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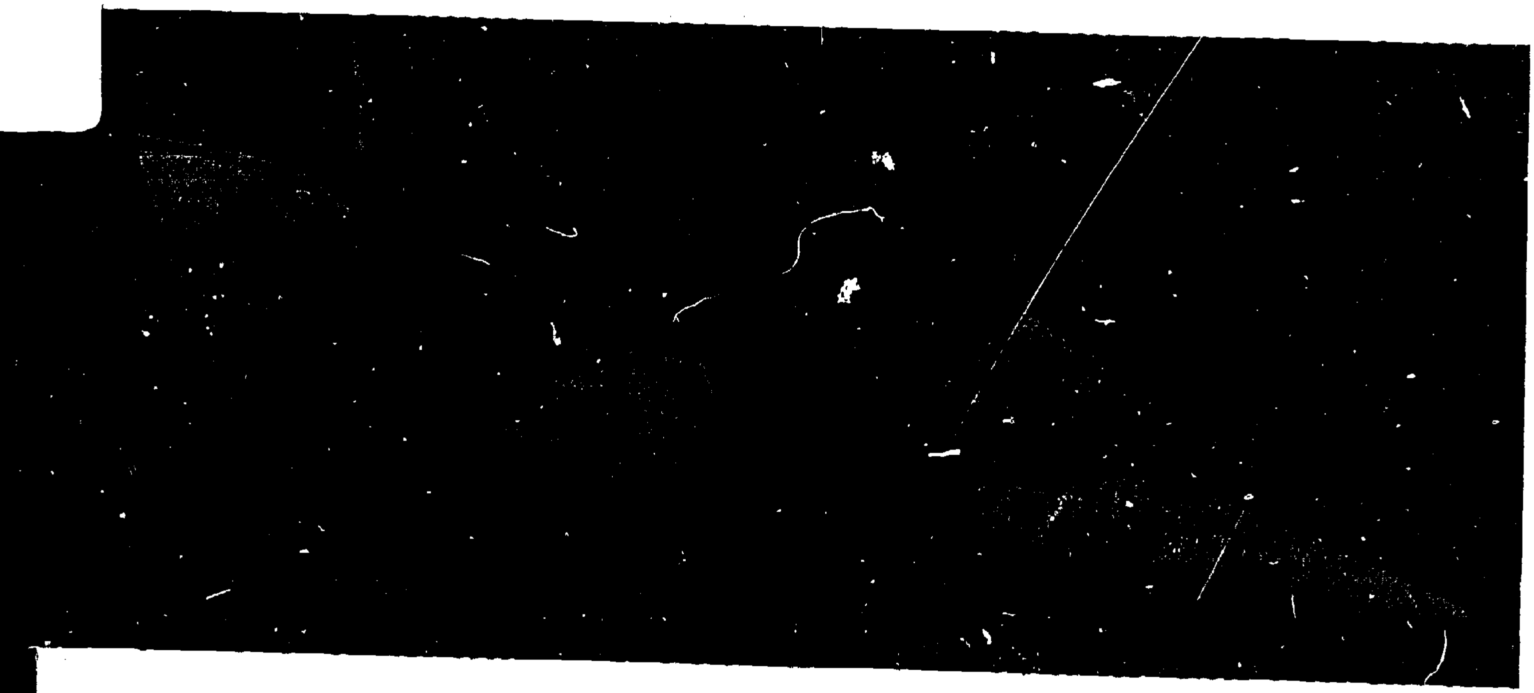
ABSTRACT

This document, the second portion of a two-part study, is designed to provide a guide for the formal training of technicians for nondestructive testing and inspection. Information in the guide is based on results of the industrial survey discussed in Part I. The subject matter is intended to be both flexible and comprehensive, and instructional goals must be focused on attainment of a high level of proficiency in each technician. This document contains an introduction consisting of considerations for instruction, significance of the manufacturing process, responsibility of the manufacturer and service company, and education objectives. Also, there are chapters on: (1) The Origin and Significance of Discontinuities, (2) Liquid Penetrant Methods, (3) Magnetic Particle Testing, (4) Eddy Current Testing, (5) Ultrasonic Testing, (6) Radiographic Testing, (7) [illegible] estructive Testing Methods, and (8) Curriculum. Sample illustrations and resource materials are appended, and a bibliography is included. Part I is available as VT 014 416. (GEB)

AN INSTRUCTIONAL PROGRAM
FOR TRAINING



NONDESTRUCTIVE TESTING
AND
INSPECTION TECHNICIANS

Texas Education Agency

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AN INSTRUCTIONAL PROGRAM FOR TRAINING NONDESTRUCTIVE TESTING AND INSPECTION TECHNICIANS

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August, 1971

FOREWORD

This research project was conducted under the direction of North Texas State University in cooperation with the Division of Occupational Research and Development, Texas Education Agency.

The study is composed of two parts:

A Study of Nondestructive Testing and Inspection Processes Used in Industry with Implications for Program Planning in the Junior Colleges of Texas

An Instructional Program for Training Nondestructive Testing and Inspection Technicians

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

The purpose of this instructional program is to provide a guide for the formal training of nondestructive testing and inspection technicians. Information contained in this guide is based on results of an industrial survey which is described in Part I of this study.

An Introduction to Nondestructive Testing

Because nondestructive testing involves the use of many forms of energy and reaches into most types of industrial occupations, the testing procedures shown in this training guide have been divided, due to this enormity, into five main methods of testing. Proficiency in the application of these five testing methods will enable the technician to test and inspect all kinds and shapes of manufactured parts and assemblies which are produced from the numerous manufacturing processes. However, these main methods of testing do not give a complete inspection coverage of the industrial field. Therefore, several independent or supplementary type tests are described in Chapter VIII.

