is limited.
(f) Crack tightness and orientation of eddy current flow to a crack or linear discontinuity will affect detectability.

Principles and basic characteristics of eddy current probes

Eddy current probes are based on relatively simple principles and usually consist of an assembly containing one or more coils in a suitable configuration. The shape of the coil, its cross-section, size, and configuration are parameters that need to be considered to produce a particular probe suitable for a specific application or range of applications. This coil is energized by an alternating current of known frequency and amplitude which gives rise to the magnetic field which is also of varying type. When this coil is brought closer to a conductive test material, there is an induced voltage generated in the sample.

3.1.1 Induction and Reception Function

There are two methods of sensing changes in the eddy current characteristics:
(a) The impedance method
(b) The send receive method

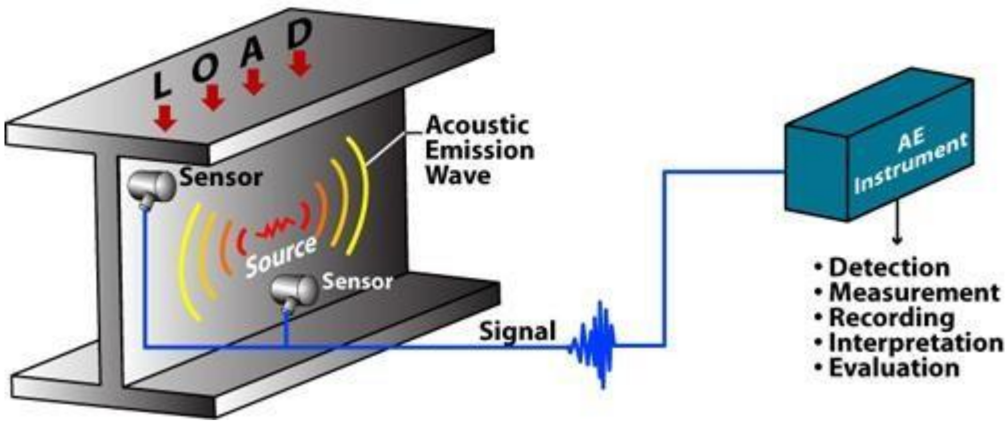
Impedance method

In the impedance method, the driving coil is monitored. As the changes in coil voltage or a coil current are due to impedance changes in the coil, it is possible to use the method for sensing any material parameters that result in impedance changes.

The resultant impedance is a sum of the coil impedance (in air) plus the impedance generated
by the eddy currents in the test material.
The impedance method of eddy current testing consists of monitoring the voltage drop across
a test coil. The impedance has resistive and inductive components. The impedance magnitude
is calculated from the equation:
½Z½= [R2+ (XL) 2]1/2 (3.1)
where
Z = impedance
R = resistance
XL = inductive reactance
and the impedance phase is calculated as:
q = Arctan (XL/R) (3.2)
where
q = phase angle
R = resistance
XL = inductive reactance
The voltage across the test coil is V= IZ, where I is the current through coil and Z is the
impedance. A test sample's resistance to the flow of eddy currents is reflected as a resistive load and is
equivalent to a resistance in parallel to the coil inductive reactance. This load results in a
resistive and inductive impedance change in the test coil. Coil impedance can be displayed on
normalized impedance diagrams. With this display we can analyse the effect of sample and
test parameters on coil impedance. The equivalent circuit derivation of coil impedance is
useful for a quantitative understanding of the effect of various test parameters.

Acoustic Emission (AE) testing:

Acoustic Emission (AE) testing is a powerful method for examining behavior of materials deforming under stress. The Acoustic Emission NDT technique is based on the detection and conversion of high frequency elastic waves to electrical signals. This is accomplished by directly coupling piezoelectric transducers on the surface of the structure under test and loading the structure. Sensors are coupled to the structure and the output of each piezoelectric sensor (during structure loading) is amplified through a low-noise preamplifier, filtered to remove any extraneous noise and furthered processed by suitable electronic equipment. The instrumentation of Acoustic Emission must provide some measure of the total quantity of detected emission for correlation with time and/or load.



Detection and analysis of AE signals can supply valuable information regarding the origin and importance of a discontinuity in a material. Because of the versatility of Acoustic Emission Testing (AET), it has many industrial applications (e.g. assessing structural integrity, detecting flaws, testing for leaks, or monitoring weld quality) and is used extensively as a research tool.

Acoustic Emission is unlike most other nondestructive testing (NDT) techniques in two regards. The first difference pertains to the origin of the signal. Instead of supplying energy to the object under examination, AET simply listens for the energy released by the object. AE tests are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions.

The second difference is that AET deals with dynamic processes, or changes, in a material. This is particularly meaningful because only active features (e.g. crack growth) are highlighted. The ability to discern between developing and stagnant defects is significant. However, it is possible for flaws to go undetected altogether if the loading is not high enough to cause an acoustic event. Furthermore, AE testing usually provides an immediate indication relating to the strength or risk of failure of a component. Other advantages of AET include fast and complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen.

