Introduction to Nondestructive Testing

For visitors who are not already familiar with NDT, the general information below is intended to provide a basic description of NDT and the most common test methods and techniques used when performing NDT. As such it is not highly detailed or all encompassing, and for more comprehensive information readers should refer to ASNT publications such as the ASNT NDT Handbooks or the ASNT Personnel Training Publications (PTP) Classroom Training Series, all of which are available from ASNT's bookstore. Also, standards covering these test methods are listed on the "Codes and Standards Bodies" page under the NDT Resources Center tab. To maintain consistency, the techniques described for each test method are those listed in the 2011 edition of ASNT's Recommended Practice No. SNT-TC-1A.

What Is Nondestructive Testing?

Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used.

In contrast to NDT, other tests are destructive in nature and are therefore done on a limited number of samples ("lot sampling"), rather than on the materials, components or assemblies actually being put into service.

These destructive tests are often used to determine the physical properties of materials such as impact resistance, ductility, yield and ultimate tensile strength, fracture toughness and fatigue strength, but discontinuities and differences in material characteristics are more effectively found by NDT.

Today modern nondestructive tests are used in manufacturing, fabrication and in-service inspections to ensure product integrity and reliability, to control manufacturing processes, lower production costs and to maintain a uniform quality level. During construction, NDT is used to ensure the quality of materials and joining processes during the fabrication and erection phases, and in-service NDT inspections are used to ensure that the products in use continue to have the integrity necessary to ensure their usefulness and the safety of the public.

It should be noted that while the medical field uses many of the same processes, the term "nondestructive testing" is generally not used to describe medical applications.

NDT Test Methods

Test method names often refer to the type of penetrating medium or the equipment used to perform that test. Current NDT methods are: Acoustic Emission Testing (AE), Electromagnetic Testing (ET), Guided Wave Testing (GW), Ground Penetrating Radar (GPR), Laser Testing Methods (LM), Leak Testing (LT), Magnetic Flux Leakage (MFL), Microwave Testing, Liquid Penetrant Testing (PT), Magnetic Particle Testing (MT), Neutron Radiographic Testing (NR), Radiographic Testing (RT), Thermal/Infrared Testing (IR), Ultrasonic Testing (UT), Vibration Analysis (VA) and Visual Testing (VT).

The six most frequently used test methods are MT, PT, RT, UT, ET and VT. Each of these test methods will be described here, followed by the other, less often used test methods.

Magnetic Particle Testing (MT)

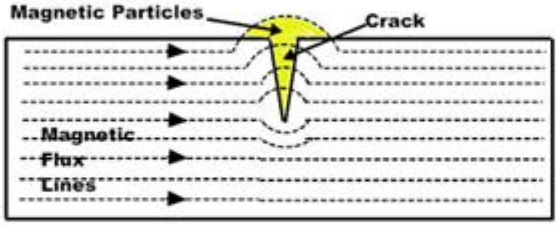


Figure 1

Magnetic Particle Testing uses one or more magnetic fields to locate surface and near-surface discontinuities in ferromagnetic materials. The magnetic field can be applied with a permanent magnet or an electromagnet. When using an electromagnet, the field is present only when the current is being applied. When the magnetic field encounters a discontinuity transverse to the direction of the magnetic field, the flux lines produce a magnetic flux leakage field of their own as shown in Figure 1. Because magnetic flux lines don't travel well in air, when very fine colored ferromagnetic particles ("magnetic particles") are applied to the surface of the part the particles will be drawn into the discontinuity, reducing the air gap and producing a visible indication on the surface of the part. The magnetic particles may be a dry powder or suspended in a liquid solution, and they may be colored with a visible dye or a fluorescent dye that fluoresces under an ultraviolet ("black") light.