The five main methods of nondestructive testing include liquid penetrant, magnetic particle, eddy current, ultrasonic, and radiographic processes. The descriptions of these testing processes are arranged in this guide so that each process is introduced and reviewed separately. The introduction to the process is aimed primarily at acquainting those concerned personnel with the general purposes, techniques, and results of the testing method. The objectives of each test are then outlined in specific terms so that a high level of technician proficiency will be expected. The outline of the proposed program which follows the objectives provides a guide for establishing key subject areas to be considered by instructional personnel in formulation of each course syllabus. This outline is not arranged in a teaching sequence, but merely reflects the general scope of needed subject matter to be covered.

Considerations for Instruction

The general subject matter outline of this proposed program is intended to be flexible and comprehensive. It includes many of the key areas involved in the several testing, inspection, and evaluation techniques. Each of these testing and inspection subject areas should therefore be included in appropriate course syllabii and should be supported with a degree of emphasis that will enable the trainee to understand and be able to apply the basic principles of the specific test. Obviously, several hours of concentrated instruction will be required in each of the outlined items of subject matter in order to accomplish the objectives of the instructional program. Further preparation for each specific course should include teaching plans stemming from the course syllabus. This type of plan is specific and relates to a specific unit of learning. This is the step in the learning process that seeks meaning in action.

Instructional methods must include a combination of techniques that will enable the trainee, over an extended period of time, to attain those behavioral objectives which are listed in subsequent chapters. The time required to attain these objectives through training is equated in semester credit hours and in turn into clock hours. For academic credit purposes, three semester hours of college credit will then require two clock hours of lecture and three clock hours of laboratory work for each three hour subject when the subject is laboratory oriented. The lecture and laboratory efforts of instruction will then aim at preparing the trainee to be able to test, inspect, and evaluate the quality and degree of reliability of typically manufactured parts and assemblies. Examples of these typical parts and assemblies are listed in Appendix A.

The goal of instruction is then to provide technical capability in the trainee and process him into a reliable technician. Therefore, principles and other elements of theory must be translated into elements of action. The trainee must be provided with the instructional environment that will allow him to "do" and be able to think about what and why he is "doing" it. Capability and dependability constitute the foundation for technical proficiency. In nondestructive testing, there is no room for guess and possible error.

Because there is no one best method of instruction, supervisors and instructors should direct their philosophies toward quality in the end product. This quality factor reflects from the industrial goal of near perfection in manufacture. A reliability factor of 100 per cent is justifiable and stands as the ultimate factor when the safety of people is concerned. As an example, in aircraft transportation, if one flight becomes a disaster out of 100 flights, a dangerous situation exists. In fact, the situation shows that personnel responsible for the flight are lacking in some requirement. An analysis of this situation could show inaccurate nondestructive testing and evaluation techniques performed on the aircraft. This analysis could be further focused on a critical part that was evaluated as acceptable, but in reality, the part was unacceptable. Just how this situation could have developed depends on the total efficiency of the inspection team, resting heavily on the operator or technician. When human life and high cost in money are concerned, a 100 per cent reliability factor must be expected. Therefore, instructional goals must be focused on attainment of a high level of proficiency in each technician. It is then estimated that at least two academic school years will be required to effectively complete the requirements of this program.

Significance of the Manufacturing Process

Prior to summarizing the main testing methods indicated in this guide, a review of several manufacturing processes will be accomplished. The purpose of this review is to portray some of the processes used in manufacturing the part. The manufacturing process tells the life history of the part and is consequently considered vital in final evaluation. To know the history of the part is to be able to accept or reject the part at the end of the manufacturing process. Acceptance or rejection rests heavily on inspection indications, part history, projected use of the part, and its future environment. How the part was made helps to understand inspection results and in turn, provides a means for a more valid evaluation.

There is a direct relationship between manufacturing process and resultant flaws in the part. Flaws are unwanted and often become dangerous areas in the part. The flaw is created during manufacture and often remains in the material for the life of the material. Flaws are accidental or incidental additions to homogeneous materials. The most dangerous flaw is the discontinuity or material separation. This discontinuity frequently manifests itself in the shape of a crack. The crack may or may not be open to the part's surface and its existence may justify scrapping the part. The flaw may be large, whereby the human eye can see it and on the other hand, it may be microscopic in size. Either type is material separation and consequently, justifies inspection and evaluation. If the cracked part is to be highly stressed, the chances are high that rejection is expected.

Responsibility of the Manufacturer and Service Company

Two areas of industry are concerned with nondestructive testing, the manufacturer and the service company. From the manufacturer's point of view, the part reflects his efficiency; therefore, he wants to be assured that his parts are made from sound material, being free from cracks and other undesirable flaws. From the point of view of the service company, the finished part, which has been in use, must be reevaluated to ascertain its continued service. Therefore, the part must be removed from its assembly and subjected to a complete inspection to verify the continued soundness of the material. This inspection is necessary because after several months of use, the part may have developed cracks and become unsound and unacceptable.

Fatigue, a time-load-use factor, frequently induces a tiny crack in a part. Then, over a period of time while under heavy loads, the small material separation becomes enlarged. If the small crack, due to service use, is not recognized during the nondestructive test and is allowed to remain in use, sudden failure rests ahead. Consequently, the service company, an airline for example, periodically performs the nondestructive test on its airplanes. Keep in mind that the original manufacturer had produced sound parts for the airplane, but in use, unsoundness may have developed. The nondestructive test is therefore vital to both the service company and the manufacturer in order to provide a high level of quality control in the part.

