NONDESTRUCTIVE TESTING OF TURBOMACHINERY COMPONENTS

by

Paul S. Gupton

Metallurgical Consultant

Technical Inspection Services, Incorporated

Houston, Texas

Paul S. Gupton is a Senior Monsanto Fellow, retired. Currently he is a Metallurgical Consultant with Technical Inspection Services, Incorporated in Houston. He has spent the last 28 years consulting on mechanical, welding and high temperature metallurgical problems in the petroleum and petrochemical industries.

Prior to his Monsanto employment, he was with the Texas Engineering Experiment Station, Texas A&M University, and Hughes Tool Company, where he was active in alloy development and welding research. Mr. Gupton holds a B.S. degree in Engineering from Lamar University, an M.S. degree in Metallurgy and Nuclear Engineering from Texas A&M University and is a Fellow of the American Society for Metals. An active member of ASM, AWS, ASTM and ASNT, Mr. Gupton has authored several technical publications and presented over 180 technical talks.

ABSTRACT

Nondestructive evaluation is becoming increasingly important in determining the quality of materials and fabrications used in the manufacture and maintenance of rotating machinery. NDE has long been used as a tool for failure analysis. However, more and more techniques are being incorporated as required steps in manufacturing to ensure defect-free parts.

NDE can be defined as a science that incorporates methods of detecting and measuring the major properties and performance capabilities of materials, parts, assemblies, equipment and structures using techniques that do not impair serviceability. NDE uses a variety of probing techniques to assist in the discovery of hidden faults and properties of materials and products.

Since most of the techniques used in nondestructive evaluation are based on well-established principles, the proper choice and application of the correct method or methods will determine the final usefulness of the examination. Each of these common classical "Big Five" NDE techniques are reviewed along with their capabilities and shortcomings. In addition, some of the more recent developments in evaluation methods are presented.

INTRODUCTION

A wise and perceptive person once wrote "you cannot expect what you do not inspect." Personal experience with equipment builders has shown that many, as a normal manufacturing sequence, do not employ nondestructive evaluation (NDE) as extensively both in technique and quantity as they could and should. Therefore, it is up to the equipment user/operator to require these necessary techniques. The most cost effective way to prevent premature failure and poor performance of machinery is to fabricate its component parts from properly engineered and *quality* materials.

NDE has become an increasingly important tool in determining/verifying the quality of both raw and finished materials. These techniques have long been used as a major input to failure analysis (after the fact QA). Today, more sophisticated methods are available to assist manufacturers in ensuring that defective or substandard component parts do not find their way into service. However, it must also be recognized that NDE is not an absolutely failsafe process. The process can also fail if the procedure is not properly performed, the equipment is not functioning properly or the expendable materials are faulty, as in magnetic particle and liquid penetrant examination. Therefore, it is most important to provide comprehensive procedures and specifications as part of the original equipment design and performance requirements.

How one looks for faults largely depends on what you are looking for and how definitive you wish to be. NDE is a science that employs many methods of detection and measurement of the significant properties and potential performance capabilities of materials, parts, assemblies, equipment and structures using tests that *do not* impair serviceability.

THE BIG FIVE OF NONDESTRUCTIVE EVALUATION

NDE uses a variety of probing techniques to aid in the discovery materials and products. These include liquid penetrant, magnetic particle, eddy current, radiography and ultrasonic inspection, frequently referred to as the "big five" of NDE.

Liquid Penetrant Inspection

By far the most widely used NDE method, liquid penetrant inspection is limited to the detection of *surface defects* in essentially nonporous materials. This method involves flooding the surface with a light oil like penetrant solution, which is drawn into the surface discontinuity by capillary action. After removal of excess liquid from the surface, a thin coating of absorbent material is applied to draw the traces of penetrant in the defects to the surface for observation. Colored dyes or fluorescent materials are added to the penetrant to make the traces more visible. The technique can be used to locate cracks from welding, grinding, shrinkage, fatigue, seams, pores, cold shuts, lack of bonding, pin holes in welds, and many others provided they are open to the surface.

Magnetic Particle Inspection

Magnetic particle inspection is based on the principle that ferromagnetic materials, when magnetized, will have distorted magnetic fields where there are material flaws. These anomalies can be mapped with the application of magnetic particles. The magnetic field perturbations detected by the magnetic particle can be caused by surface flaws or by subsurface discontinuities like nonmetallic inclusions or differences in density of the material. Magnetic particle inspection includes three basic steps: establish a suitable magnetic field in the part, apply magnetic particles to the surface, and examine the surface for accumulation of particles.

Eddy Current Testing

When an electrically conductive material is subjected to an alternating magnetic field, small circulating electric currents are generated in the material. These eddy currents are affected by variations in conductivity, magnetic permeability, mass and homogeneity of the primary material. These characteristics are detected by measuring the eddy current response of the part. Eddy currents are induced in the part by means of a coil carrying an alternating current. The eddy current generate their own magnetic field which interacts with the magnetic field of the exciting coil. This interaction affects the impedance of the exciting coil. Impedance variation is used to detect flaws such as cracks, voids, inclusions, seams and laps. Eddy current systems all use a source of magnetic field capable of inducing eddy currents in the part, a means of sensing the field changes and a method of measuring and interpreting the resulting impedance changes.

Ultrasonic Inspection

Ultrasonic inspection involves sending a high frequency vibration through a component and observing what happens when this beam hits a discontinuity or a change in density. By listening to the altered signal, ultrasonic inspection can be used to detect flaws within the material, measure thickness from one side and characterize metallurgical structure. The basic principle of ultrasonic inspection uses the transformation of electrical energy into mechanical vibrations and the subsequent conversion of those vibrations back into electrical impulses for analysis. Generally, test instruments consist of a pulsed oscillator, sending and receiving transducers, a receiver which amplifies the signal, a clock for timing the response and a display oscilloscope for observing the wave forms.

Radiography

One of the best ways to look inside a part for hidden faults without dissecting it is with the aid of radiography. A radiograph essentially is a shadow pattern created when certain types of radiation (x-ray, gamma rays) penetrate an object and are absorbed depending on variations in thickness, density and chemical composition of the part. The results are most frequently recorded by registering the attenuated radiation on a photographic film, fluoroscope or closed-circuit television scanning.

INDICATION-DISCONTINUITY-DEFECT

The word *indication* as defined in the ASM Handbook means "response or evidence of a response, that requires interpretation to determine its significance." In relation to NDE, the term *indication* refers to a response (particle buildup, penetrant bleedout, ultrasonic signal, change in density on a radiograph or noise signal on an AE test) that requires interpretation to determine its significance.