MT Techniques

Yokes

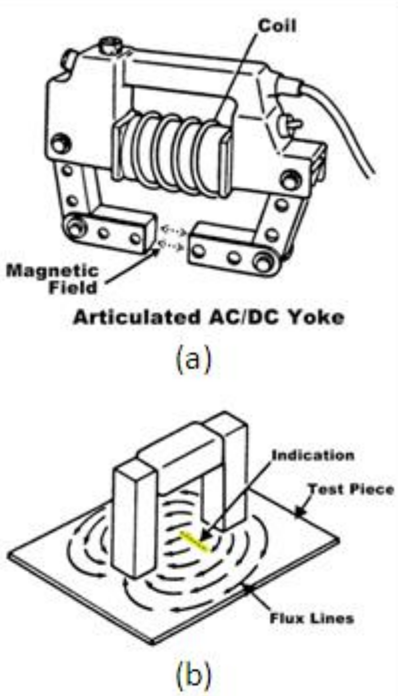


Figure 2

Most field inspections are performed using a Yoke, as shown at the right. As shown in Figure 2(a), an electric coil is wrapped around a central core, and when the current is applied, a magnetic field is generated that extends from the core down through the articulated legs into the part. This is known as longitudinal magnetization because the magnetic flux lines run from one leg to the other.

When the legs are placed on a ferromagnetic part and the yoke is energized, a magnetic field is introduced into the part as shown in (b). Because the flux lines do run from one leg to the other, discontinuities oriented perpendicular to a line drawn between the legs can be found. To ensure no indications are missed, the yoke is used once in the position shown then used again with the yoke turned 90^{o} so no indications are missed. Because all of the electric current is contained in the yoke and only the magnetic field penetrates the part, this type of application is known as *indirect* induction.

Prods

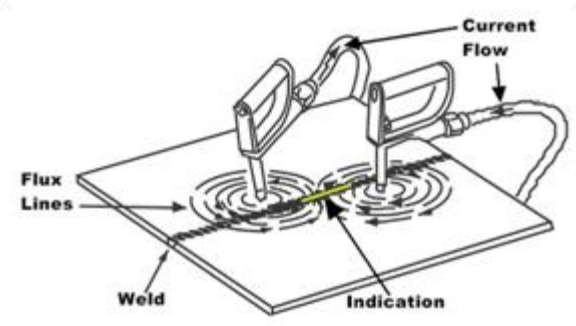


Figure 3

Prod units use *direct* induction, where the current runs through the part and a circular magnetic field is generated around the legs as shown in Figure 3. Because the magnetic field between the prods is travelling perpendicular to a line drawn between the prods, indications oriented parallel to a line drawn between the prods can be found. As with the yoke, two inspections are done, the second with the prods oriented 90^{o} to the first application.

Coils

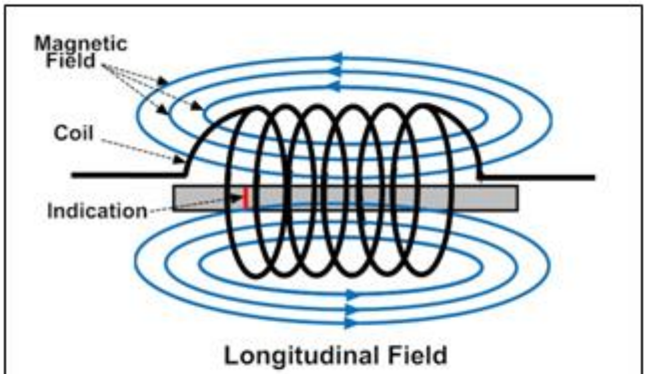
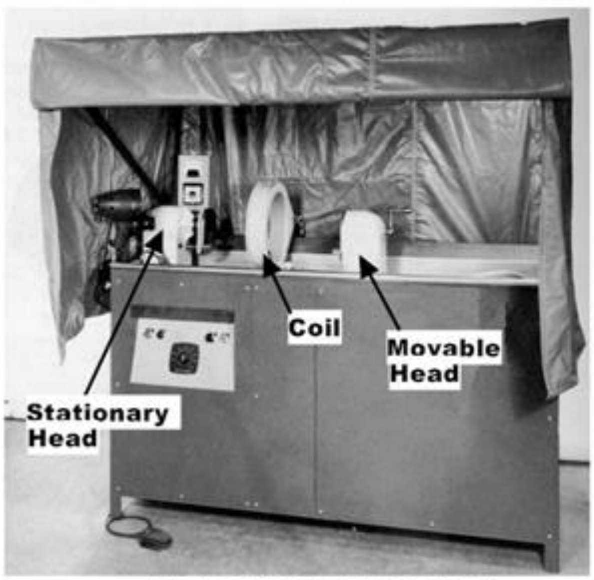


Figure 4

Electric coils are used to generate a longitudinal magnetic field. When energized, the current creates a magnetic field around the wires making up the coil so that the resulting flux lines are oriented through the coil as shown at the right. Because of the longitudinal field, indications in parts placed in a coil are oriented transverse to the longitudinal field.

