11

Nondestructive Inspection and Testing

A major emphasis in any manufacturing operation should be the prevention of defects that may lead to material or product failure. Care in product design, material selection, fabrication of the desired shape. heat treatment, and surface treatment, as well as consideration of all possible service conditions, can do much to ensure the manufacture of a quality product. Now do we determine whether these efforts have been successful? How can we he sure that the product is free from any harmful defects or flaws?

Various types of testing can be used to help evaluate the quality of products and ensure the absence of any flaws that might prevent an acceptable service performance. *Destructive testing* subjects selected components to test conditions that intentionally induce failure. By determining the specific conditions under which these components fail, insight can be gained into the general characteristics of a larger production lot. Statistical methods can be used to determine the probability that the entire production run will he good, provided that a certain number of test specimens prove to be satisfactory. Since each of the products tested is destroyed during the evaluation, the cost of such methods must be borne by the remaining products. **In** addition, there is still some degree of uncertainty about the quality of each of the remaining products, because they have never been individually evaluated.

To provide an increased measure of assurance. *proof resting* may be used. Here, a product is subjected to loads of a determined magnitude, generally equal to or greater than the designed capacity. If the part remains intact, then there is reason to believe that it will perform adequately in the absence of abuse or loads in excess of its rated level. *Proof* tests can be performed either under laboratory conditions or at the site of installation, as on large manufactured assemblies such as pressure vessels.

In some situations, *hardness tests* can be used to evaluate the quality of a product. Proper material and heat treatment can he reasonably ensured by requiring that all test results fall within a desired range. The tests can be performed quickly, and the surface markings arc often small enough so that they can be concealed or easily removed from a product. The results, however, relate only to the surface strength of the product and cannot detect serious defects, such as cracks or voids.

Nondestructive testing is the examination of a product in a manner that will not render it useless for future service. Testing can be performed directly on production items, or even on parts in service, and the only scrap losses are those defective parts that are detected. The entire production lot can be inspected, or representative samples can be taken. Different tests can be applied to the same item, either simultaneously or sequentially, and the same test can be repeated on the same specimen for additional verification. Little or no specimen preparation is required, and the equipment is often portable, permitting on-site testing in most locations.

Various objectives can he sought in nondestructive tests, including the detection of internal or surface flaws, the measurement of dimensions, a determination of the material's structure or chemistry, or the evaluation of a material's physical or mechanical properties. In general, nondestructive tests involve each of the following aspects: (1) a probing medium applied to the product; (2) a possible modification of this probing medium by a flaw, a defect, a material property, or a specimen feature; (3) a sensor to detect the response signal; (4) a device to indicate or record the detector signals; and (5) a means of interpreting the response and of evaluating quality.

How you look at a material or product generally depends on what you are looking at, what you wish to sec, and how finely you wish to see it. Each of the various inspection processes has its characteristic advantages and limitations. Some can be performed on only certain types of materials (such as conductors or ferromagnetic materials). Each is limited in the type, size, and orientation of flaws that it can detect. Various degrees of accessibility may be required, and there may be geometric restrictions on part size or complexity. The available or required equipment, the cost of its operation, the need for a skilled operator or technician, and the possibility of producing a permanent test record are all considerations when selecting a test procedure.

Regardless of the specific method, nondestructive testing is a vital element in good manufacturing practice, and its potential value is becoming more widely recognized as productivity demands increase, consumers demand higher-quality products, and product liability continues to be a concern. Rather than being an added manufacturing cost, this practice can

actually expand profit by ensuring product reliability and customer satisfaction. While essentially a quality-control operation, nondestructive testing can also be used to aid in product design, to provide on-line control of a manufacturing process, and to reduce overall manufacturing costs.
The remainder of this chapter seeks to **provide** an overview of the various nondestructive test methods. Each *is* presented along with its underlying principle, associated advantages and limitations, compatible materials, and typical applications.

Visual Inspection

Probably the simplest and most widely used nondestructive testing method is simple visual inspection. The human eye is a very discerning instrument, and with training, the brain can readily interpret the signals. Optical aids such as mirrors, magnifying glasses, and microscopes can enhance the capabilities of the system. Digital image analyzers can be used to automate the testing and to make a number of quantitative geometrical evaluations. Borescopes and similar tools can provide accessibility to otherwise inaccessible locations. In the area of limitations, only the surfaces of the product can be examined.

TABLE 11.1 Visual Inspection

Method: Visual inspection.
Principle: Illuminate the test specimen **and** observe the surface with the eye. Use of optical aids or assists is permitted.
Advantages: Simple, easy to use, cheap.
Limitations: Depends on the skill and knowledge of the inspector. Limited to detection of surface flaws.
Material limitations: None.
Geometrical limitations: Any size or shape providing accessibility of surfaces to be viewed.
Permanent record: Photographs or videotapes are possible. Inspectors' reports also provide valuable records.