An example of maximum effort in the use of nondestructive testing is displayed on the cover of this guide. The F-111 is a fine example of quality control at work. All methods and techniques of nondestructive testing are applied in the manufacture and service of this airplane.

Educational Objectives

The objectives of this nondestructive testing and inspection training program are to provide skilled technicians who will be able to help assure a high degree of quality control and part reliability in the manufacturing processes. Part reliability through quality control depends on the technician's attainment of specific objectives which are outlined in subsequent chapters for each of the major testing and inspection methods.

The specific behavioral objective must include provision for comprehension as well as for capability. Attainment of educational objectives will be considered accomplished when the trainee can effectively perform the several techniques and tasks included in each of the major inspection processes.

The trainee must be able to routinely and effectively test for discontinuities, inspect the indications, and evaluate the findings. Evaluation, the end product of testing, must then be followed by sound logic in deciding either acceptance or rejection of the part.

Another goal of this proposed program is attainment of a high level of proficiency in the technician so that industrial qualification and certification can be effected. Educational aims and related criteria outlined by the American Society for Nondestructive Testing (Recommended Practice No. SNT-TC-1A), should be reviewed prior to establishment of a program. In this respect, another fine source of educational literature is the Materials Evaluation magazine, published by the American Society for Nondestructive Testing.

In addition to the objectives listed in this guide, reference should be made to Part Thirty-one, Annual Book of ASTM Standards. The American Society for Testing and Materials provides detailed information in regard to nondestructive tests. Another source of helpful information can be formulated from the Metals Handbook, published by the American Society for Metals.

One precaution concerning evaluation is stated and must be realized by the inspection team. During the inspection and evaluation of a part, some border line decisions in evaluation occur. It must not be considered inefficiency to consult higher authority prior to final acceptance of a part when circumstances are not clearly defined.

CHAPTER II

THE ORIGIN AND SIGNIFICANCE OF DISCONTINUITIES

A discontinuity is a break or separation in a material. The separation is either an inherent flaw or some kind of crack. When the base material, metal for example, of a part is separated by nonmetallic particles (inclusions) or voids, a discontinuity in the base metal exists. Because discontinuities are material separations, the load carrying ability of the material is reduced. When this reduction in stress reaction within the material is lowered to a critical point, failure occurs. If the part is critical with respect to total design, tragedy may result. Therefore, the manufacturer and service company have established special procedures to find discontinuities in order to prevent these material failures.

Because the designer is constantly trying to use more of a material's strength, the need to assure material capability has increased in great proportions during the past decade. Man has increasingly insisted that sound materials be provided for his vehicles, his structures, and his tools. However, this insistence has not always provided flawless materials. Due to the fact that unsound materials are being produced, the manufacturer has been alerted and has taken action to find these unwanted flaws. The search has been nondestructive; consequently, the nondestructive test was originated. The test indicates that discontinuities are detected in such a manner that the material's physical, chemical, and mechanical properties are not altered. Because metals occupy a major portion of parts produced by American industry and because most of the nondestructive tests are more relevant to metals than nonmetals, this guide is primarily concerned with the inspection of metals. However, several of the tests are equally applicable to the nonmetals.

Metal Production

During metal production and refinement, many flaws are sometimes created within the new metal. Because these flaws are often developed during and soon after the molten metal is poured, they are inherent and often remain with the associated areas of metal to its end of existence. These flaws, including the discontinuity, take many shapes and forms. Foreign materials, for example, similar to slags, are sometimes captured in the molten metal as it solidifies and before they have an opportunity to float to the surface. These captured inclusions will remain as many sided particles in the casting, but will elongate into stringers when the casting (ingot) is subsequently reheated and rolled into bars or other shapes. Cracks and holes which formed during the solidification stage also remain as metal separations even during subsequent shaping operations. The separation does not always weld itself while in the presence of high temperature and pressure during the forming operation because an oxide coating rests between the two surfaces of metal.

Metals are produced in either the cast shape or in some other shape produced from the casting. The casting, being produced first, is the result of liquid metal cooling within a mold. As the liquid metal solidifies (especially in intricate castings), some metallic droplets may solidify ahead of the stream of molten metal, possibly by splashing, and become quickly covered with the input of the moving stream. Because of this temperature differential, the outside surfaces of these partially solid droplets become cold shuts, and at the same time, become discontinuities. In other words, two masses of metal are held tightly together, but are not fused together. The cold shut sometimes occurs in the area of thick and thin sections of metal. The shape of these discontinuities is more rounded than elongated and their dimensional changes are smooth. Parts containing these discontinuities will not transmit stress across the metallic separation and are therefore not used for high strength fittings. Several types of discontinuities are illustrated in Appendix B.

The Discontinuity in the Ingot

Because an ingot (a casting) cools in an uneven way and because of the high temperature involved, its very coarse grain structure provides no directional properties. Due to uneven cooling, inclusions and cold shuts sometimes become enclosed within the solid metal and remain in their geometrical positions unless forced into different shapes by subsequent forming operations. As solidification proceeds, should hot gas at the mold's walls force itself into the mushy metal prior to solidification, blow holes or cavities will result in the metal, being open to the surface. Should entrapped gas leak towards the metal's surface prior to solidification, tiny pin holes or rounded porosity holes will form. Sometimes, one area of metal may cool faster than another, causing a stress concentration. Should this stress concentration overcome the metal's strength at the moment of solidification, tearing of the metal results. This tear is jagged in shape as opposed to rounded edges of holes and cold shuts. Reference should again be made to Appendix B.