Heads

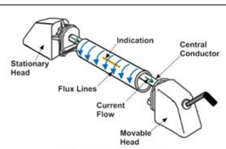


Horizontal Wet Bath Unit

Figure 5

Most horizontal wet bath machines ("bench units") have both a coil and a set of heads through which electric current can be passed, generating a magnetic field. Most use fluorescent magnetic particles in a liquid solution, hence the name "wet bath." A typical bench unit is shown at the right. When testing a part between the heads, the part is placed between the heads, the moveable head is moved up so that the part being tested is held tightly between the heads, the part is wetted down with the bath solution containing the magnetic particles and the current is applied while the particle are flowing over the part. Since the current flow is from head to head and the magnetic field is oriented 90° to the current, indications oriented parallel to a line between the heads will be visible. This type of inspection is commonly called a "head shot."

Central Conductor



Central Conductor

Figure 6

When testing hollow parts such as pipes, tubes and fittings, a conductive circular bar can be placed between the heads with the part suspended on the bar (the "central conductor") as shown in Figure 6. The part is then wetted down with the bath solution and the current is applied, travelling through the central conductor rather than through the part. The ID and OD of the part can then be inspected. As with a head shot, the magnetic field is perpendicular to the current flow, wrapping around the test piece, so indications running axially down the length of the part can be found using this technique.

Liquid Penetrant Testing (PT)

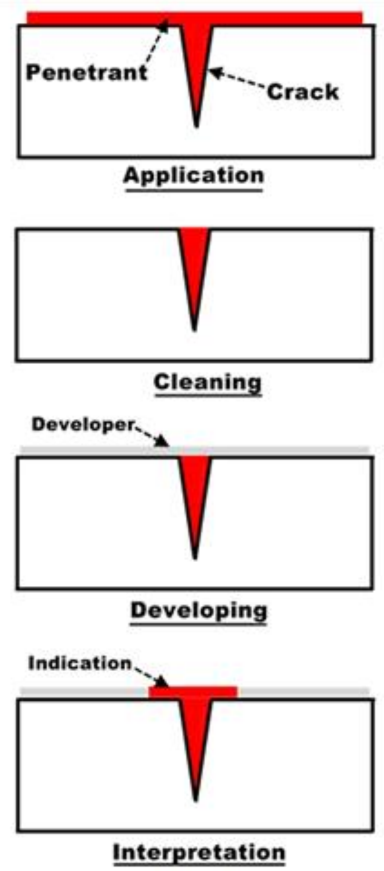


Figure 7

The basic principle of liquid penetrant testing is that when a very low viscosity (highly fluid) liquid (the penetrant) is applied to the surface of a part, it will penetrate into fissures and voids open to the surface. Once the excess penetrant is removed, the penetrant trapped in those voids will flow back out, creating an indication. Penetrant testing can be performed on magnetic and non-magnetic materials, but does not work well on porous materials. Penetrants may be "visible", meaning they can be seen in ambient light, or fluorescent, requiring the use of a "black" light. The visible dye penetrant process is shown in Figure 7. When performing a PT inspection, it is imperative that the surface being tested is clean and free of any foreign materials or liquids that might block the penetrant from entering voids or fissures open to the surface of the part. After applying the penetrant, it is permitted to sit on the surface for a specified period of time (the "penetrant dwell time"), then the part is carefully cleaned to remove excess penetrant from the surface. When removing the penetrant, the operator must be careful not to remove any penetrant that has flowed into voids. A light coating of developer is then be applied to the surface and given time ("developer dwell time") to allow the penetrant from any voids or fissures to seep up into the developer, creating a visible indication. Following the prescribed developer dwell time, the part is inspected visually, with the aid of a black light for fluorescent penetrants. Most developers are fine-grained, white talcum-like powders that provide a color contrast to the penetrant being used.

PT Techniques

Solvent Removable

Solvent Removable penetrants are those penetrants that require a solvent other than water to remove the excess penetrant. These penetrants are usually visible in nature, commonly dyed a bright red color that will contrast well against a white developer. The penetrant is usually sprayed or brushed onto the part, then after the penetrant dwell time has expired, the part is cleaned with a cloth dampened with penetrant cleaner after which the developer is applied. Following the developer dwell time the part is examined to detect any penetrant bleed-out showing through the developer.