Liquid Penetrant

Liquid penetrant testing is a simple method of detecting surface defects in metals and other nonporous material surfaces. The piece to he tested is first subjected to a thorough cleaning, often by means of solvent-type materials, and is dried **Inspection** before the test. Then, *a penetrant,* a liquid material capable of wetting the entire surface and being drawn into fine openings, is applied to the surface of the prepared workpiece by dipping, spraying, or brushing. After a period of time that permits capillary action to draw the penetrant into the surface discontinuities, the excess penetrant liquid is removed. The surface is then coated with a thin film of "developer," an absorbent material capable of drawing traces of penetrant from the defects back onto the surface. Brightly colored dyes or fluorescent materials that radiate in ultraviolet light are generally added to the penetrant to make these traces more visible, and the developer is often selected so as to provide a contrasting background. Radioactive tracers can be added and used in conjunction with photographic paper to produce a permanent image of the defects. Cracks, laps, seams, lack of bonding, pinholes, gouges, and tool marks can all be detected. After inspection, the developer and the residual_ penetrant are removed by a second cleaning operation. Figure 11-1 shows a schematic representation of the liquid penetrant procedure.

If previous processing involved techniques that could have induced a flow of the surface layers, such as shot peening, honing, burnishing, or various forms of cold \ orking. a chemical etching *may* be required to first remove any material covering the surface defects. An alternative procedure is to penetrant-test *before* the final surface-finishing operation. when the defects are still open and available for detection. Penetrant inspection systems can range from *a* set of aerosol spray cans of cleaner. penetrant. and developer (for portable applications), to automated, mass-production equipment using laser scanners and computer control.

TABLE 11.2 Liquid Penetrant Inspection

Method: Liquid penetrant.

Principle:.- liquid penetrant is drain into surface flaws by capillary action and is subsequently revealed b\ decelore material in conjunction with visual inspection.

Advantages: Simple, inexpensive. \ernatile, portable. easily interpreted, and applicable to complex shapes.

Limitations: Can detect only-flats s that are open to the surface; surfaces must be cleaned before and after inspection. deformed surfaces and surface coatings may prevent detection; and the penetrant may be washed out of large defects. Material limitations: Must hate a nenpuwus surface.

Geometric limitations: Any sire and shape permitting accessibility of the surfaces to he inspected.

Permanent record: Can he made hx same techniques as visual inspection.

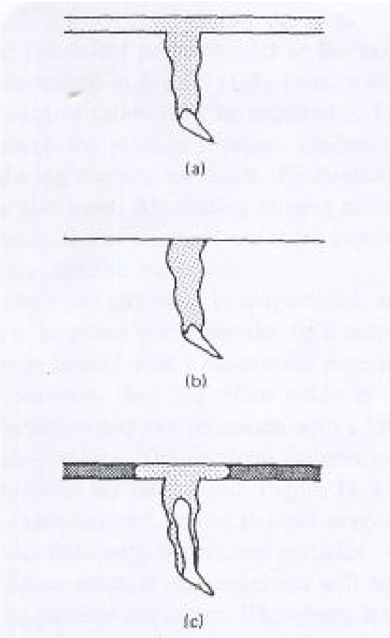

FIGURE 11-1 Liquid penetrant testing: a) application of the penetrant to a clean surface; b) excess penetrant is removed: c) developer is applied and the product inspected.

Magnetic Particle Inspection

Magnetic particle inspection is haled on the principle that ferromagnetic materials (such as iron, steel, nickel. and cobalt alloys), when magnetized, will have distorted magnetic fields in the vicinity of material defects, as shown in Figure 11-2. Surface and subsurface flaws. such as cracks and inclusions, can produce magnetic anomalies that can be mapped with the aid of magnetic particles on the specimen surface.

As in the previous methods. the specimen must be cleaned before inspection. A suitable magnetic field is then established in the part, produced so as to reveal selected defects. Orientation considerations are quite important since a flaw must produce a significant disturbance of the magnetic field at or near the surface if the flaw is to be detected. For example. placing a bar of steel within an energized coil will produce a magnetic field whose lines of flux travel along the axis of the bar. Any defect perpendicular to this axis will significantly alter the field. If the perturbation is sufficiently large and close enough to the surface, it can be detected by the inspection methods. However, if the flaw is in the form of a crack running down the specimen axis, the defect is oriented in such a way as to produce little perturbation of the lines of flux and is likely to go undetected.

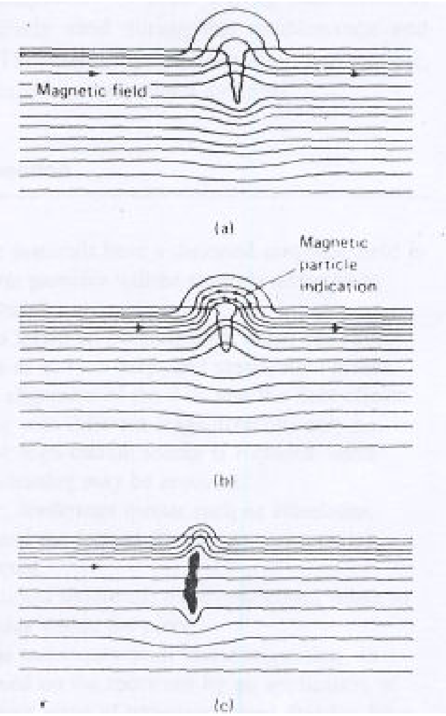

FIGURE 11-2 a) Magnetic field being disrupted by a surface crack; b) Magnetic particles applied and attracted to field leakage; c) Subsurface defects can produce surface-detectable disruptions.

If the same sample is magnetized by passing a current through it to create a circumferential magnetic field, the axial defect now becomes highly detectable, and the defect perpendicular to the axis may go unnoticed. These features are summarized in Figure 11-3. Thus, a series of inspections using different forms of magnetization may be required to fully inspect a product. Passing a current through the product between various points of contact is a popular means of inducing the desired fields. Electromagnetic coils of various shapes and sizes are also used. Alternating current methods are most sensitive to surface flaws. Direct current methods are more capable of detecting subsurface defects, such as nonmetallic inclusions.