The tear, inclusion, or cold shut may be internal or either flaw may be exposed to the surface. Because these flaws are born as metal solidification occurs, they are then part of the metal and are not fit for carrying heavy or alternating loads. In nonstressed areas under static loads, however, the flaw may sometimes be considered as not critical. As stress lines, because of loads, contact the flaw, they make a curved path around the flaw. This concentration of curved stress movements around the flaw creates stress raisers and concentration points for internal overload and subsequent potential failure. Also, in the presence of alternating loads, the discontinuity will increase in size, thereby decreasing the cross sectional area of metal. Obviously, when this area reduction occurs, failure can be expected without further warning. These types of discontinuities are usually highly significant. The stress pattern is illustrated in Appendix C.

Cast parts take their shape from the frozen liquid, an ingot being a typical example. When liquid metal is poured into the ingot mold, solidification first begins at the bottom and sides of the mold due to the cooling effects of the mold's walls. Solidification proceeds outwards from these solid nuclei to the mold's center until all metal has been transformed from liquid to solid. When the mold becomes full, pouring ceases. Because hot metal requires more volume of space than cooler metal, shrinkage occurs along with cooling, primarily at the top of the mold. As the last amount of molten metal begins to solidify, the top center portion (last to contain liquid) may sometimes sink. In some types of molds, this depressed area contains a connecting void deeper into the center region of the metal. The total depressed area including the void is known as "pipe." Because of this pipe and in order to avoid the possibility of including more discontinuities in future products stemming from the pipe, the top section of the mold is cropped away. Hopefully, the cropped off area contained all of the unwanted pipe, porosity, and other undesirable discontinuities. The removal of ingot tops precedes the rolling operation. Appendix D illustrates the discontinuity in the ingot. At this point, it must be pointed out that all ingots do not contain the top depression and are therefore not cropped. Frequently, the design of the mold helps allow for desired solidification in the top portion of the mold.

Shapes of Discontinuities

After cooling, the ingot is reheated and then processed into different shapes by one of the wrought processes. These processes include rolling, pressing, forging, and extrusion. If any discontinuities remain in the ingot, they are then carried within the finished wrought shape because they are part of the shape. However, the initial shape of the discontinuity as it existed in the ingot is changed to conform with the mechanical pressures during surface operations. As an example, the cold shut, the inclusion, the hole, and the crack are elongated or flattened by forces of the forging hammer or the rolls of the mill, and are always present but existing in their new shapes. The new shape is often thin and flat or long and thin. Regardless of the shape, the discontinuity is a metal separation. Therefore, caution must be exercised in judging the potential of these flaws. Refer to Appendix E for illustrations of these types of discontinuities.

Depending on the type of wrought operation performed, discontinuities therefore take different shapes. As an example, if the ingot is rolled into plate and sheet stock, the inclusion and other discontinuities are often flattened into pancake shapes and act as laminations between sound areas of metal. Parts subsequently manufactured which contain these laminations are subject to failure if severely stressed. When welded pipe, for example, is machine folded into the rounded shape from sheet stock containing this lamination, the pipe will also contain this discontinuity. Also, pipe edges that are not properly fused during welding will produce seams. The seam is a longitudinally shaped discontinuity open to the surface in which a layer of oxide prevents the parent metal from fusing. Appendix F illustrates these types of discontinuities. Again, stressed parts must not be manufactured from metals containing discontinuities. In this respect, it is not always possible to produce a metal that is 100 per cent sound. In order to determine the acceptable limit of discontinuities, reference must be made to governing specifications and standards pertaining to the particular test. Should a flawless metal be required, however, it is then often advantageous to inspect the large mass of metal prior to forming and machining operations. The presence of the discontinuity is then evaluated.

Other forming operations which produce bars from the ingot have different effects on discontinuities. Because the bar is more confined on all sides as it moves longitudinally through the rolls, the discontinuity becomes elongated as a stringer in the direction of rolling. Should a seamless tube or other extrusion be produced from this bar, the inherent stringer would then become a discontinuity in the tube, either running parallel to the direction of extrusion or rolling and existing along the axis of the tube or following the surface contour in the form of a helix due to roll effects. The discontinuity which is open to the surface as a result of the extrusion process takes the shape of a seam and must not be used to carry loads. Stress will not cross the metal's separation at the seam; therefore, a satisfactory stress reaction to an applied load will not occur. Consequently, the load, having an inadequate reaction from the metal at a critical point produces quick failure. If the ruptured part is arranged in some type of "domino" design in the assembly, chain reaction will often follow until complete failure of the assembly results.

During the process of forming smaller shapes from the ingot, other types of cracks often occur. Some cracks become open to the surface and then remain as seams during continued rolling or other wrought type of operations. Cracks are also formed from sound metal during heat treatment. This type of crack may run in any direction and may move across the grain (intragranular) or along the grain boundaries (intergranular). Also, this type of crack will remain as an internal discontinuity and may relieve the surrounding areas of stress by moving to the surface. When metal is hardened by heating and quenching, this type of heat treating crack will sometimes occur. The crack may be deep within the metal or it may be open to the surface. The crack results due to the inability of the hardened metal to flow with the pressure of the internal stress. In other words, hardened metal is stiff metal and will not bend or flow an appreciable amount. The ductility factor is low while the hardness factor is high. Due to a sudden concentration of stress at a point of high resistance, metal separation will occur as a crack when the stress is greater than the metal's strength. Appendix F also illustrates these cracks.