Water-washable

Water-washable penetrants have an emulsifier included in the penetrant that allows the penetrant to be removed using a water spray. They are most often applied by dipping the part in a penetrant tank, but the penetrant may be applied to large parts by spraying or brushing. Once the part is fully covered with penetrant, the part is placed on a drain board for the penetrant dwell time, then taken to a rinse station where it is washed with a course water spray to remove the excess penetrant. Once the excess penetrant has been removed, the part may be placed in a warm air dryer or in front of a gentle fan until the water has been removed. The part can then be placed in a dry developer tank and coated with developer, or allowed to sit for the remaining dwell time then inspected.

Post-emulsifiable

Post-emulsifiable penetrants are penetrants that do not have an emulsifier included in its chemical make-up like water-washable penetrants. Post-emulsifiable penetrants are applied in a similar manner, but prior to the water-washing step, emulsifier is applied to the surface for a prescribed period of time (emulsifier dwell) to remove the excess penetrant. When the emulsifier dwell time has elapsed, the part is subjected to the same water wash and developing process used for water-washable penetrants. Emulsifiers can be lipophilic (oil-based) or hydrophilic (water-based).

Radiographic Testing (RT)

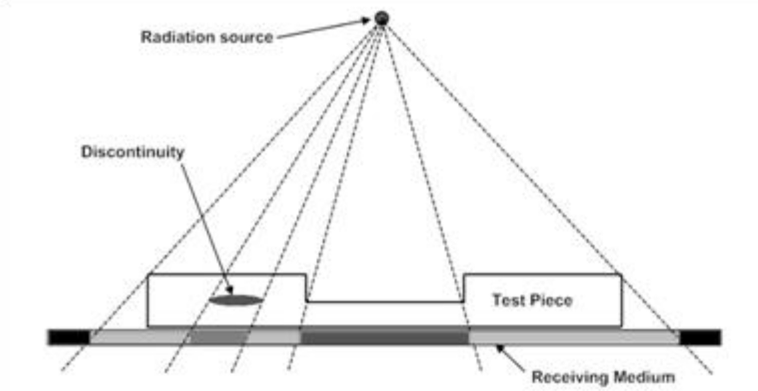


Figure 8

Industrial radiography involves exposing a test object to penetrating radiation so that the radiation passes through the object being inspected and a recording medium placed against the opposite side of that object. For thinner or less dense materials such as aluminum, electrically generated x-radiation (X-rays) are commonly used, and for thicker or denser materials, gamma radiation is generally used.

Gamma radiation is given off by decaying radioactive materials, with the two most commonly used sources of gamma radiation being Iridium-192 (Ir-192) and Cobalt-60 (Co-60). IR-192 is generally used for steel up to 2-1/2 - 3 inches, depending on the Curie strength of the source, and Co-60 is usually used for thicker materials due to its greater penetrating ability.

The recording media can be industrial x-ray film or one of several types of digital radiation detectors. With both, the radiation passing through the test object exposes the media, causing an end effect of having darker areas where more radiation has passed through the part and lighter areas where less radiation has penetrated. If there is a void or defect in the part, more radiation passes through, causing a darker image on the film or detector, as shown in Figure 8.

RT Techniques

Film Radiography

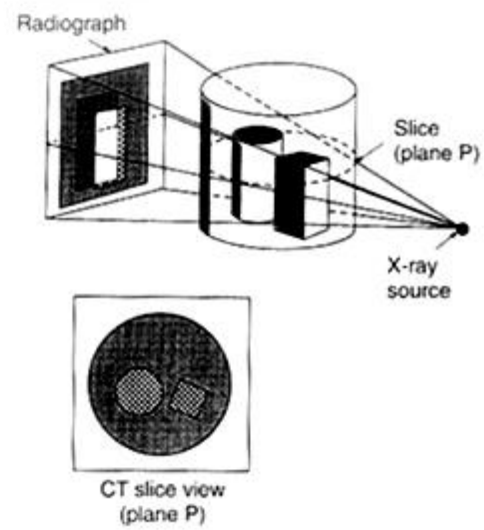
Film radiography uses a film made up of a thin transparent plastic coated with a fine layer of silver bromide on one or both sides of the plastic. When exposed to radiation these crystals undergo a reaction that allows them, when developed, to convert to black metallic silver. That silver is then "fixed" to the plastic during the developing process, and when dried, becomes a finished radiographic film.