Once the specimen is magnetized, magnetic particles are applied to the surface, as either a dry powder or a suspension in a liquid carrier. The particles can be treated with a fluorescent material for observation under ultraviolet light. In addition, they are often made in an elongated form to better reveal the orientation and can be coated with a lubricant to prevent oxidation and enhance their mobility. The resultant distribution of particles is then examined. and any anomalies are interpreted. Figure 11-4 shows the kingpin for a truck front axle: as manufactured, under straight magnetic-particle inspection, and adder ultra; violet light with fluorescent particles.

Some residual magnetization will be retained by all parts subjected to magnetic particle inspection. Therefore, it is usually necessary to demagnetize them before further processing or before placing them in use. One common means of' demagnetization is to place the parts inside a coil powered by alternating current and then gradually to reduce the current to zero. A final cleaning operation completes the process.

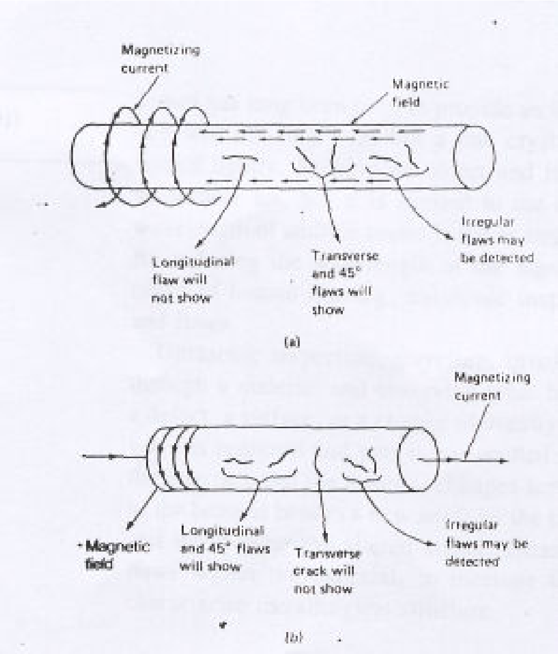

FIGURE 11-3 a) A bar placed within a magnetizing coil will have an axial magnetic field. Defects parallel to this field will go unnoticed while those disrupting the field and sufficiently close to a surface will he detected. b) When magnetized by a cur-rent passing through it, the bar has a circumferential magnetic field and the geometries of detectable flaws are reversed.

In addition to in-process and, final inspection of parts during manufacture, magnetic particle inspection is extensively used during the maintenance and overhaul of equipment and machinery. The testing equipment ranges from small, lightweight, portable units to heavy, complex, automated systems.

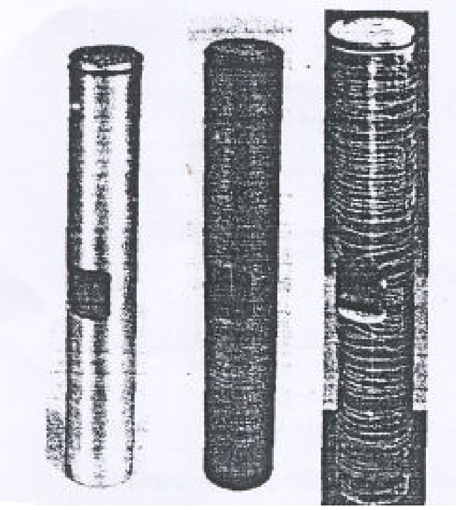

FIGURE 11-4 A front axle kingpin tor a truck (Left) As manufactured and apparently sound. (Center) Inspected under conventional magnetic particle inspection to reveal numerous grinding-induced cracks. (Right) Fluorescent particles and ultraviolet light make the cracks even more visible. (Courtesy Magnaflux Corporation.)

TABLE 11.3 Magnetic Particle Inspection

Method: Magnetic particle.

Principle: When magnetized, ferromagnetic materials have a distorted magnetic field in the vicinity of flaws and defects. Magnetic particles will be strongly attracted to surface regions where the flux is concentrated.

Advantages: Relative!, simple, fast; easy to interpret; portable units exist; can reveal subsurface flaws and inclusions (as much as ½ inch deep) and small, tight cracks.

Limitations: Parts must be relatively clean; alignment of the flaw and the field affects the sensitivity so that multiple inspections with different magnetizations may be required; must demagnetize part after test; high current source is required; some surface processes can mask defects; postcleaning may be required.

Material limitations: Must he ferromagnetic; nonferrous metals such as aluminum, magnesium, copper, lead, tin, titanium, and the ferrous (but not ferromagnetic) austenitic stainless steels cannot be inspected.

Geometric limitations: Size and shape are almost unlimited; most restrictions relate to the ability to induce uniform magnetic fields within the piece.

Permanent record: Can he made by the same techniques as in visual inspection. In addition, the defect pattern can he preserved on the specimen by an application of transparent lacquer or can be transferred to a piece of transparent tape that has been applied to the specimen and peeled off.