Metals that are subject to changing loads may also initiate very small separations in the metal, often along the edges. Continued stress variation, especially from tension to compression in cyclic patterns, elongates the initially small separation into a dangerous fatigue crack. As the crack reduces the effective cross sectional area of the part, failure approaches, and at the critical moment, when no safety factor remains, failure occurs without warning. Cracks beginning at the surfaces of materials often lead to fatigue failure. Use of the part must then be known in order to understand the strength pattern. Parts manufactured from materials that subsequently function in cyclic loading patterns must be sound throughout the cross section. The surface crack is especially dangerous when the part is used in alternating loading cycles. The nondestructive test must be especially aimed at this type of discontinuity. Appendix G illustrates this discontinuity.

Machining operations often leave indented areas and n[illegible] on the surface of the part. In effect, these are not discontinuities, but are sometimes points where stress may concentrate. The machine mark must therefore be evaluated in terms of its significance to the stress pattern. Also, when the part's design calls for abrupt change in direction or dimension, conditions prevail for potential stress concentration and possible failures either through heat treating cracks or stress overload. The designer must therefore consider this stress condition during the design process.

Another source of cracks results from improper grinding techniques during finishing operations. When too much pressure is placed on the grinding wheel, the metal's surface will overheat and often check into numerous tiny cracks. These small cracks develop in a pattern which is across the direction of grinding wheel rotation. Depending on the use of the part, checks may or may not be harmful. Highly stressed parts however, must not include any types of cracks or other discontinuities. Checked areas in a ground part are illustrated in Appendix H.

Sections of metal which are exposed to forging operations may often contain discontinuities. The lap is a typical example. The lap is a thin area of metal which has been lapped over the metal's surface and then folded back onto the surface by means of the forging hammer. The folded metal is subsequently hammered into the surface. The lap is a discontinuity because oxide coatings along the edges of the lap prevent fusion of the metal while hot. Also during forging, metal may burst internally and form cracks and voids as the result of excessive pressure while the metal is underheated, being much too cold. These cracks become discontinuities. The burst may also extend to the surface. This type of crack is consequently the beginning of further cracking; therefore, predetermined plans for the part will dictate acceptance or rejection. Cracks are normally unacceptable unless their location rests within nonstressed areas of the part. Forging laps and cracks are illustrated in Appendix I.

Discontinuity in the Weld

Another form of discontinuity results from any and all of the several welding operations. Because welding causes sections of metal to fuse together through melting actions, chance provides a means for inclusions to become entrapped in the molten pool. The inclusion is a discontinuity and is sometimes found in the fusion zone. Usually, these small particles of nonmetal float to the surface prior to solidification, but too often, some become entrapped within the solid metal.

Because welding involves the heating and cooling of a metal, a temperature differential always exists along the path of fusion. Because this temperature difference exists, uneven stresses prevail which tend to warp and tear the metal. Sometimes, a starlike crack will appear in the weld as the result of over stress. When the metal is restrained to prevent warping, transverse cracks may occur in the weld. The transverse crack occurs across the weld while the longitudinal crack occurs parallel to the weld.

Another unwanted discontinuity resulting from welding is the pin hole. This small separation in the metal results from porosity or rising gas bubbles. Good welding techniques and proper welding temperatures help eliminate the presence of the pin hole and the inclusion.

Finally, faulty welding techniques often result in improperly shaped beads. When stress follows the surface contour of a part, an undercut in the welded metal provides a stress raiser and a potential trouble spot. Also, lack of fusion and poor penetration of the weld act as stress concentration points when the part is loaded. Therefore, inspection must be carefully aimed at bead shape and dimensions and these relationships with the parent metal.

Because the welded zone of metal is cast and frequently joins wrought metal, strength variations in the metal exist across the welded zone. The shape of the bead across the welded zone provides the shape of the stress path across the zone. Undercut, poor fusion, inadequate penetration, inclusions, porosity, cracks, and craters provide stress detours and subsequent points of stress concentration.

A welded joint that is highly stressed must transmit the stress pattern effectively. The presence of discontinuities in the fusion zone acts as possible points for failure. The nondestructive test must therefore search for these flaws and find them. Welding flaws are illustrated in Appendix J.

Discontinuities are found in other types of manufactured products, but the principles of their creation have been noted in this summary. It can be safely stated that the search for these unwanted flaws must continue with aggressive efforts. The nondestructive test therefore, seeks out these undesirables and arranges for their judgement.

Objectives

The understanding of the origin and significance of discontinuities is vital in the evaluation of parts which have been previously tested and inspected by the nondestructive testing process. Objectives to be obtained in this phase of instruction are listed below.

I. The trainee should:

A. Be familiar with the main processes used in the manufacture of parts.

B. Be especially aware of the actions occurring inside the metal during the pouring, solidification, and forming sequences.