To be a usable film, the area of interest (weld area, etc.) on the film must be within a certain density (darkness) range and must show enough contrast and sensitivity so that discontinuities of interest can be seen. These items are a function of the strength of the radiation, the distance of the source from the film and the thickness of the part being inspected. If any of these parameters are not met, another exposure ("shot") must be made for that area of the part.

Computed Radiography

Computed radiography (CR) is a transitional technology between film and direct digital radiography. This technique uses a reusable, flexible, photo-stimulated phosphor (PSP) plate which is loaded into a cassette and is exposed in a manner similar to traditional film radiography. The cassette is then placed in a laser reader where it is scanned and translated into a digital image, which take from one to five minutes. The image can then be uploaded to a computer or other electronic media for interpretation and storage.

Computed Tomography



CT image vs. a radiographic image

Figure 9

Computed tomography (CT) uses a computer to reconstruct an image of a cross sectional plane of an object as opposed to a conventional radiograph, as shown in Figure 9. The CT image is developed from multiple views taken at different viewing angles that are reconstructed using a computer. With traditional radiography, the position of internal discontinuities cannot be accurately determined without making exposures from several angles to locate the item by triangulation. With computed tomography, the computer triangulates using every point in the plane as viewed from many different directions.

Digital Radiography

Digital radiography (DR) digitizes the radiation that passes through an object directly into an image that can be displayed on a computer monitor. The three principle technologies used in direct digital imaging are amorphous silicon, charge coupled devices (CCDs), and complementary metal oxide semiconductors (CMOSs). These images are available for viewing and analysis in seconds compared to the time needed to scan in computed radiography images. The increased processing speed is a result of the unique construction of the pixels; an arrangement that also allows a superior resolution than is found in computed radiography and most film applications.

UT Techniques

Straight Beam

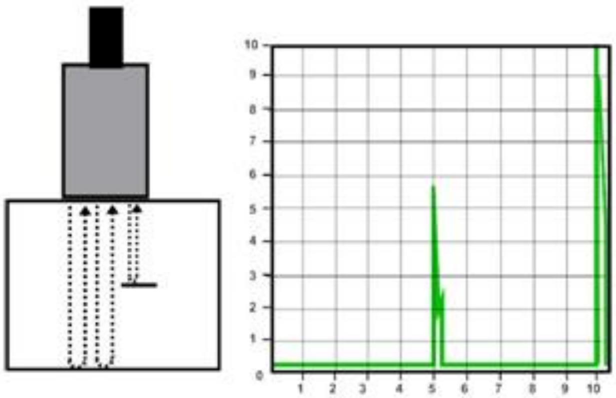
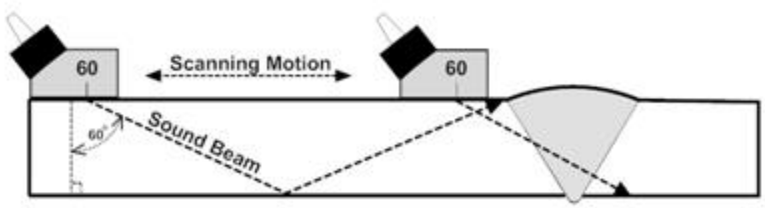


Figure 11

Straight beam inspection uses longitudinal waves to interrogate the test piece as shown at the right. If the sound hits an internal reflector, the sound from that reflector will reflect to the transducer faster than the sound coming back from the back-wall of the part due to the shorter distance from the transducer. This results in a screen display like that shown at the right in Figure 11. Digital thickness testers use the same process, but the output is shown as a digital numeric readout rather than a screen presentation.

Angle Beam



Angle Beam Testing

Figure 12

Angle beam inspection uses the same type of transducer but it is mounted on an angled wedge (also called a "probe") that is designed to transmit the sound beam into the part at a known angle. The most commonly used inspection angles are 45^o, 60^o and 70^o, with the angle being calculated up from a line drawn through the thickness of the part (not the part surface). A 60^o probe is shown in Figure 12. If the frequency and wedge angle is not specified by the governing code or specification, it is up to the operator to select a combination that will adequately inspect the part being tested.