The word "discontinuity" is a broad term referring to a foreign condition of a normal structure of a material or an interruption in the normal configuration of a part. A *defect* is a discontinuity which makes the part or material unacceptable for use or which may cause premature failure of the part when it is placed in service. All indications are not caused by discontinuities. The three general types of indications are classified as follows:

False Indication

These occur most frequently in magnetic particle or penetrant inspection due primarily to particle buildup held mechanically or by gravity. A false indication can usually be removed by air pressure since there is no magnetic attraction. Improper procedure is generally the cause of false indications in penetrant inspection. Such causes as inadequate cleaning, surface roughness or precleaning will result in this problem.

Nonrelevant Indication

Nonrelevant indications are caused by normal or known conditions in the part or material. Examples are sharp fillets, abrupt changes in section thickness and thread roots. During magnetic particle inspection, high amperage can cause a nonrelevant indication known as *flow lines*. Variations in part and section thickness cause density differences in a radiograph causing difficulty in interpretation. Ultrasonic beams may reflect from an interface between two mating parts just as readily as it will from a discontinuity. Edge effect can result in a nonrelevant indication during eddy current inspection.

True Indications

A true discontinuity may be acceptable or rejectable depending upon the *specification requirements*. A defect is a discontinuity that does not meet the acceptance standards specified for the material or part tested. It is conceivable that an acceptable discontinuity could increase in size during the stressing of service. All discontinuities resulting from the original melting, casting and solidification of the ingot of primary metal or alloy are called inherent discontinuities. The most common are nonmetallic inclusions, cracks, seams, lamination and pipe. All inherent discontinuities can be detected and their extremes defined by both magnetic particle and ultrasonic examinations.

Discontinuities associated with primary processing are found during the rough shaping and forming of metals during such processes as forging, casting, rolling, and drawing. The most common forging defect is the lap. It is generally the result of improper handling of the displaced metal. Magnetic particle or liquid penetrants are normally used for detection since it is open to the surface. Burst and flaking are the most common internal defects. Radiography or ultrasonic are widely used for their detection.

Casting defects occur during the process of solidification of the molten metal. The most frequently encountered discontinuities are porosity, blow holes, sand/slag inclusions, cold shuts, and shrinkage cracks. Due to the large grain size of most castings, ultrasonic penetration is not practical. Radiography is the most widely used technique for locating these subsurface discontinuities. Surface defects, such as cold shuts, can be detected by either magnetic particle or liquid penetrant examination.

Secondary processing discontinuities are associated with the final finishing operation of the material. Secondary processing includes both mechanical operations such as machining and any thermal treatments. The most frequently occurring discontinuity caused by heat treatment is cracking due to thermal shock of uneven heating and cooling. These are commonly known as "quench cracks." Since they are most always open to the surface, magnetic particle, penetrant or eddy current inspections can be used effectively. Grinding cracks caused by localized heating of the surface from too heavy a cut or too rapid a feed are easily detected by magnetic particle or penetrant examinations. Plating cracks from high internal stresses may be both subsurface and surface. Therefore, their detection may require both techniques.

Since welding and brazing are the most widely used techniques for joining fabricated equipment, they also receive the most scrutiny. Since the welding operation is similar to the casting process (solidified weld metal is actually a localized casting) the discontinuities present in a weldment will be similar to those found in castings, discussed earlier. Both surface magnetic particle, eddy current and liquid penetrant and subsurface radiography and ultrasonic are required to fully examine welds. Brazing, on the other hand, involves a single discontinuity of unbond between the brazing the other hand, involves a single discontinuity of unbound between the brazing material and substitute. Ultrasonic is most effective for the detection of unbound.

NDE STANDARDS AND SPECIFICATIONS

Specifications are generally either performance or design. A performance specification stipulates the performance required from an item while a design specification may detail size, shape and strength requirements. For test results to be meaningful, the method of test or test conditions must be specified. These items which are sometimes referred to as standards are: specifications, test methods and reference standards.

The most frequently used wording in NDE specifications is "The part shall be free of detrimental defects." This non specific approach is convenient for specification writers but in no way defines the needed requirements. Unfortunately, an x-ray machine is unable to determine if a discontinuity is detrimental or not. Nondestructive evaluation specifications must include a description of an acceptable quality level. This level must be defined in terms of or related to a recognized measurable reference standard which can be understood by both persons performing and interpreting test results.

Nondestructive evaluations are not tests but measurements since they offer an indication of a discontinuity size or another measured property. In reality, all engineering materials contain discontinuities which vary in size from the atomic lattice up to those that may be visually apparent. The specification requiring nondestructive evaluation must define the limits of acceptable quality. Failing to do so is like asking an inspector to measure a part to a drawing that does not have dimensional tolerance.

When engineering problems defy theoretical solutions, empirical methods are used. Correlation of service performance, fatigue life, etc., to nondestructive test results are desirable. It is extravagant to establish a quality acceptance level beyond that which has existed for similar parts that past experience has shown to have performed satisfactorily. A specification must include not only a specific description of the acceptable quality level, but also specify the method of test and the reference standards. Frequently, the specification document will not contain the detailed method of test but instead will be included by reference standard to other procedures.

There are three major sources of nondestructive evaluation specifications: military, technical societies, and industry. An extensive listing of these specifications and standards was published by ASNT in 1969. Most of these are still valid except for minor updates. This listing has been reproduced in Figure 1. A summary of nondestructive testing as discussed herein is presented in Table 1.

Commonly Used Specifications and Standards For Nondestructive Testing

Compiled by the ASNT Technical Council

NDT Method Codes: GS—General, ET—Eddy Current, HT—Hardness, TT—Thickness, LT—Leak Testing, MT—Magnetic, PT—Penetrant, RT—Radiographic, UT—Ultrasonic

NDT Method	Issued by	Number	Date	Title/Explanation
GS	AEC	F 3-2	Feb. 1969	Calibration System Requirements. Div., Reactor Dev. & Tech.
GS	AEC	F 3-6	Feb. 1969	Nondestructive Examination, Supplementary Criteria for Use of ASME Sec. III. Div., Reactor Dev. & Tech.
GS	AEC	E 4-1	Feb. 1969	Requirements for Design, Fabrication, Testing and Inspection of Steam Generators for Pressurized Water Reactors. Div., Reactor Dev. & Tech.
GS	AEC	F 3-7	Feb. 1969	Inspection Requirements for Materials in Wear Applications. Div., Reactor Dev. & Tech.
GS	AEC	F 6-1	Feb. 1969	Welding: Examination & Testing for Water Cooled Reactor Systems and Liquid Metal Systems. Div., Reactor Dev. & Tech.
GS	ASNT	SNT-TC-1A	1966	NDT Personnel Qualification Recommended Practice
GS	ASTM		Annually	Index to ASTM Standards
GS	AWS			Fourth Edition, AWS Handbook. 8.24 to 8.36
GS	AWS	A2.2-58	1958	Nondestructive Testing Symbols
GS	DOD	Mil-STD-278C Notice 1 & 2	10/26/67	Military Standard; Welds and Allied Processes for Machinery for Ships of the U.S. Navy
GS	MSS	SP-55	April 1961	Quality Standard for Steel Castings for Valves, Fittings and Other Piping Components
GS	USASI	USAS-B31.3	1966	Petroleum Refinery Piping
GS	USN	NAVSHIPS 250-634-7		Standard Terminology and Definitions for Weld Conditions and Defects