C. Be familiar with the types, shapes, sizes, and locations of typical discontinuities.

D. Be cognizant of stress relations to load and the resultant stress patterns.

II. The trainee will be able to:

A. Differentiate among the several discontinuities.

B. Relate the possible cause of the discontinuity.

C. Understand the significance of the particular discontinuity.

D. Recapitulate the possible history of the part and then relate this history to the discontinuity.

E. Determine the degree of severity of the discontinuity.

F. Correlate the discontinuity with a view of acceptance or rejection of the part.

Outline of Key Points

I. Metal refinement and production

  A. Ores

    1. Ferrous and nonferrous
    2. Mining ore
    3. Mechanical separation and refinement
    4. Furnace refinement processes

  B. Ingot production

    1. Reheating for further refinement
    2. Types, shapes, and sizes

  C. Casting production

    1. Types, shapes, and sizes

  D. Wrought shapes

    1. Principles of wrought processes
    2. Types of processes
    3. Kinds of parts

II. The Casting

  A. Kinds of metals used in casting

    1. Ferrous group
    2. Nonferrous group

  B. Molds

    1. Types, shapes, and sizes
    2. Mold materials

  C. Pure metals and alloys

    1. Typical elements and alloys
    2. Chemistry of metals
    3. Physical constants of metals
    4. Mechanical properties
    5. Grain structure and pattern
    6. Allotropic changes

D. Pouring processes

1. Liquid action as temperature drops
2. Formation of solid nuclei
3. Slags and flotation
4. Gases, internal and external
5. Inclusions, specific gravity, and time
6. Coefficients of expansions
7. Nuclei growth patterns
8. Gates, sprues and risers
9. Escape holes for gas
10. Thick and thin section factors
11. Top portions of solidified metal

E. The finished casting

1. Birth of discontinuities upon solidification
2. The cold shut
3. The inclusion
4. The pin hole and porosity
5. The blow hole
6. The tear or crack
7. The void
8. Sub-surface defects
9. Surface defects

F. Heat treating processes

1. Ferrous procedures
2. Nonferrous procedures

G. Appearance of new discontinuities

1. Cracks
2. Causes

H. Surface irregularities

1. Mold marks
2. Machine marks

III. The ingot

A. Ferrous and nonferrous

1. Chemistry of metal
2. Physics of metal

B. Molds

1. Mold materials
2. Sizes, shapes, and types
3. Principle of mold cooling

C. Pouring processes

1. Liquidus to solidus curves
2. Slags and flotation
3. Gases, internal and external
4. Inclusion characteristics
5. From liquid to solid
6. Actions along bottom and sides of mold
7. Actions at top of mold
8. Pipe and porosity

D. The cold ingot

1. Grain structure
2. Structural patterns
3. Surface conditions
4. Top section irregularities
5. Birth of discontinuity

IV. Wrought sections and parts

A. Slabs and billets

1. Reduction in size of ingot
2. Shapes of smaller sizes

B. The plate and sheet

1. Geometry changes to plate and sheet
2. The rolling process
3. Discontinuity dimensional changes
4. Flat and pancake types of discontinuities
5. Rounded voids to elongated laminations

C. The bar and rod

1. Geometrical shape changes
2. Discontinuity elongation to stringers
3. The surface seam and the internal stringer
4. Curved flaws to elongated

D. The pipe

1. Curved sheet to welded pipe
2. The lamination and the stringer
3. Oxide action and the seam

E. The tube and other extrusions

1. Piercing processes and extrusions
2. Mandrel movement
3. Surface parallel seams

    4. The helical seam
    5. Inside and outside flaws
    6. Discontinuity patterns

  F. The wire

    1. Geometry of bar and rod to wire
    2. Discontinuity transfer to wire

  G. The forging

    1. The lap
    2. The discontinuity
    3. The internal burst
    4. The surface burst
    5. The crack

V. The welded part

  A. The fusion zone

    1. Metallurgy of the weld
    2. Cast metal joined to wrought or cast
    3. Bead shape and dimensions
    4. Heat and cooling effects
    5. Expansion and contraction factors
    6. Discontinuity birth on cooling

  B. Geometry factors

    1. The bead shape
    2. Penetration
    3. Undercut
    4. Inadequate fusion

  C. Discontinuity types

    1. Inclusions
    2. Cracks; heat treating, tears, and fatigue
    3. Voids; porosity
    4. Irregularities

VI. Design factors

  A. Mechanical properties

    1. Loads and reactions
    2. Stress patterns
    3. Material factors

- B. Part's use
  - 1. Operating conditions
  - 2. Safety factors in stress
- C. Discontinuity data

VII. Discontinuities

- A. Birth and evaluation
  - 1. Environmental factors
  - 2. Geometry conditions
  - 3. Chemistry and physics factors
  - 4. Final shape, size, and location
- B. Relationship to load carrying ability
  - 1. Stress pattern and discontinuity
  - 2. Elastic nature of stress

CHAPTER III

LIQUID PENETRANT METHOD

The liquid penetrant method of nondestructive testing is based upon the entry of a penetrating liquid into a discontinuity. Because the special penetrant must be able to enter the discontinuity, only surface types of flaws and irregularities can be evaluated by this method. The penetrant is usually an oil in which either a colored dye is added or a fluorescent powder is suspended.

If a penetrant is allowed to soak at the surface of a solid material, some of the penetrant will enter a crack or pin hole if these discontinuities are open to the surface. When the part's surface is then washed so that all penetrant is removed, a small amount of penetrant will later appear at the surface, if any had entered a discontinuity. If this late appearing penetrant contains a colored dye, visual observation and inspection will indicate its origin. If the penetrant is fluorescent, inspection will also indicate its origin in the presence of black light. Black light is in the ultraviolet spectrum of light rays and exists in the vicinity of 3600 angstrom units. The penetrant method is used on all solid materials, except those of a porous nature. These solid materials include the metals, plastics, and ceramics.

Testing and Inspection Techniques

Penetrants are manufactured according to different specifications; therefore, the operator should review the instructions for use as indicated by the manufacturer. Because surface discontinuities exist in many types, the penetrant must be capable of entering any type of surface irregularity. Capillary action occurs during the process of penetrant entry. Much of this action is associated with adhesion and cohesion forces. Also, the penetrant's viscosity, along with pulling forces, cause the liquid to move into surface breaks and proceed to the bottom of the openings. Sometimes, air is entrapped ahead of the penetrant causing a slowing down of penetration. In these respects, thin cracks often allow penetrant entry easier access than do larger porosity holes because of the possibility of entrapped air in the hole.