In angle beam inspections, the transducer and wedge combination (also referred to as a "probe") is moved back and forth towards the weld so that the sound beam passes through the full volume of the weld. As with straight beam inspections, reflectors aligned more or less perpendicular to the sound beam will send sound back to the transducer and are displayed on the screen.

Immersion Testing

Immersion Testing is a technique where the part is immersed in a tank of water with the water being used as the coupling medium to allow the sound beam to travel between the transducer and the part. The UT machine is mounted on a movable platform (a "bridge") on the side of the tank so it can travel down the length of the tank. The transducer is swivel-mounted on at the bottom of a waterproof tube that can be raised, lowered and moved across the tank. The bridge and tube movement permits the transducer to be moved on the X-, Y- and Z-axes. All directions of travel are gear driven so the transducer can be moved in accurate increments in all directions, and the swivel allows the transducer to be oriented so the sound beam enters the part at the required angle. Round test parts are often mounted on powered rollers so that the part can be rotated as the transducer travels down its length, allowing the full circumference to be tested. Multiple transducers can be used at the same time so that multiple scans can be performed.

Through Transmission

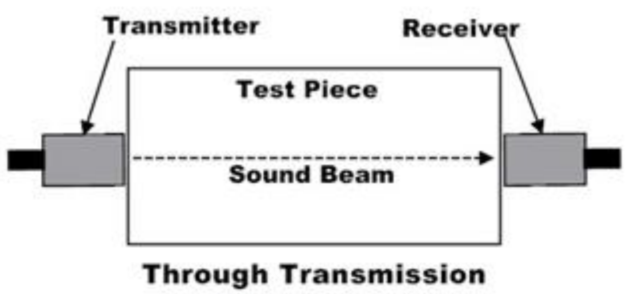


Figure 13

Through transmission inspections are performed using two transducers, one on each side of the part as shown in Figure 13. The transmitting transducer sends sound through the part and the receiving transducer receives the sound. Reflectors in the part will cause a reduction in the amount of sound reaching the receiver so that the screen presentation will show a signal with a lower amplitude (screen height).

Phased Array

Phased array inspections are done using a probe with multiple elements that can be individually activated. By varying the time when each element is activated, the resulting sound beam can be "steered", and the resulting data can be combined to form a visual image representing a slice through the part being inspected.

Time of Flight Diffraction

Time of Flight Diffraction (TOFD) uses two transducers located on opposite sides of a weld with the transducers set at a specified distance from each other. One transducer transmits sound waves and the other transducer acting as a receiver. Unlike other angle beam inspections, the transducers are not manipulated back and forth towards the weld, but travel along the length of the weld with the transducers remaining at the same distance from the weld. Two sound waves are generated, one travelling along the part surface between the transducers, and the other travelling down through the weld at an angle then back up to the receiver. When a crack is encountered, some of the sound is diffracted from the tips of the crack, generating a low strength sound wave that can be picked up by the receiving unit. By amplifying and running these signals through a computer, defect size and location can be determined with much greater accuracy than by conventional UT methods.

Electromagnetic Testing (ET)

Electromagnetic testing is a general test category that includes Eddy Current testing, Alternating Current Field Measurement (ACFM) and Remote Field testing. While magnetic particle testing is also an electromagnetic test, due to its widespread use it is considered a stand-alone test method rather as than an electromagnetic testing technique. All of these techniques use the induction of an electric current or magnetic field into a conductive part, then the resulting effects are recorded and evaluated.