Ultrasonic Inspection

Sound has long been used to provide an indication of product quality. A cracked bell will not ring true, but a fine crystal goblet will have a clear ring when tapped lightly. Striking an object and listening to the characteristic "ring" is an ancient art, but it is limited to the detection of large defects because the wavelength of audible sound is rather large compared to the size of most defects. By reducing the wavelength of the signal to the ultrasonic range, beyond the range of human hearing, ultrasonic inspection can detect rather small defects and flaws.

Ultrasonic inspection, therefore, involves sending high-frequency vibrations through a material and observing what happens when this ultrasonic beam hits a defect, a surface, or a change of density. At the interface, part of the ultrasonic wave is reflected and part is transmitted. If the incident beam is at an angle to the interface and the material changes across the surface, the transmitted portion of the beam is bent to a new angle by the phenomenon of refraction. By receiving and interpreting the altered signal, ultrasonic inspection can be used to detect flaws within the material, to measure thickness from only one side, and to characterize metallurgical structure.

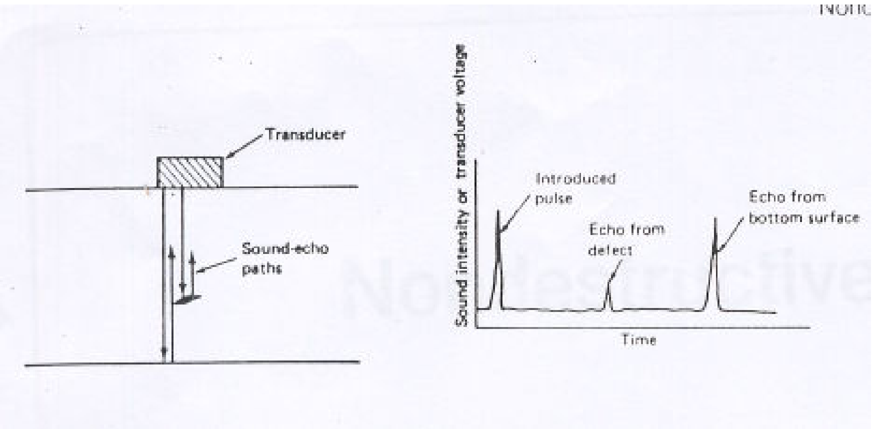

FIGURE 11-5 (Left) Ultrasonic inspection of flat plate with a single transducer. (Right) A plot of sound intensity or transducer voltage versus time depicting the base signal and a secondary peak indicative of an intervening defect.

An ultrasonic inspection system begins with a pulsed oscillator and a transducer, which serves to transform electrical energy into mechanical vibrations The pulsed oscillator generates a burst of alternating voltage the principal frequency, duration, profile, and repetition rate being either fixed or variable. This burst is then applied to a sending transducer, which uses a piezoelectric crystal to convert the electrical oscillations into mechanical vibrations. Because air is a poor transmitter of ultrasonic waves, an acoustic coupling medium generally a liquid such as oil or water is required to link the transducer to the piece to be inspected and to transmit the vibrations into the part. A receiving transducer is then used to convert the received ultrasonic vibrations hack into electrical signals. The receiving transducer can be identical to the sending unit, and the same transducer can even be used for both functions. A receiving unit then amplifies, filters, and processes the signal for display on an oscilloscope, for recording *on* some form of electromechanical recorder, and for final interpretation. An electronic clock is generally integrated into the system to time the responses and to provide reference signals for comparison purposes.

Depending on the test objectives and the part *geometry.* several different 'inspection techniques can be used:

1. In the *pulse-echo* technique, a pulsed ultrasonic beam is introduced into the piece to be inspected, and the echoes from the opposing surfaces and any intervening flaws are monitored by the receiver. The time interval between the initial emitted pulse and the various echoes is displayed on the horizontal axis of an oscilloscope screen. Defects are identified by the position and amplitude of the various echoes. Figure 11.5 shows a schematic of this technique using a single transducer and the companion signal as it would be recorded on an oscilloscope. Figure 11-6a shows the dual-transducer pulse-echo technique.
2. The *through-transmission* technique requires separate sending and receiving transducers. A pulsed beam is sent through the part by the sending transducer, and the transmitted signal is picked up by the receiver, as shown in Figure 11.6b. Flaws in the material decrease the amplitude of the transmitted beam because oft back-reflection and scattering.

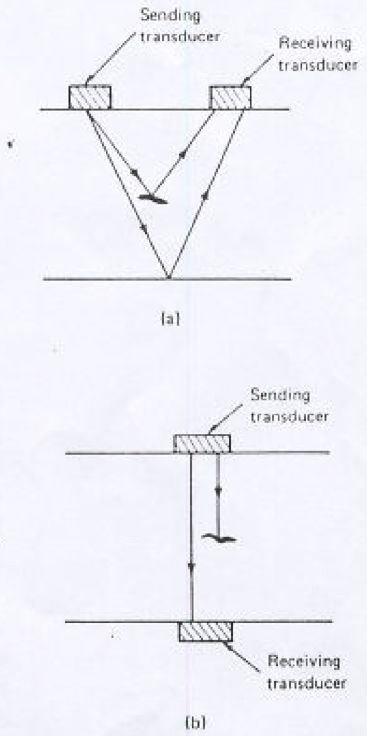

FIGURE 11-6 a) Dual transducer ultrasonic inspection in the pulse-echo mode. b) Dual transducers in through-transmission inspection.

-6 a) Dual transducer ultrasonic inspection in the pulse-echo mode. b) Dual transducers in through-transmission inspection.