NDT Method Codes: GS—General, ET—Eddy Current, HT—Hardness, TT—Thickness, LT—Leak Testing, MT—Magnetic, PT—Penetrant, RT—Radiographic, UT—Ultrasonic

NDT Method	Issued by	Number	Date	Title/Explanation
GS	USN	NAVSHIPS 0900-001-9000	May 1965	Glossary of Management and Shipbuilding
GS	USN	NAVSHIPS 0900-014-6010		Naval Terminology Manual
GS	USN	NAVSHIPS 0900-999-9000		Arc Cut Surfaces
ET	AEC	F 3-6	Feb. 1969	Nondestructive Examination, Supplementary Criteria for Use of ASME Sec. III and USASI 831.7. Div., Reactor Dev. & Tech.
ET	ASTM	E215-66T	1966	Recommended Practice for Standardizing Equipment for Electromagnetic Testing of Seamless Aluminum-Alloy Tube
ET	ASTM	E216-63T	1963	Tentative Recommended Practice for Measuring Coating Thickness by Magnetic or Electromagnetic Methods
ET	ASTM	E268-65T	1965	Tentative Definitions of Terms Relating to Electromagnetic Testing
ET	ASTM	B342-63	1963	Method of Test for Electrical Conductivity by Use of Eddy Currents
ET	USASI	B31.7	Feb. 1968 Errata June 1968	Code for Pressure Piping Nuclear Power Piping
ET	SAE G-3	Proposed Aerospace Recommended Practice	11/10/64	Determination of Aluminum Alloy Tempers through Electrical Conductivity Measurement
ET	U.S. Gov't. Secy. of Air Force	T0-00-25-224	10/12/64	Welding, High Pressure and Cryogenic Systems (Section 4—Nondestructive Inspection by Ultrasonic and Eddy Current Methods
HT	ASTM	E10-66	1966	Brinell, Metallic Materials
HT	ASTM	E18-67	1967	Rockwell, and Rockwell Superficial, Metallic Materials
HT	ASTM	E92-67	1967	Test for Diamond Pyramid Hardness of Metallic Materials
HT	ASTM	E103-61	1961	Rapid Indentation Hardness Testing of Metallic Materials
HT	ASTM	E140-61	1961	Portable Hardness Testers
HT	ASTM	140-67	1967	Conversion Tables for Metals (Relationship Between Brinell Hardness, Diamond Pyramid Hardness, Rockwell Superficial Hardness)
LT	AEC	F 3-6	Feb. 1969	Nondestructive Evaluation Criteria for Use of ASME Sec. III and USASI B31.7. Div., Reactor Dev. & Tech.
LT	ASME	Sec. III	1968	ASME Boiler and Pressure Vessel Code, Nuclear Vessels
MT	AEC	F 3-6	Feb. 1969	Nondestructive Examination, Supplementary Criteria for Use of ASME Sec. III and USASI B 31.7. Div., Reactor Dev. & Tech.
MT	ASME	Sec. VIII	1968	ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels
MT	ASME	Sec. VIII Div. 2	1968	ASME Boiler and Pressure Vessel Code, Alternative Rules for Pressure Vessels
MT	ASME	Sec. III	1968	ASME Boiler and Pressure Vessel Code, Nuclear Vessels
MT	ASTM	A275-61T	1961	Steel Forgings, Heavy, Magnetic Particle Testing and Inspection of
MT	ASTM	A340-65	1965	Definitions of Terms, Symbols and Conversion Factors Relating to Magnetic Testing
MT	ASTM	A456-64	1964	Method and Specification for Magnetic Particle Inspection of Large Crankshaft Forgings
MT	ASTM	E109-63	1963	Standard Method for Dry Powder Magnetic Particle Inspection
MT	ASTM	E125-63	1963	Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings
MT	ASTM	E138-63	1963	Standard Method for Wet Magnetic Particle Inspection
MT	ASTM	E269-65T	1965	Tentative Definitions of Terms Relating to Magnetic Particle Inspection
MT	DOD	MIL-M-11473	9-24-51	Magnetic Particle Inspection, Soundness Requirements for Weldments
MT	DOD	MIL-M-6867B	9-13-61	Military Standard; Magnetic Inspection Units
MT	DOD	Mil-STD-410A	8-13-62	Military Standard; Qualification of Inspection Personnel (Magnetic Particle and Penetrant)
MT	DOD	MIL-STD-271D	3-11-65	Military Standard; Nondestructive Testing Requirements for Metals
MT	DOD	MIL-I-6868C & Amend. #1	2-17-67	Military Standard; Inspection Process, Magnetic Particle
MT	Naval Sup. Depot, Philo., Pa.	MIL-I-6870B	2-25-65	Military Standard; Inspection Requirements, Nondestructive, for Aircraft Materials and Parts
MT	Navy Dept.	NAVSHIPS 250-637-3	1-2-62	Fabrication, Welding and Inspection of HY-80 Submarine Hulls
MT	Navy Dept.	NAVSHIPS 0900-003-8000	Sept.1967	Surface Inspection Acceptance Standards for Metals
MT	SAE	AMS-2300A	7-15-61	Magnetic Particle Inspection, Premium Aircraft Quality Steel Cleanliness
MT	SAE	AMS-2301D	4-15-67	Magnetic Particle Inspection, Aircraft Quality Steel Cleanliness
MT	SAE	AMS 2640G	1-31-64	Magnetic Particle Inspection
MT	USASI	831.7	Feb. 1968 Errata June 1968	Code for Pressure Piping, Nuclear Power Piping