Penetrants may be placed on the surface of parts by spraying, dipping, or swabbing. Room temperature is often acceptable for conducting this process. Often, the portable type of arrangement allows spraying from pressurized cans. On the other hand, heavy parts are easily processed by immersion techniques. Because excess penetrant must be removed, washing is accomplished by any feasible means. Spray washing is acceptable when pressures do not exceed 40 psi. and the spray angle does not exceed 40 degrees. Immersion washing is a common process because of its speed in penetrant removal.

In order that surface inspection be effectively evaluated, the discontinuity must be outlined so that the operator can see it. After removal of excess penetrant, the part is dried at temperatures below 212 degrees F. and allowed to set for a short period of time. This dwelling period allows bleeding of any penetrant from a discontinuity. Bleeding is expedited with the use of a developer (powder). The developer accelerates the emerging of the retained penetrant and helps to spread it at the discontinuity. When dyes or fluorescent particles are added to the very thin liquid penetrant, visual observation is facilitated. Colored dyes mark their presence at all surface contour breaks and are visible in the presence of white light. Often, a more effective inspection is accomplished when fluorescent particles are placed in the penetrant. When bleeding occurs during the developing process, a black light causes the emerged liquid to fluoresce. The discontinuity is clearly outlined.

Cleaning of Part

When a part is to be tested and inspected by the liquid penetrant method, thorough cleaning of the part is required. There are several processes available for cleaning such as detergents, steam, vapors, and solvents. Because a part is often contaminated with various types of unwanted materials, consideration must be given to the process that removes the unwanted grease, dirt, paint, and scale without doing injury to the material. As an example, wire brushing or blasting a surface (especially soft materials) is not desirable because the mechanical action may cause the metal at a discontinuity to fold over and hide the break. Plated materials require plating removal. Parts that have been machined just prior to inspection may require burr removal with acid or alkaline etch. Neutralization of the material's surface is then required immediately following the etching process. In other words, the parent material must be available to the penetrant in order that all surface irregularities will be exposed.

Equipment

The liquid penetrant method of nondestructive testing lends itself favorably to local fabrication of test benches and inspection booths. However, manufacturers have provided various types of equipment for completing the inspection process. Basically, a means must be available for holding and processing the parts to be tested. A table top or bench arrangement usually suffices. Appendix K shows a simplified process arrangement of locally manufactured equipment used in conjunction with manufacturers' equipment. Station A is merely a resting place to assemble the parts to be tested, only after they have been thoroughly cleaned. Station B serves as a platform for arranging the parts in some sort of testing sequence. Station C is the soaking tank. Parts are soaked in the liquid penetrant for a given period of time in accordance with the manufacturer's instructions. After the soak, parts are allowed to drain at Station D. Should there have been any discontinuities at the surface of the part, the penetrant would have entered and would have been retained for a short period of time. Station D allows excess penetrant to drain from the surface. In a short while, the part is then washed free of the penetrant at Station E. Washing may include detergent, steam, vapor, solvent, or other processes, depending on the type of penetrant. Station F provides an examination station to assure that all penetrant has been removed from the surface. A black light is often used at this station to ascertain a clean surface. Station G provides for drying of the part. After a short period in the dryer (or at room temperature), a wet or dry developer is applied to the part at Station H for the purpose of drawing out any penetrant that may have entered a discontinuity. If the wet method is used, drying will again be required. If needed, visual inspection of the part is available at Station I. Final inspection is then completed at Station J. Here, white light for colored dye is used or a black light is used for energizing the fluorescent particles. Either way, the surface irregularities are revealed in sharp contrast to the surface. Prior to release of the inspected parts, they are then thoroughly washed to remove all traces of the inspection medium. Appendix K also indicates a discontinuity discovered by this process.

Evaluation

Following the testing and inspection processes, evaluation is accomplished. In effect, evaluation is the end process of testing. The ability of the operator to adequately test and inspect parts is focused on his ability to evaluate what he sees. Evaluation is critical. Wrong judgement in evaluation could allow subsequent part failure and possible disaster to personnel. Therefore, operators must be well informed as to the meaning of the inspection.

Safety Precautions

A few safety precautions are necessary when handling penetrants. Fumes from the several liquids can be injurious; therefore, adequate ventilation is required during the testing process. Also, the flash point of the penetrant may be similar to that of kerosene. Low flash point oils may catch fire; consequently, fire precautions are necessary. Do not use oils with flash points near room temperature and do not allow penetrants to become overheated.

Because the light beam emerging from the purple glass filter of the inspection lamp is black light, it is not within the injurious spectrum of ultraviolet. Avoid, however, a direct view into the light.

Objectives

Objectives of the liquid penetrant method of nondestructive testing are stated below.