ET Techniques

Eddy Current Testing

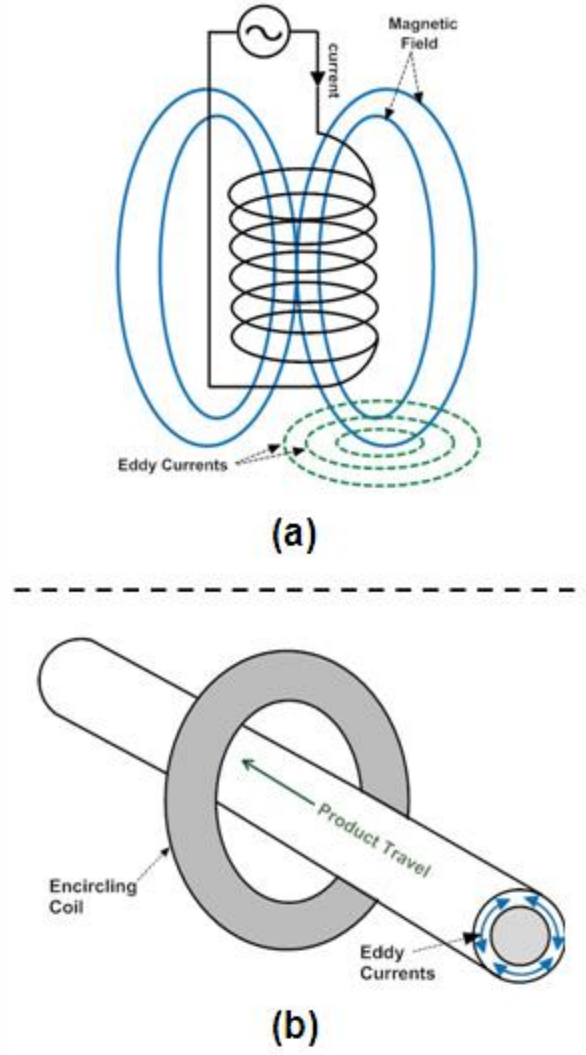


Figure 14

Eddy Current Testing uses the fact that when a an alternating current coil induces an electromagnetic field into a conductive test piece, a small current is created around the magnetic flux field, much like a magnetic field is generated around an electric current. The flow pattern of this secondary current, called an "eddy" current, will be affected when it encounters a discontinuity in the test piece, and the change in the eddy current density can be detected and used to characterize the discontinuity causing that change. A simplified schematic of eddy currents generated by an alternating current coil ("probe") is shown in Figure 14-a. By varying the type of coil, this test method can be applied to flat surfaces or tubular products. This technique works best on smooth surfaces and has limited penetration, usually less than ¼".

Encircling coils (Figure 14-b) are used to test tubular and bar-shaped products. The tube or bar can be fed through the coil at a relatively high speed, allowing the full cross-section of the test object to be interrogated. However, due to the direction of the flux lines, circumferentially oriented discontinuities may not be detected with this application.

Alternating Current Field Measurement

Alternating Current Field Measurement (ACFM) uses a specialized probe that introduces an alternating current into the surface of the test piece, creating a magnetic field. In parts with no discontinuities this field will be uniform, but if there is a discontinuity open to the surface, the magnetic field will flow around and under the discontinuity, causing a disruption of the field that can be detected by sensors within the probe. The resulting feedback can then be fed to software that can determine the length and depth of the discontinuity. ACFM provides better results on rough surfaces than Eddy Current and can be used through many surface coatings.

Remote Field Testing

Remote Field Testing (RFT) is most commonly used to inspect ferromagnetic tubing due to the presence of a strong skin effect found in such tubes. Compared to standard eddy current techniques, remote field testing provides better results throughout the thickness of the tube, having approximately equal sensitivity at both the ID and OD surfaces of the tube. For non-ferromagnetic tubes, eddy current tends to provide more sensitivity.

Vibration Analysis (VA)

Vibration analysis refers to the process of monitoring the vibration signatures specific to a piece of rotating machinery and analyzing that information to determine the condition of that equipment. Three types of sensors are commonly used: displacement sensors, velocity sensors and accelerometers.

Displacement sensors uses eddy current to detect vertical and/or horizontal motion (depending on whether one or two sensors are used) and are well suited to detect shaft motion and changes in clearance tolerances.

Basic velocity sensors use a spring-mounted magnet that moves through a coil of wire, with the outer case of the sensor attached to the part being inspected. The coil of wire moves through the magnetic field, generating an electrical signal that is sent back to a receiver and recorded for analysis. Newer model vibration sensors use time-of-flight technology and improved analysis software. Velocity sensors are commonly used in handheld sensors.

Basic accelerometers use a piezoelectric crystal (that converts sound waves to electrical impulses and back) attached to a mass that vibrates due to the motion of the part to which the sensor casing is attached. As the mass and crystal vibrate, a low voltage current is generated which is passed through a pre-amplifier and sent to the recording device. Accelerometers are very effective for detecting the high frequencies created by high speed turbine blades, gears and ball and roller bearings that travel at much greater speeds than the shafts to which they are attached.

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