3. *Resonance testing* can be used to determine the thickness of a plate or sheet from one-side of the material. Input pulses of varying frequency are fed into the material. When resonance is detected by an increase of the energy at the transducer, the thickness can be calculated from the speed of sound in the material and the time of traverse. Some instruments can be calibrated to provide a direct digital readout of the thickness of the material.

Reference standards, consisting of a series of specimens with known thicknesses or various types and sizes of machined "flaws," are generally used to ensure consistent results and to aid in interpreting any indications of internal discontinuities.

TABLE 11.4 Ultrasonic Inspection

Method: Ultrasonic inspection.

Principle: Sound waves are propagated through a test specimen, and the transmitted or reflected signal is monitored and interpreted.

Advantage: high sensitivity to most cracks and flaws; high-speed test with immediate results; can be automated and recorded; portable; high penetration in most important materials (up to 60 feet in steel); indicates flaw size and location; access to only one side is required; can also be used to measure thickness, Poisson's ratio, or elastic modulus; presents no radiation or safety hazard.

Limitations: Difficult to use with complex shapes; external surfaces and defect orientation can affect the test (may need dual transducer or multiple inspections); a couplant is required; the area of coverage is small (inspection of large areas requires scanning); trained, experienced, and motivated technicians may be required.

Material limitations: Few-- can be used on metals, plastics, ceramics, glass. rubber, graphite, and concrete. as well as joints and interfaces between materials.

Geometric limitations: Small, thin, complex-shape parts or parts with rough surfaces and nonhomogeneous structure pose the greatest difficulty,

Permanent record: Ultrasonic signals can be recorded for subsequent playback and analysis. Strip charts can also be used.

Radiography

Radiographic inspection uses the same principles and techniques as medical X rays. In essence. a shadow pattern is created when certain types of radiation (X rays, gamma rays. or neutron beams) penetrate an object and are differentially absorbed because of variations in thickness, density, or chemistry, or because of the presence of defects in the specimen. The transmitted radiation is registered on a photographic film that provides a permanent record and a means of analyzing the component. Fluorescent screens can provide a direct conversion of radiation into visible light and can enable fast and inexpensive viewing without the need for film processing. The image, however, has relatively poor sensitivity compared to that possible by the photographic methods.

X rays are an extremely short-wavelength form of electromagnetic radiation and are capable of penetrating many materials that reflect or absorb visible light. X rays are generated by high-voltage electrical apparatus, the higher the voltage, the shorter the X ray wavelength and the greater the energy and penetrating power of the beam. *Gamma rays* are also electromagnetic radiation, but they *are* emitted during the disintegration of radioactive nuclei. Various radioactive isotopes can be selected as the radiation source. *Neutron beams* for radiography are generally derived from nuclear reactors, nuclear accelerators, or radio-isotopes. For most applications, it is necessary to moderate the energy and to collimate the beam before use.

The absorption of X rays and gamma rays depends on the thickness, density, and atomic structure of the material being inspected. The higher the atomic number, the greater the attenuation of the beam. Figure 11-7 and the lead photo for Part III of the text show a radiograph of the historic Liberty Bell. Clearly visible is the famous crack, along with the internal spider (installed to support the clapper in 1915) and the steel beam and supports installed in the wooden yoke in 1929. Additional radiographs disclosed shrinkage separations and cracks that were not known to exist, as well as an additional crack in the bell's clapper.

In contrast to X ray absorption, neutron absorption varies widely from atom to atom, with no pattern in terms of atomic number. Unusual contrasts can be obtained that would be impossible with other inspection methods. For example, hydrogen has a high neutron absorption, so the presence of water in regions of a product can be easily detected by neutron radiography. X rays, on the other hand, are readily transmitted through water.

In addition, when the penetrating beam passes through an object, part of the radiation is scattered in all directions, producing an overall "fogging" of the radiograph and a reduction in contrast and image sharpness. The thicker the material, the more troublesome the scattered radiation becomes. Fortunately. measures can be taken to minimize this effect, such as beam filtering, beam collimation, shielding of the specimen, and shielding of the back and sides of the film cassette. Photographic considerations of exposure time and development also affect the quality of the radiographic image.

In order to have a reference for the image densities on a radiograph, it is standard practice to include a standard test piece, or *penetrameter,* in the exposure of the part being inspected. The penetrameters are made of the same material as the specimen or of similar material and contain structural features of known dimensions. The image of the penetrameter then permits direct comparison with the features present in the image of the product being inspected.

Density-sensitive aids have been developed to assist in detecting subtle, but important, details in the image. Television cameras connected to electronic processors with image-enhancing software can do much to accentuate density variations.

Because of the expense of testing, many users recommend extensive use of radiography during the development of a product and a process, followed by spot checks and statistical methods for subsequent production.