Unfortunately, AE systems can only qualitatively gauge how much damage is contained in a structure. In order to obtain quantitative results about size, depth, and overall acceptability of a part, other NDT methods (often ultrasonic testing) are necessary. Another drawback of AE stems from loud service environments which contribute extraneous noise to the signals. For successful applications, signal discrimination and noise reduction are crucial.

Applications

Acoustic emission is a very versatile, non-invasive way to gather information about a material or structure. Acoustic Emission testing (AET) is be applied to inspect and monitor pipelines, pressure vessels, storage tanks, bridges, aircraft, and bucket trucks, and a variety of composite and ceramic components. It is also used in process control applications such as monitoring welding processes. A few examples of AET applications follow.

Weld Monitoring

During the welding process, temperature changes induce stresses between the weld and the base metal. These stresses are often relieved by heat treating the weld. However, in some cases tempering the weld is not possible and minor cracking occurs. Amazingly, cracking can continue for up to 10 days after the weld has been completed. Using stainless steel welds with known inclusions and accelerometers for detection purposes and background noise monitoring, it was found by W. D. Jolly (1969) that low level signals and more sizeable bursts were related to the growth of microfissures and larger cracks respectively. ASTM E 749-96 is a standard practice of AE monitoring of continuous welding.

Bucket Truck (Cherry Pickers) Integrity Evaluation: Accidents, overloads and fatigue can all occur when operating bucket trucks or other aerial equipment. If a mechanical or structural defect is ignored, serious injury or fatality can result. In 1976, the Georgia Power Company pioneered the aerial manlift device inspection. Testing by independent labs and electrical utilities followed. Although originally intended to examine only the boom sections, the method is now used for inspecting the pedestal, pins, and various other components. Normally, the AE tests are second in a chain of inspections which start with visual checks. If necessary, follow-up tests take the form of magnetic particle, dye penetrant, or ultrasonic inspections. Experienced personnel can perform five to ten tests per day, saving valuable time and money along the way. ASTM F914 governs the procedures for examining insulated aerial personnel devices.

Gas Trailer Tubes
Acoustic emission testing on pressurized jumbo tube trailers was authorized by the Department of Transportation in 1983. Instead of using hydrostatic retesting, where tubes must be removed from service and disassembled, AET allows for in situ testing. A 10% over-pressurization is performed at a normal filling station with AE sensors attached to the tubes at each end. A multichannel acoustic system is used to detection and mapped source locations. Suspect locations are further evaluated using ultrasonic inspection, and when defects are confirmed the tube is removed from use. AET can detect subcritical flaws whereas hydrostatic testing cannot detect cracks until they cause rupture of the tube. Because of the high stresses in the circumferential direction of the tubes, tests are geared toward finding longitudinal fatigue cracks.

Bridges
Bridges contain many welds, joints and connections, and a combination of load and environmental factors heavily influence damage mechanisms such as fatigue cracking and metal thinning due to corrosion. Bridges receive a visual inspection about every two years and when damage is detected, the bridge is either shut down, its weight capacity is lowered, or it is singled out for more frequent monitoring. Acoustic Emission is increasingly being used for bridge monitoring applications because it can continuously gather data and detect changes that may be due to damage without requiring lane closures or bridge shutdown. In fact, traffic flow is commonly used to load or stress the bridge for the AE testing.

Aerospace Structures
Most aerospace structures consist of complex assemblies of components that have been design to carry significant loads while being as light as possible. This combination of requirements leads to many parts that can tolerate only a minor amount of damage before failing. This fact makes detection of damage extremely important but components are often packed tightly together making access for inspections difficult. AET has found applications in monitoring the health of aerospace structures because sensors can be attached in easily accessed areas that are remotely located from damage prone sites. AET has been used in laboratory structural tests, as well as in flight test applications. NASA's Wing Leading Edge Impact Detection System is partially based on AE technology. The image to the right shows a technician applying AE transducers on the inside of the Space Shuttle Discovery wing structure. The impact detection system was developed to alert NASA officials to events such as the sprayed-on-foam insulation impact that damaged the Space Shuttle Columbia's wing leading edge during launch and lead to its breakup on reentry to the Earth's atmosphere.

Others

- Fiber-reinforced polymer-matrix composites, in particular glass-fiber reinforced parts or structures (e.g. fan blades)
- Material research (e.g. investigation of material properties, breakdown mechanisms, and damage behavior)
- Inspection and quality assurance, (e.g. wood drying processes, scratch tests)
- Real-time leakage test and location within various components (small valves, steam lines, tank bottoms)
- Detection and location of high-voltage partial discharges in transformers
- Railroad tank car and rocket motor testing

There are a number of standards and guidelines that describe AE testing and application procedures as supplied by the American Society for Testing and Materials (ASTM). Examples are ASTM E 1932 for the AE examination of small parts and ASTM E1419-00 for the method of examining seamless, gas-filled, pressure vessels.

NDT is utilised across all industry sectors from transport and aerospace to oil and gas, power and medical. It includes inspection of both metallic and non-metallic (polymer and composite) components and structures. According to requirements, NDT can be undertaken during production, post-production, in-service and following repair. NDT inspection is a key component of failure investigation service and can provide key test data as part of a fitness for service or risk-based inspection procedure.