MT	U.S. Air Force	T.O.3382-1-1	4-1-63	Inspection of Material, Magnetic Particle Method
MT	U.S. Coast Guard	CG-115	3-1-66	Marine Engineering Regulations and Material Specifications Subchapter F
MT	U.S. Gov't	MIL-M-11472(2)	11-24-52	Magnetic Particle Inspection, Process, for Ferro-Magnetic Materials
MT	U.S. Gov't	MIL-M-23527	12-17-62	Magnetic Particle Inspection Unit, Lightweight
MT	U.S. Gov't	MS-17980A	5-14-63	Magnetic Particle Indications on Steel Nuts
MT	U.S. Navy	NAVAER 00-15PC-503		Technical Inspection Manual, Vol. 3, Sec. 4, Magnetic Particle Inspection
MT	U.S. Navy Bu-Ships	MIL-STD-288	11-29-57	Inspection Procedure for Determining the Magnetic Permeability of Wrought Austenite Steels
MT	U.S. Navy	MIL-S-23284	8-16-65	NDT of Basic Electric Furnace Vacuum Degassed Forgings for Shafting Used on Naval Ships
MT	U.S. Navy	NAVSHIPS 0900-006-9010	June 1966	Fabrication, Welding and Inspection of HY-80 Submarine Hulls
MT	U.S. Navy	NAVSHIPS 0900-000-1000	3-1-67	Fabrication, Welding and Inspection of Ship Hulls
MT	U.S. Navy Bu-Ships	NAVSHIPS 250-1500-1 Rev. 4	Nov. 1967	Welding Standard; PWR & Assoc. Systems
PT	AEC	F 3-6	Feb. 1969	Nondestructive Evaluation, Supplementary Criteria for Use of ASME Sec. III and USASI 831.7. Div., Reactor Dev. & Tech.
PT	ASME	Sec. III	1968	ASME Boiler and Pressure Vessel Code, Nuclear Vessels
PT	ASME	Sec. VIII	1968	ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels
PT	ASME	Sec. VIII, Div. 2	1968	ASME Boiler and Pressure Vessel Code, Alternative Rules for Pressure Vessels
PT	ASME	Sec. IX	1968	ASME Boiler and Pressure Vessel Code (Welding Qualifications)
PT	ASTM	A462-64	1964	Method for Liquid Penetrant Inspection of Steel Forgings
PT	ASTM	E165-65	1965	Standard Methods for Liquid Penetrant Inspection
PT	ASTM	E270-65T	1965	Tentative Definitions of Terms Relating to Liquid Penetrant Inspection
PT	Bu. of Ships	NAVSHIPS 0991-023-3000		Repairs to Bronze Propellers
PT	DOD	MIL-STD-410A	8-13-62	Military Standard; Qualification of Inspection Personnel (Magnetic Particle and Penetrant)
PT	DOD	MIL-T-23226	4-3-63	Military Pipe and Tube Specification for CRES Produced by Electric Furnace
PT	DOD	MIL-I-6866B & Amend. #1	8-10-64	Military Standard; Inspection, Penetrant Method of
PT	DOD	MIL-STD-271D	3-11-65	Military Standard; Nondestructive Testing Requirements for Metals
PT	DOD	MIL-F-38762	4-26-66	Fluorescent Penetrant Inspection Units
PT	NAVAL Sup. Depot Philo., Pa.	MIL-I-6870B	2-25-65	Military Standard; Inspection Requirements, Nondestructive, for Aircraft Materials and Parts
PT	Navy Dept.	NAVSHIPS 250-637-3	1-2-62	Fabrication, Welding and Inspection of HY-80 Submarine Hulls
PT	Navy Dept.	NAVSHIPS 0900-003-8000	Sept. 1967	Surface Inspection Acceptance Standards for Metals
PT	SAE	AMS 2645F	1962	Fluorescent Penetrant Inspection
PT	SAE	AMS-2646A	1-31-64	Contrast Dye Penetrant Inspection
PT	SAE	AMS-3155A	6-30-64	Oil, Fluorescent Penetrant, Water Soluble
PT	SAE	AMS-3156A	5-30-64	Oil, Fluorescent Penetrant, Water Soluble
PT	SAE	AMS-3157	1-31-64	Oil, Fluorescent Penetrant, High Fluorescence, Solvent Soluble
PT	SAE	AMS-3158	6-30-64	Solution, Fluorescent Penetrant, Water Base
PT	USASI	B31.7	Feb.1968 Errata June 1968	Code for Pressure Piping, Nuclear Power Piping
PT	U.S. Air Force	T.O.42C-1-10	11-1-66	Inspection of Material Fluorescent and Dye Penetrant Methods
PT	U.S. Air Force	MIL-I-25135C & Amend. #3	6-1-64	Inspection Materials, Penetrant (AS G)
PT	U.S. Navy	NAVSHIPS 0900-000-1000	3-1-67	Fabrication, Welding & Inspection of Ship Hulls
PT	U.S. Navy Bu-Ships	NAVSHIPS 250-1500-1 Rev. 4	Nov. 1967	Welding Standard; PWR & Assoc. Systems
PT	U.S. Navy	NAVSHIPS 0900-006-9010	June 1966	Fabrication, Welding & Inspection of HY-80 Submarine Hulls
RT	ABS		1967	American Bureau of Shipping
RT	AEC	Title 10, Chapter 1	5-12-59	Atomic Energy Title 10, Atomic Energy Chapter 1
RT	AEC	F 3-6	Feb. 1969	Nondestructive Evaluation, Criteria for Use of ASME Sec. III and USASI B31.7. Div., Reactor Dev. & Tech.
RT	Am. Petroleum Inst., Div. Trans.	APISTD 1104 9th Edition	March 1965	API Specification for Field Welding of Pipelines
RT	ASME	Sec. I	1968	ASME Boiler and Pressure Vessel Code, Power Boilers
RT	ASME	Sec. III	1968	ASME Boiler and Pressure Vessel Code, Nuclear Vessels
RT	ASME	Sec. VIII	1968	ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels

NDT Method Codes: LT—Leak Testing; GS—General; MT—Magnetic; ET—Eddy Current; PT—Penetrant; HT—Hardness; RT—Radiographic; TT—Thickness; UT—Ultrasonic

NDT Method	Issued by	Number	Date	Title/Explanation
RT	ASME	Sec. VIII, Div. 2	1968	ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels. Alternative Rules for Pressure Vessels
RT	ASME	Sec. IX	1968	ASME Boiler and Pressure Vessel Code, Welding Qualifications
RT	ASTM, AWS	ASTM B285-61 AWS A5-10	1961	X-Ray Standard for AWS-ASTM; Specs. for Aluminum and Aluminum Alloy Welding Rods and Rare Electrodes
RT	ASTM	E71-64	1964	Reference Radiographs for Steel Castings up to 2 in. in Thickness
RT	ASTM	E94-62T	1962	Tentative Recommended Practices for Radiographic Testing
RT	ASTM	E99-63	1963	Standard Reference Radiographs for Steel Welds
RT	ASTM	E142-64	1964	Standard Method for Controlling Quality of Radiographic Testing
RT	ASTM	E155-64	1964	Standard Reference Radiographs for Inspection of Aluminum and Magnesium Castings, Series II
RT	ASTM	E181-62		General Methods for Analysis of Radioisotopes
RT	ASTM	E182-62		Analysis of Phosphorus 32
RT	ASTM	E186-65T	1965	Tentative Reference Radiographs for Heavy-Walled (2 to 4½ in.) Steel Castings
RT	ASTM	E192-64	1964	Standard Reference Radiographs of Investment Steel Castings for Aerospace Applications
RT	ASTM	E242-64T	1964	Tentative Reference Radiographs for Appearances of Radiographic Images as Certain Parameters Are Changed
RT	ASTM	E272-65T	1965	Tentative Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
RT	ASTM	E280-65T	1965	Tentative Reference Radiographs for Heavy-Walled (4½-12 in.) Steel Castings
RT	ASTM	E310-66T	1966	Tentative Reference Radiographs for Tin-Bronze Castings
RT	AWS	D1.0-63	1963	Code for Welding in Building Construction
RT	AWS	D2.0-56	1956	Standard Specifications for Welded Highway and Railway Bridges
RT	AWS	D3,3-53	3-3-53	Rules for Welding Piping in Marine Construction (Carbon Steel)
RT	AWS	D3.4-52	1952	Rules for Welding Piping in Marine Construction
RT	AWS	A5.10-61	1961	Specifications for Aluminum and Aluminum Alloy Welding Rods and Bare Electrodes: Aluminum X-ray Standard
RT	DOD	MIL-STD-271D	3-11-65	Military Standard; Nondestructive Testing Requirements for Metals
RT	DOD	MIL-STD-437A	12-9-58	Military Standard; X-Ray Standard for Bare Aluminum Alloy Electrode Welds
RT	DOD	MIL-STD-453 & Ch. Notice 1	9/14/63	Military Standard; Inspection, Radiographic
RT	DOD	MIL-STD-775A	9/26/63	Military Standard; X-Ray Standards for Welding Electrode Qualification and Quality Conformance Test Welds
RT	DOD	MIL-R-11468		Military Standard; Radiographic Inspection, Soundness Requirements for Arc and Gas Welds in Steel
RT	DOD	MIL-R-11469 & Amend. #1	5-28-53	Military Standard; Radiographic Inspection, Soundness Requirements for Steel Castings
RT	DOD	MIL-R-11470 & Amend. #2	1-16-53	Radiographic Inspection, Qualification of Equipment, Operators, and Procedures
RT	DOD	MIL-R-45774(1)	10-25-63	Military Standard; Radiographic Inspection, Soundness Requirements for Fusion Welds in Aluminum and Magnesium Missile Components
RT	DOD	MIL-C-6021G	9-9-67	Military Specification; Casting, Classification and Inspection of
RT	DOD	MIL-STD-00248B	1-8-68	Military Standard; Qualification Tests for Welders (Other Than Aircraft Weldments) [Navy]
RT	IIW		1962	International Institute of Welding (Reference Radiographs)
RT	Naval Sup. Depot	MIL-I-6870B	2-25-65	Military Standard; Inspection Requirements, Nondestructive, for Aircraft Materials and Parts
RT	Navy Dept.	MIL-STD-779		Reference Radiographs for Steel Fusion Welds; Vol. 1 0.030", 0.080" and 3/16"; Vol. II ⅜", ¾" and 2.0"; Vol. III 5.0"
RT	Navy Dept.	NAVSHIPS 250-637-3	1-2-62	Fabrication, Welding and Inspection of HY-80 Submarine Hulls
RT	Navy Dept.	NAVSHIPS 250-692-2	Jan. 1961	X-Ray Standards for Production and Repair Welds
RT	Navy Dept.	NAVSHIPS 250-692-2, Suppl. 1		X-Ray Standards for Hull Structure Welds
RT	Navy Dept.	NAVSHIPS 0900-003-9000 & Change I	Nov. 1967	Radiographic Standards for Production and Repair Welds
RT	NCRP	Report No. 10	1952	Radiological Monitoring Methods and Instruments, National Bureau of Standards Handbook 51
RT	NCRP	Report No. 14	1954	Protection Against Betatron-Synchotron Radiations Up to 100 Million Electron Volts, National Bureau of Standards Handbook 55
RT	NCRP	ReportNo. 17	1958	Permissible Dose from External Sources of Ionizing Radiation, National Bureau of Standards Handbook 59
RT	NCRP	Report No. 24	1960	Protection Against Radiations From Sealed Gamma Sources, National Bureau of Standards Handbook 73
RT	NCRP	Report No. 30	1964	Safe Handling of Radioactive Materials, National Bureau of Standards Handbook 92
RT	N.Y. State Labor Dept., Bu-Stds & Appeals	Rule No. 38	12-15-55	The Industrial Code Rule No. 38 Radiation Protection
RT	SAE	AMS-2635B		Radiographic Inspection
RT	SAE	AMS 2650		Fluoroscopic X-Ray Inspection
RT	USASI	B31.7	Feb. 1968 Errata June 1968	Code for Pressure Piping, Nuclear Power Piping
RT	USASI	B31.1	1955	Code for Pressure Piping
RT	USASI	B31.8	1967	Gas Transmission and Distribution Piping Systems
RT	USASI	Ph 2.8-1964	1964	Sensitometry of Industrial X-ray Films for Energies Up to 3 Million Electron Volts
RT	USASI	Z54.1-1963		Non-Medical X-Ray and Sealed Gamma Ray Sources Safety Standards for Part 1, General (NBS Handbook H93)
RT	USASI	Z54.2-1958		Industrial Beta Ray Sources, Safe Design and Use of (N BS Handbook 66-1958)
RT	U.S. Air Force	T.O.3383-1-1	9-15-58	Inspection of Material Radiography
RT	U.S. Army	57-0-10	Sept. 1949	U.S. Army Specification; Radiographic Procedure and Qualification Tests
RT	U.S. Army Ordnance	MIL-STD-139A	1-15-65	Radiographic Inspection: Soundness Requirements for Aluminum and Magnesium Castings (for small arms parts)
RT	U.S.Army Chemical Corps.	MIL-R-51060	June 1961	Radioactive Test Sample, Strontium 90 and Yttrium 90
RT	U.S. Coast Guard	CG-115	3-1-66	Marine Engineering Regulations and Material Specifications, Subchapter F
RT	U.S. Dept. Commerce, Nat'l Bu. of Stds.	Handbook 57		Photographic Dosimetry of X and Gamma Rays
RT	U.S. Dept. Commerce, Nat'l Bu. of Stds.	Handbook 50		X-Ray Protection Design
RT	U.S. Dept. Commerce, Nat'lBu. of Stds.	Handbook 66	1958	Safe Design and Use of Industrial Beta-Ray Sources
RT	U.S. Gov't.	MIL-A-11356D(1)	4-13-62	Military Specification; Steel Armor, Cast, Homogenous Combat Vehicle Type, (¼ to 12 in., inclusive)