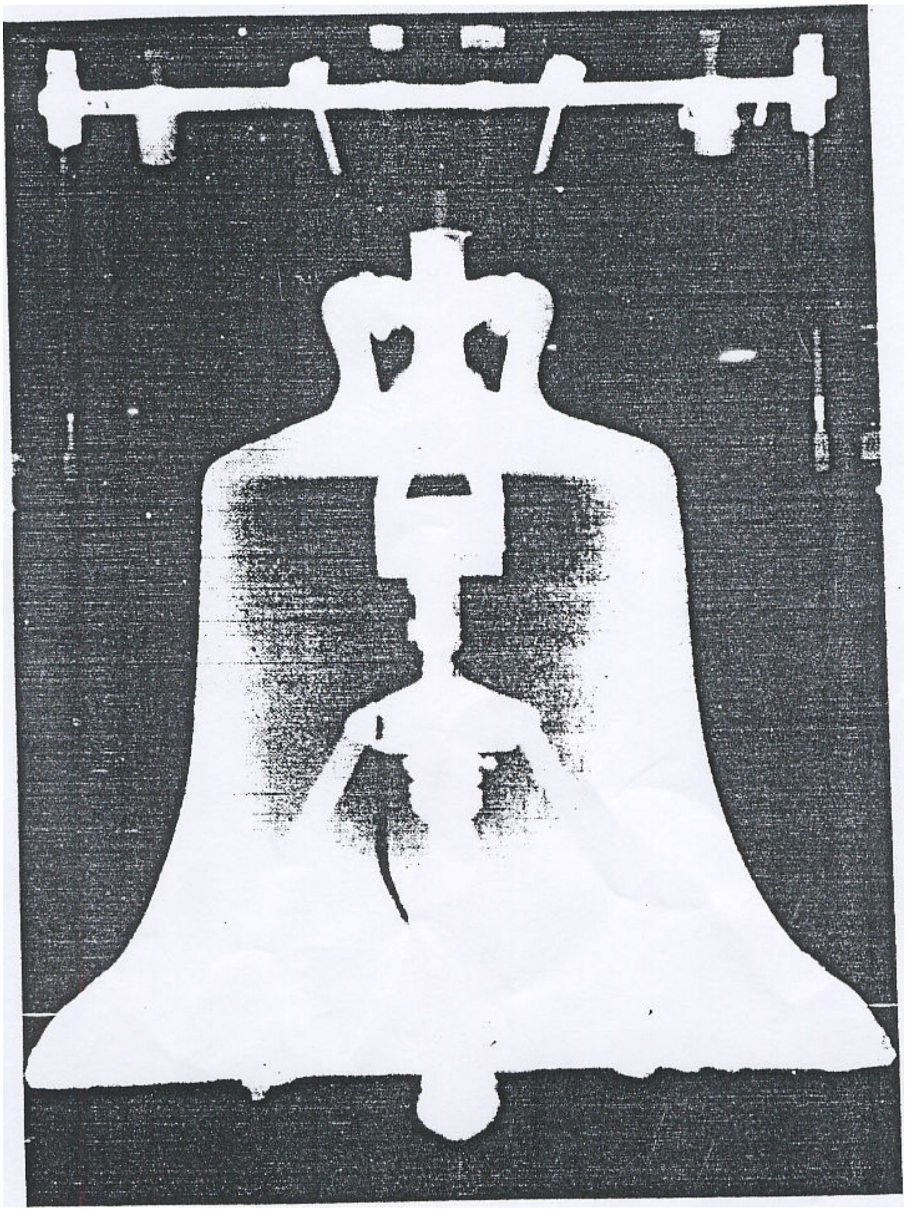

FIGURE 11-7 Full-size radiograph of the Liberty Bell. Photo reveals the famous crack, as well as the iron spider installed in 1915 to support the clapper and the steel beam and sup-ports which were set into the yoke in 1929. (Courtesy Eastman Kodak Company)

TABLE 11.5 **Radiography**

Method: Radiography.
Principle: Some form of radiation is passed through the material and is differentially absorbed depending on the thickness, the type of material, and the presence of flaw,; or defects.
Advantages: Probes the internal regions of a material; provides a permanent record of the inspection; can he used to determine thickness of a material; very sensitive to density changes.
Limitations: Most costly of the nondestructive testing methods (involves expensive equipment, film, and processing); radiation precautions are necessary (potentially dangerous to human health); the defect must be at least ?`,', of the total . tion thickness io be detected (thin cracks can be missed it oriented perpendicular in the beam); film processing requires time, facilities, and care, complex shapes can present problems: location of an internal defect requires a second inspection at a different angle.
Material limitations: Applicable to most engineering materials.
Geometric limitations: Complex shapes can present problems in setting exposure conditions and obtaining proper orientation of source, specimen, and film. Two-side accessibility is required.
Permanent record: A photographic image is part of the standard test procedure

When an electrically conductive material is exposed to an alternating magnetic field, such as that generated by a coil of wire carrying an alternating current.small electric currents are generated on or near the surface of the material, as indicated in Figure I 1-8. These *eddy currents,* in turn, generate their own magnetic field, which then interacts with the magnetic field of the exciting coil to change its electrical impedance. By measuring the impedance of the exciting coil, or a separate indicating coil, eddy current testing can he used to detect any condition that would affect the current-carrying conditions (or conductivity) of the test specimen, such as that indicated in Figure I 1-9.

Eddy current testing can be used to detect surface and near-surface flaws. such as cracks, voids, inclusions, seams, and even stress concentrations. Differences in metal chemistry or heat treatment will affect the magnetic permeability and conductivity of a metal and, hence, the eddy current characteristics. Material mix-ups can be detected. Specimens can he sorted by hardness, case depth, residual stresses, or any other structure-related property. Thicknesses or variations in thickness of platings, coatings, or even corrosion can be detected or measured.

Test equipment can range from simple, portable units with hand-held probes to fully automated systems with computer control and analysis. Each system. however, includes:

1. A source of magnetic field capable of inducing eddy currents in the part being tested. This source generally takes the loam of a

coil (or coil-con-(z fining probe) carrying alternating current. Various coil geometries are used for different-shaped specimens.

TABLE 11.6 Eddy Current Testing

Method: Eddy current testing.

Principle: When an electrically conductive material is brought near an *alternating* current coil, producing an alternating magnetic field, surface currents (eddy currents) are generated in the material. These surface currents generate their own magnetic field, which interacts with the original, modifying the impedance of the originating coil. Various material properties and defects affect the magnitude and nature of the induced eddy current and can be detected by the electronics.

Advantages: Can detect both surface and near-surface irregularities; applicable to both ferrous and nonferrous metals; versatile—can detect flaws, variations in alloy or heat treatment, variations in plating or coating thickness, wall thickness, and crack depth; intimate contact with the :•^cimen is not required; can be automated; electrical circuitry can be adjusted to select sensitivity and function; pass–fail inspection is easily conducted; high speed; low cost; no final cleanup is required.

Limitations: Response is sensitive to a number of variables, so interpretation may be difficult; sensitivity varies with depth, and depth of inspection depends on the test frequency; reference standards are needed for comparison; trained operators are generally required.

Material limitations: Applicable only to conductive materials, such as metals; some difficulties may be encountered with ferromagnetic materials.

Geometric limitations: Depth of penetration is limited; must have accessibility of coil or probe; constant separation between coils and specimen is required for good results.

Permanent record: Electronic signals can be recorded for pennanent record by means of devices such as strip chart recorders.

2. A means of sensing the field changes caused by the interaction of the eddy currents with the original magnetic field. Either the exciting coil itself or a secondary sensing coil can be used to detect the impedance changes. Differential testing can be performed by means of two oppositely wound coils wired in series. In this method, only differences in the signals between the two coils are detected as one or both coils are scanned over the specimen.
3. A means of measuring and interpreting the resulting impedance changes. The simplest method is to measure the induced voltage of the sensing coil, a reading that evaluates the cumulative effect of all variables affecting the

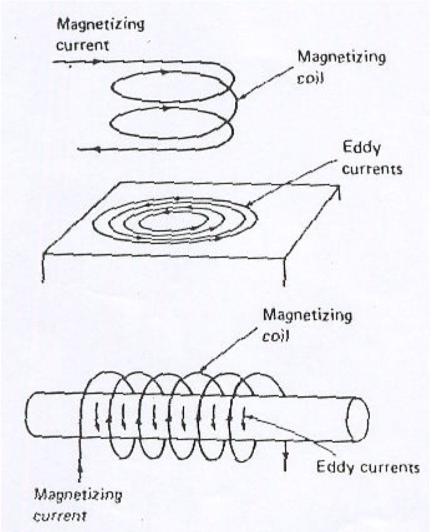

FIGURE 11-8 Relation of the magnetizing coil, magnetizing current, and induced eddy currents. Note: the magnetizing current is actually an alternating current such that the magnetic field forms, collapses, and re-forms in the opposite direction. This changing field induces the eddy cur-rents and the changes in the eddy currents induce the secondary magnetic field which interacts with the sensor coil or probe.

FIGURE 11-9 While eddy currents are constrained to travel within the material, the principles of detectability are quite similar to those of magnetic particle inspection. The eddy current method is more flexible, however. since it can detect features such as differences in heat treatment which simply alter conductivity.

eddy current field. Phase analysis can **be** used to deter nine the magnitude and direction of the induced eddy current field Familiarity with characteristic impedance responses can then be used to identity selected features in the specimen.

According to one comparison, eddy current testing egos not as sensitive as penetrant testing in detecting small, open flaws, but the eddy current method requires none of the cleanup operations and is noticeahly faster. Likewise, it is not as sensitive to small, subsurface flaws as magnetic particle inspection but can be applied to all metals (ferromagnetic and nonten'otnaenctic alike). In addition, eddy current testing offers capabilities that cannot be duplicated by the other methods, such as the ability to differentiate chemistries and heat treatments.

Materials undergoing stressing, deformation, or fracture, emit sound waves in frequencies as high as 1 megahertz. While these sounds are inaudible to the human ear, they are detectable through the use of sophisticated electronics. Transducers, amplifiers, filters, counters, and microcomputers can be used to isolate and analyze the sonic emissions of cracking or deforming material. Much like the warning sound of ice cracking underneath skates. the acoustic emissions of materials can he used to provide a warning of impending danger. They can detect deformations as small as 10^{-12} in/in that occur in short intervals of time, as well as the delamination of layered materials and titter failure in composites. In addition, multiple sensors can be coupled to accurate!\ pinpoint the source of these sounds in a triangulation method similar to that used to locate seismic sources (earthquakes) in the earth.

TABLE 11.7 Acoustic Emission **Monitoring**

Method: Acoustic emission monitoring

Principle: Almost all materials emit high-frequency sound acoustic emissions) when stressed, deformed, or undergoing structural changes, such as the formation or growth of a crack or a defect. These emissions can now be detected and provide an indication of dynamic change within the material.

Advantages: The entire structure can be monitored with near-instantaneous detection and response; only "active" flaws are detected; defects inaccessible to other methods are detected; inspection can be in harsh environments: the location of the emission source can be determined.

Limitations: Only growing flaws can he detected (the mere presence of defects is not detected); background signals may cause difficulty; there is no indication of the size or shape of the flaw; experience is required to interpret the signals.