RT	U.S. Gov't.	MIL-R-81080	5-26-64	Radiographic Inspection, Quality Levels for (Torpedo MK 46 MOD 0)
RT	U.S. Navy	NAVSHIPS 250-537-2	June 1958	Radiographic Standards for Bronze Castings for Radium, Cobalt (60) and High Voltage X Rays (1,000 kvp and Over)
RT	U.S. Navy	NAVSHIPS 0900-006-9010	June 1966	Fabrication, Welding and Inspection of HY-80 Submarine Hulls
RT	U.S. Navy	NAVSHIPS 0900-000-1000	3-1-67	Fabrication, Welding and Inspection of Ship Hulls
RT	U.S. Navy Bu-Aeronautics	NAVAER 00-15PC-504		Aeronautical-Technical Inspection Manual Vol. 3, Section 5: Reference Radiographs for Inspection of Aluminum and Magnesium Castings
RT	U.S. Navy Bu-Naval Weapons	MIL-STD-746A	7/31/63	Radiographic Testing Requirements for Cast Explosions
RT	U.S. Navy Bu-Ships	NAVSHIPS 250-537-1		Radiographic Standards for Bronze Castings for X-Ray (to 400 kvp and Iridium—192)
RT	U.S. Navy Bu-Ships	NAVSHIPS 250-692-13	7-1-42	Radiographic Standards for Steel Castings
RT	U.S. Navy Bu-Ships	NAVSHIPS 250692-13, Suppl. 1	Jan. 1962	Radiographic Standards for Nickel-Copper, Copper-Nickel and Aluminum Bronze Alloy Castings
RT	U.S. Navy Bu-Ships	NAVSHIPS 250-1500-1, Rev. 4	Nov. 1967	Welding Standard: PWR & Assoc. Systems
TT	ASTM	B244-62	1962	Anodic Coatings of Aluminum with Eddy Current Instruments
TT	ASTM	A464-62T	1962	Zinc Coatings on Iron & Steel, Rec. Practice for Use of Magnetic Type Instruments
TT	ASTM	D1005-51	1951	Measurement of Dry Film Thickness of Paint, Varnish, Lacquer & Related Products
TT	ASTM	D1186-53	1953	Measurement of Non-Magnetic Coatings of Paint, Varnish, Lacquer & Related Products Applied on Magnetic Base (Dry)
TT	ASTM	D1400-67	1967	Measurement of Non-Metallic Coatings of Paint, Varnish, Lacquer & Related Products Applied on Non-Magnetic Metal Base
UT	AEC	F 3-3	Feb. 1969	Ultrasonic Examination of Heavy Steel Forgings. Div., Reactor Dev. & Tech.
UT	AEC	F 3-4	Feb. 1969	Ultrasonic Shear Wave Examination of Plates. Div., Reactor Dev. & Tech.
UT	AEC	F 3-5	Feb. 1969	Longitudinal Wave Ultrasonic Testing of Plain and Clad Steel Plates. Div., Reactor Dev. & Tech.
UT	AEC	F 3-6	Feb. 1969	Nondestructive Evaluation, Criteria for Using ASME Sec. III and USASI B31.7. Div., Reactor Dev. & Tech.
UT	AEC	F 3-8	Feb. 1969	Ultrasonic Examination of Metal Pipe and Tubing for Longitudinal Discontinuities. Div., Reactor Dev. & Tech.
UT	AISI		April 1959	Ultrasonic Inspection of Steel Products
UT	AISI		April 1959	Industry Practices for Ultrasonic Nondestructive Testing of Steel Tubular Products
UT	Al. Assoc.		9-1-58	Ultrasonic Quality Limits for Aluminum Mill Products
UT	Al. Assoc.		1968-69	Ultrasonic Standards for Plate, Extrusions and Forgings
UT	ASME	Sec. III	1968	ASME Boiler and Pressure Vessel Code, Nuclear Vessels
UT	ASME	Sec. VIII, Div. 2	1968	ASME Boiler and Pressure Vessel Code, Alternative Rules for Pressure Vessels
UT	ASNT		Feb. 1964	Recommended Ultrasonic Acceptance Standards for Airframe Aluminum Alloy Plate, Forgings and Extrusions
UT	ASTM	A376-64	1964	Tentative Specifications for Seamless Austentic Steel for High-Temperature Central Station Service
UT	ASTM	A388-67	1967	Recommended Practice, Ultrasonic Testing and Inspection of Heavy Steel Forgings
UT	ASTM	A418-64	1964	Method for Ultrasonic Testing and Inspection of Turbine & Generator Steel Rotor Forgings
UT	ASTM	A435-67	1967	Longitudinal Wave Ultrasonic Inspection of Steel Plates for Pressure Vessels
UT	ASTM	E113-55T	1955	Tentative Recommended Practice for Ultrasonic Testing by the Resonance Method
UT	ASTM	E114-63	1963	Recommended Practice for Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves Induced by Direct Contrast
UT	ASTM	E127-64	1964	Recommended Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks
UT	ASTM	E164-65	1965	Standard Method for Ultrasonic Contact Inspection of Weldments
UT	ASTM	E213-63T	1963	Tentative Method for Ultrasonic Inspection of Metal Pipe and Tubing for Longitudinal Discontinuities
UT	ASTM	E214-63T	1963	Tentative Recommended Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves
UT	ASTM	E273-65T	1965	Tentative Method for Ultrasonic Inspection of Longitudinal and Spiral Welds of Welded Pipe and Tubing
UT	ASTM	E317-67T	1967	Recommended Practice for Evaluating Performance Characteristics of Pulse-Echo Ultrasonic Testing Systems
UT	DOD	MIL-C-1526E	8-20-65	Military Specification for CuNi Alloy, Rod, Flat Products (Flat Wire, Strip, Sheet, Bar and Plate) and Forgings
UT	DOD	MIL-I-8950A	5-5-66	Inspection, Ultrasonic, Wrought Metals, Process for
UT	DOD	MIL-T-16420J	3-12-65	Specification for Tube for Use in Sea Water
UT	DOD	MIL-S-23008B	7-6-65	Military Specification for Steel Castings, Alloy, High Yield Strength (H Y-80 and HY-100)
UT	DOD	MIL-T-23226	4-3-63	Military Pipe and Tube Specification for CRES Produced by Electric Furnace
UT	DOD	MIL-STD-271D	3-11-65	Military Standard; Nondestructive Testing Requirements for Metals
UT	DOD	MIL-STD-770	7-16-62	Military Standard; Ultrasonic Inspection of Lead
UT	MSFC	MSFC-Spec-283	12-10-63	Testing, Ultrasonic; Aluminum Alloy Plate, Specifications for
UT	NAS	NAS 824 (Rev. 1)	1-15-64	Inspection, Ultrasonic, Wrought Metal
UT	Naval Sup. Depot	MIL-I6870B	2-25-65	Military Standard; Inspection Requirements, Nondestructive for Aircraft Materials and Parts
UT	SAE	AMS 2630		Ultrasonic Testing
UT	USASI	B31-7		Code for Pressure Piping, Nuclear Power Piping
UT	U.S. Gov't.	MIL-U-81055	5-26-64	Ultrasonic Inspection, Immersion, of Wrought Metal, General Specification for (Torpedo MK 46 MOD 0)
UT	U.S. Gov't. Secy. Air Force	T0-00-25-224	10-12-64	Welding High Pressure and Cryogenic Systems (Section 4—Nondestructive Inspection by Ultrasonic and Eddy Current Methods)
UT	U.S. Navy	NAVSHIPS 0900-000-1000	3-1-67	Fabrication, Welding and Inspection of Ship Hulls
UT	U.S. Navy	NAVSHIPS 0900-001-7000	Oct. 1963	Fabrication and Inspection of Brazed Piping Systems
UT	U.S. Navy	NAVSHIPS 0900-006-3010	Jan. 1966	Ultrasonic Inspection, Procedure and Acceptance Standards for Hull Structure, Production Repair Welds
UT	U.S. Navy	NAVSHIPS 0900-006-9010	June 1966	Fabrication, Welding and Inspection of HY-80 Submarine Hulls
UT	U.S. Navy	MIL-S-23284	8-16-65	NDT of Basic Electric Furnace Vacuum Degassed Forgings for Shafting Used on Naval Ships
UT	U.S. Navy Bu-Ships	NAVSHIPS 250-1500-1, Rev. 4	Nov. 1967	Welding Standard, PWR & Assoc. Systems