Material limitations: Virtually unlimited.

Geometric limitations: Requires a continuous sound-transmitting path between the source and the detector; size and shape also determine the relative strengths of the emissions signals that reach the detector.

In essence, acoustic emission monitoring involves simply listening for failure indications. Temporary or transient monitoring can be used to detect the formation of cracks in materials during production, _such as in welding operations and the subsequent cooling of the weld region. Monitoring cat also be performed during preservice proof testing. Continuous surveillance is often used where the application is particularly critical, such as in bridges and nuclear reactor vessels. The sensing electronics can he coupled with an alarm and a shutdown system to protect and maintain the integrity of the structure.

In contrast to the previous inspection methods, acoustic emission is not a means of detecting an existing defect in a static product.

Instead, it is a monitoring technique designed to detect a dynamic change in the material, such as the formation or growth of a cracx, a fracture, or a defect, or the onset of plastic deformation.

Leak Testing. Leak testing is a form of nondestructive testing designed to determine the absence or existence of leak sites and the rate of material loss through the leaks. Various testing methods have been developed, ranging from the rather crude bubble-emission test (pressurize, immerse, and look for bubbles) to advanced techniques involving tracers, detectors, and sophisticated apparatus. Each has its characteristic advantages, limitations, and sensitivity. Selection should be made on the basis of cost, sensitivity, and reliability.

Thermal Methods. Temperature-based techniques can also be used to evaluate the soundness of engineering materials and components. The parts are heated, and various means are used to detect abnormal temperature distributions, indicative of faults or flaws. Temperature-sensing tools include, thermometers, thermocouples, pyrometers. temperature-sensitive paints and coatings, liquid crystals, infrared scanners. and infrared film. The location of "hot spots" on an operating component can he a valuable means of defect detection and can provide advanced warning of impending failure. Electrical components are frequently inspected by this technique, since the faulty components tend to be hotter than their defect-free counterparts. Composite materials can be subjected to brief pulses of intense heat and can then be inspected to reveal the thermal diffusion pattern. Thermal anomalies appear in the areas of poor bonding between the components.

Strain Sensing. While primarily used in laboratories as a part of product development, strain-sensing techniques can he used to provide valuable insight into the stresses and the stress distribution within a part. Brittle coatings, photo-elastic coatings, or electrical-resistance strain gages are applied to the external surfaces of the part, which is then subjected to an applied stress. The extent and nature of cracking, the photoelastic pattern produced as a result of thinning of the coating, or electrical resistance changes then provide insight into the strain at various locations X-ras diffraction methods and extensiometcrs have also been used.

Other Methods of Nondestructive Testing and Inspection

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Advanced Optical Methods. Visual inspection is the simplest of the optical methods and can be assisted by a variety of means, as previously discussed More recently, we have seen the development of several advanced optical methods. Monochromatic, coherent, high-intensity laser light has been used to detect differences in the backscattered pattern from a part and a "master." The presence or absence of geometrical features, such as holes or gear teeth, is readily detected. Holograms can provide three-dimensional images of an object, and holographic interferometry can be used to detect minute changes in an object under stress.

Resistivity Methods. The electrical resistivity of a conductive ntateli.rl is a function of its chemistry, its processing history, and its structural soundness. Changes in resistivity from one sample to another can therefore be used for alloy identification, flaw detection, and the assurance of proper processing (such as evaluating heat treatment, the amount of cold work, the integrity of welds, or the depth of case hardening). The development of a sensitive micro-ohm-meter (microhmeter) has greatly expanded the possibilities in this area.

Review Questions

1. What are some of the unattractive features of destructive testing methods?
2. What is a proof test, and what assurance does it provide°
3. How can hardness tests be used to indicate quality?
4. What exactly is nondestructive testing, and what are some attractive features of the approach?
5. What are some of the factors that should be considered when selecting a nondestructive testing method?
6. What are some of the optical aids that may be used during a visual inspection?
7. What are some **types** of defects that can be detected in a liquid penetrant test'?
8. Describe how the orientation of a flaw with respect to a magnetic field can affect its detestability during magnetic particle inspection.
9. Why is part demagnetization a necessary step in magnetic particle inspection?
10. What is the major limitation of "sonic testing," where one listens to the characteristic "ring" of a product in an attempt to detect defects'?
11. Why is it necessary to use an acoustic coupling medium to transmit the ultrasonic waves from the transducer into the product?
12. What are some of the types of radiation used in the radio-graphic inspection of manufactured products?
13. What is a pznetrameter, and what is its use in a radiographic inspection?

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15. How does eddy current testing compare with liquid-penetrwu and magnetic-particle testing in its ability to detect flaws and in its general, usefulness?

16. Why can't acoustic emission methods detect the presence of an existing, but static, defect?

17. I low do the various thermal methods of nondestructive testing reveal the presence of defects?

18. What are some of the product features that can be evaluated by the resistivity methods'?

19. One manufacturing company routinely uses X ray radiography to ensure the absence of cracks in its products. The primary reason for selecting radiography is the production of a *"hard-copy" record of each inspection for use in any* possible liability litigation. Do you agree with their selection? If not, which of the other processes might you prefer. and why'?

20. For each of the methods listed below, cite one major limitation, in its use:
—Visual inspection
—Liquid penetrant inspection
--Magnetic particle inspection
--Ultrasonic inspection
—Radiography
—Eddy current testing
—Acoustic emission monitoring