NDT Method Codes: LT—Leak Testing; GS—General; MT—Magnetic; ET—Eddy Current; PT—Penetrant; HT—Hardness; RT—Radiographic; TT—Thickness; UT—Ultrasonic

Explanations of Abbreviations under "Issued by":

ABS—American Bureau of Shipping
45 Broad Street
New York, New York 10004

*AEC—U.S. Atomic Energy Commission
Washington, D.C. 20545

AISI—American Iron & Steel Institute
350 Fifth Avenue
New York, New York 10001

Al. Assoc.—The Aluminum Association
420 Lexington Avenue
New York, New York 10017

API—American Petroleum Institute
50 West 50th Street
New York, New York 10019

ASME—American Society of Mechanical Engineers
345 East 47th Street
New York, New York 10017

ASNT—American Society for Nondestructive Testing, Inc.
914 Chicago Avenue
Evanston, Illinois 60202

ASTM—American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

AWS—American Welding Society, Inc.
345 East 47th Street
New York, New York 10017

*DOD—Department of Defense

IIW—International Institute of Welding
54 Princes Gate
Exhibition Road
London, S. W. 7
or
American Council of IIW
345 E. 47th Street
New York, New York 10017

MSFC—National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

*MSS—Military Supply Standard

NCRP—National Commission on Radiation Protection
NCRP Publications
P.O. Box 4867
Washington, D.C. 20008

SAE—Society of Automotive Engineers, Inc.
485 Lexington Avenue
New York, New York 10017

USASI—United States of America Standards Institute
10 East 40th Street
New York, New York 10016

Where to Obtain Specifications and Standards

1. All specifications or standards shown as issued by the organizations listed immediately above (with exception of asterisked entries) are available directly from the organization at the address shown.
2. All U.S. Department of Commerce, National Bureau of Standards Handbooks are available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.
3. All other government agency specifications or standards are under the control of the Department of Defense.

All requests for copies of specifications, standards, and qualified products lists should state the title and identifying number and should be submitted to Commanding Officer, Naval Supply Depot, 5801 Tabor Ave., Philadelphia, Pa. 19120, Attention—Code CDS, except

a) Copies of specifications, standards and qualified products lists required by contractors in connection with specific procurement functions should be obtained from the procuring agency awarding the contract or as directed by the contracting officer.
b) Federal Specifications and Standards and Military Book Form Standards will not generally be furnished by the Naval Supply Depot to commercial concerns unless required in conjunction with a bid or contract, or for sufficient other justification. Copies of Federal documents may be purchased from the Business Service Center, General Service Administration, Washington, D.C. 20405. Most book-form Military Standards may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
c) Only current, "in effect" issues of standardization documents will be available from the Naval Supply Depot. Copies of canceled or superseded documents required for contractual purposes will have to be obtained from the contracting office of the concerned service.
d) Information regarding obtaining AEC standards relative to the Division of Reactor Development and Technology may be obtained from Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830, or R. S. Hammond, Battelle Northwest, Richland, Washington 99352

NOTE: Comments, corrections, additions, deletions and revisions to this list of specifications are requested. Correspondence should be addressed to the Chairman of the Technical Council, ASNT, 914 Chicago Ave., Evanston, Ill. 60202.

Figure 1. ASNT Specifications and Standards. Reprinted with permission from Materials Evaluation, *Volume 28, July 1969. Copyright 1969, The American Society for Nondestructive Testing, Inc., Columbus, Ohio.*

Table 1. Summary of Nondestructive Testing Methods.

Method	Measure or Defects	Applications	Advantages	Limitations
Acoustic emission	Crack initiation and growth rate; Internal cracking in welds during cooling; Boiling or cavitation; Friction or wear; Plastic deformation; Phase transformations	Pressure vessels; Stressed structures; Turbine or gear boxes; Fracture-mechanics research; Weldments; Sonic signature analysis	Remote and continuous surveillance; Permanent record; Dynamic (rather than static) detection of cracks; Portable; Triangulation techniques to locate flaws	Transducer must be placed on part surface; Highly ductile materials yield low amplitude emissions; Parts must be stressed or operating; Test system noise must be filtered out
Eddy current (200 Hz to 6 MHz)	Surface and sub-surface cracks and seams; Alloy content; Heat treatment variations; Wall thickness, coating thickness; Crack depth; Conductivity; Permeability	Tubing; Wire; Ball bearings; "Spot checks" on all types of surfaces; Proximity gage; Metal detector; Metal sorting; Measure conductivity in % IACS	No special operator skills required; High speed, low cost; Automation possible for symmetrical parts; Permanent record capability for symmetrical parts; No couplant or probe contact required	Conductive materials; Shallow depth of penetration (thin walls only); Masked or false indications caused by sensitivity to variations, such as part geometry, lift-off; Reference standards required; Permeability variations
Electric Current	Cracks; Crack depth; Resistivity; Wall thickness; Corrosion-induced wall-thinning	Metallic materials; Electrically conductive materials; Train rails; Nuclear fuel elements; Bars, plates, other shapes	Access to only one surface required; Battery or dc source; Portable	Edge effect; Surface contamination; Good surface contact required; Difficult to automate; Electrode spacing; Reference standards required
Filtered particle	Cracks; Porosity; Differential absorption	Porous materials such as clay, carbon, powdered metals, concrete; Grinding wheels; High-tension insulators; Sanitary ware	Colored or fluorescent particles; Leaves no residue after baking part over 400°F; Quickly and easily applied; Portable	Size and shape of particles must be selected before use; Penetrating power of suspension medium is critical; Particle concentration must be controlled; Skin irritation
Holography (Interferometry)	Strain; Plastic deformation; Cracks; Debonded areas; Voids and inclusions; Vibration	Bonded and composite structures; Automotive or aircraft tires; Three-dimensional imaging	Surface of test object can be uneven; No special surface preparations or coatings required; No physical contact with test specimen	Vibration-free environment is required; Heavy base to dampen vibrations; Difficult to identify type of flaw detected
Infrared (Radiometers)	Lack of bond; Hot spots; Heat transfer; Isotherms; Temperature ranges	Brazed joints; Adhesive-bonded joints; Metallic platings or coatings; debonded areas of thickness; Electrical assemblies; Temperature monitoring	Sensitive to 1.5 temperature variation; Permanent record of thermal picture; Quantitative; Remote sensing: need not contact part; Portable	Emissivity; Liquid nitrogen cooled detector; Critical time-temperature relationship; Poor resolution for thick specimens; Reference standards required
Leak Testing	Helium; Ammonia; Smoke; Water; Air bubbles; Radioactive gas; Halogens	Joints: Welded, Brazed, Adhesive-bonded; Sealed assemblies; Pressure or vacuum chambers; Fuel or gas tanks	High sensitivity to extremely small, tight separations not detectable by other NDT methods; Sensitivity related to method selected	Accessibility to both surfaces of part required; Smeared metal or contaminants may prevent detection; Cost related to sensitivity
Magnetic particles	Surface and slightly subsurface defects; cracks, seams, porosity, inclusions; Permeability variations; Extremely sensitive for locating small, tight cracks	Ferromagnetic materials: bar, forgings, weldments, extrusions, etc.	Advantage over penetrant in that it indicates subsurface defects, particularly inclusions; Relatively fast and low cost; May be portable	Alignment of magnetic field is critical; Demagnetization of parts required after tests; Parts must be cleaned before and after inspection; Masking by surface coatings
Magnetic field	Cracks; Wall thickness; Hardness; Coercive force; Magnetic anisotropy, Magnetic field; Nonmagnetic coating thickness on steel	Ferromagnetic materials; Ship degaussing; Liquid level control; Treasure hunting; Wall thickness of nonmetallic materials; Material sorting	Measurement of magnetic material properties; May be automated; Easily detects magnetic objects in nonmagnetic material; Portable	Permeability; Reference standards required; Edge-effect; Probe lift-off
Penetrants	Defects open to surface of parts: cracks, porosity, seams, laps, etc.; Through-wall leaks	All parts with non-absorbing surfaces (forgings, weldments, castings, etc.) Note: Bleed-out from porous surfaces can mask indications of defects	Low cost; Portable; Indications may be further examined visually; Results easily interpreted	Surface films, such as coatings, scale, and smeared metal may prevent detection of defects; Parts must be cleaned before and after inspection; Defect must be open to surface
Radiography (Gamma rays); Cobalt-60; Iridium-192	Internal defects and variations: porosity, inclusions, cracks, lack of fusion, geometry variations, corrosion thinning; Density variations; Thickness, gap and position	Usually where X-ray machines are not suitable because source cannot be placed in part with small openings and/or power source not available; Panoramic imaging	Low initial cost; Permanent records: film; Small sources can be placed in parts with small openings; Portable; Low contrast	One energy level per source; Source decay; Radiation hazard; Trained operators needed; Lower image resolution; Cost related to source size
Radiography (X-rays—film)	Internal defects and variations; porosity; inclusions; cracks; lack of fusion; geometry variations; corrosion thinning; Density variations; Thickness, gap and position; Misassembly; Misalignment	Castings; Electrical assemblies; Weldments; Small, thin, complex wrought products; Nonmetallics; Solid propellant; rocket motors; Composites	Permanent records: film; Adjustable energy levels (5 kv-25 mev); High sensitivity to density changes; No couplant required; Geometry variations do not effect direction of X-ray beam	High initial costs; Orientation of linear defects in part may not be favorable; Radiation hazard; Depth of defect not indicated; Sensitivity decreases with increase in scattered radiation
Radiometry (X-ray, gamma-ray, beta-ray); (Transmission or backscatter)	Wall thickness; Plating thickness; Variations in density or composition; Fill level in cans or containers; Inclusions or voids	Sheet, plate, foil, strip, tubing; Nuclear reactor fuel rods; Cans or containers; Plated parts; Composites	Fully automatic; Fast; Extremely accurate; In-line process control; Portable	Radiation hazard; Beta ray useful for ultrathin coatings only; Source decay; Reference standards required
Sonic (Less than 0.1 MHz)	Debonded areas or delaminations in metal or nonmetal composites or laminates; Cohesive bond strength under controlled conditions; Crushed or fractured core; Bond integrity of metal insert fasteners	Metal or nonmetal composite or laminates brazed or adhesive-bonded; Plywood; Rocket motor nozzles; Honeycomb	Portable; Easy to operate; Locates far-side debonded areas; May be automated; Access to only one surface required	Surface geometry influences test results; Reference standards required; Adhesive or core thickness variations; influence results
Thermal (Thermo-chromic paint, liquid crystals)	Lack of bond; Hot spots; Heat transfer; Isotherms; Temperature ranges; Blockage in coolant passages	Brazed joints; Adhesive-bonded joints; Metallic platings or coatings; Electrical assemblies; Temp. monitoring	Very low initial cost; Can be readily applied to surfaces which may be difficult to inspect by other methods; No special operator skills	Thin-walled surfaces only; Critical time-temperature relationship; Image retentivity affected by humidity; Reference standards required
Thermoelectric probe	Thermoelectric potential; Coating thickness; Physical properties; Thompson effect; P-N junctions in semiconductors	Metal sorting; Ceramic coating thickness on metals; Semiconductors	Portable; Simple to operate; Access to only one surface required	Hot probe; Difficult to automate; Reference standards required; Surface contaminants; Conductive coatings
Ultrasonic (0.1-25 MHz)	Internal defects and variations: cracks, lack of fusion, porosity, inclusions, delaminations, lack of bond, texturing	Wrought metals; Welds; Brazed joints; Adhesive-bonded joints; Nonmetallics	Most sensitive to cracks; Test results known immediately; Automating and permanent record capability	Couplant required; Small, thin, complex parts may be difficult to check; Reference standards required
Ultrasonic (0.1-25 MHz) continued	Thickness or velocity; Poisson's ratio, elastic modulus	In-service parts	Portable; High penetration	Trained operators for manual inspection; Special probes

BIBLIOGRAPHY

Betz, C. E., "Principles of Penetrants," Magnaflux Corporation (1969).

Betz, C. E., "Principles of Magnetic Particle Testing," Magnaflux Corporation.

Krautkramer, J., and Krautkramer, H., "Ultrasonic Testing of Materials," ASNT (1983).

McMaster, R. C., *Non-Destructive Testing Handbook*, ASNT, R. Pressco, Ed., New York (1959).

Mester, Mike, *Electromagnetic Testing*, NDT Handbook, ASNT. *Non-destructive Inspection and Quality Control*, ASM Handbook, *11*, 8th Edition.

Properties and Selection of Metals, ASM Handbook, *1* 8th Edition.

"Radiography in Modern Industry," Eastman Kodak Company (1980).