I. The trainee should:

A. Understand the principles governing the liquid penetrant testing and inspection process.

B. Be familiar with the various types of parts which are commonly tested with the aid of penetrating liquid.

C. Be cognizant of the routine procedures involved in accomplishing the test.

D. Understand the requirements for a specific testing technique and be able to select the proper technique.

E. Understand the advantages and disadvantages of the test.

F. Comprehend the reasons for visual indications on the material's surface.

G. Realize the need for increased objectivity in standards.

II. The trainee will be able to:

A. Use typical penetrant units of equipment.

B. Decide on necessary inspection items needed in completing the inspection.

C. Follow an authorized testing procedure.

D. Differentiate among the several surface irregularities.

E. Use white and black light efficiently in the inspection process.

F. Use the dye process effectively.

G. Identify surface discontinuities and other surface type flaws.

H. Analyze the total inspection results.

I. Evaluate the total situation.

J. Accept or reject each indication.

Outline of Key Points

I. Equipment

A. Operator's ability to use

1. Basic principles of the test
2. Purposes of the test
3. Functions of equipment
4. Basic understanding of operation
5. Exercises in use of equipment

B. Spot check type

1. Local needs
2. Group of canned testing materials
3. Sequence of use
4. Understanding of principles

C. Dye facilities

1. Types of dyes
2. Purposes and principles of application
3. White light

D. Fluorescent capability

1. Principles of penetrant application
2. Reaction of penetrant in black light
3. Need for black light processes

E. Wet and dry methods

1. Types of penetrants
2. Emulsifiers
3. Washing control
4. Developing procedures
5. Types of developers
6. Setting and drying principles
7. Testing and inspection processes
8. White and black lighting

F. Portable type

1. Need for mobility
2. Emergency inspections
3. Effectiveness of procedures
4. Units of complete set

G. Stationary type

1. Sequential functions
2. Size and shape to suit needs
3. Penetrant application and draining stations
4. Ovens and resting stations
5. Black light booth
6. Automated

II. Surface preparation

A. Degreasing processes

1. Requirements for clean surfaces
2. Detergents, solvents, and vapors
3. Care of original surface during cleaning
4. Cleaning vs. the kind of material

B. Scale removal

1. Mechanical and hand removal
2. Care of original surfaces; danger to surface
3. Nature of scale and related coatings

C. Paint and plating removal

1. Need for removal
2. Paint removers and procedures
3. Plating removal procedures

III. Penetrants

A. Purpose of penetrants

1. Mobility and penetration capability
2. Vehicle for inspection particles
3. Principles of mobility and penetration

B. Preparation of penetrants

1. Need for particular type
2. Kinds and percentages of mixtures
3. Need for several types

C. Water washable fluorescent

1. Penetrant application
2. Setting time
3. Need for controlled washing

D. Post-emulsification fluorescent

1. Purpose of emulsifiers
2. Care in procedural applications
3. Requirements

E. Water emulsification visible dye

1. Requirements for dye processes
2. Water emulsification processes
3. Reaction of visible dyes
4. Special uses on certain metals

F. Application to surfaces

1. Spray processes
2. Dipping and soaking processes
3. Portable and stationary applications
4. Proper observance during application
5. Need for complete coverage

G. Area temperature

1. Need for proper application temperatures
2. Temperatures of penetrant, parts, and atmosphere

H. Emulsifiers

1. Flow or dipping processes required
2. Precautions against penetrant removal

I. Safety precautions

1. Fire hazards
2. Flash and fire points of penetrants
3. Fumes
4. Eye and skin protection

IV. Washing

A. Coarse spray

1. Bombardment effects on surface
2. Need for controlled pressures
3. Volume control
4. Temperature control

B. Solid stream or dip

1. Less impact on surfaces
2. Greater coverage vs. time
3. Opportunity for soak

C. Liquid temperature
    1. Variations in room temperature
    2. Advantage of warm liquid

D. Black light check
    1. Need to have clean surfaces
    2. Fast inspection of surfaces
    3. Things to look for

V. Developer

A. Purpose of developers
    1. Application procedures
    2. Types of developers
    3. Actions of developers

B. Wet procedure
    1. Need for wet processes
    2. Similarity to penetrant processes

C. Drying time
    1. Draining time
    2. Drying temperature and time
    3. Air circulation at approximately 212 degrees F.
    4. Need for drying time control
    5. Actions of penetrant during drying

D. Dry procedure
    1. Need for drying after washing
    2. Application of dry powder
    3. Surface coverage requirements

E. Persistence characteristics
    1. Holding power of penetrant to discontinuity
    2. Capabilities of developers

VI. Inspection with black light

A. Procedures
    1. Need for sequential processes
    2. Prior need for white light
    3. Reflection angles of black light
    4. Need for movement of black light

B. Illumination levels

1. Proper types of equipment
2. Manufacturer's recommendations
3. Specification requirements

C. Black light filters

1. Need for proper filter
2. The angstrom unit and wavelength
3. Care of the filter

D. Black light intensities

1. The ultraviolet spectrum
2. Need for prior use of white light
3. The purple filter

Control blocks

1. Need for standards and references
2. Control blocks of different materials
3. Specification requirements
4. Shapes, sizes, and uses

F. Surface crack recognition

1. Surface inspection capability only
2. Crack characteristics
3. Types and shapes of cracks
4. Grain structure relationship to crack
5. Crack development
6. Crack orientation to stress patterns
7. The jagged edges (possible need for magnification)

G. Porosity at surfaces

1. Causes of porosity at surface
2. Recognition of the rounded edge depression
3. Quantity in given areas of surface
4. Relationship to stress patterns

H. Shut and seam recognition

1. The smooth and rounded edge type
2. The straight line seam
3. The nonfused areas of metal
4. Recognition characteristics

I. Machine marks

1. Recognition of the straight line
2. Depth factors
3. Edge characteristics
4. Pointed and dull marks
5. Similarities to other discontinuities

J. Post cleaning processes

1. Need for testing materials removal
2. Processes used in cleaning
3. The proper drying procedures

VII. Evaluation techniques

A. Need for standards

1. Comparison needs in accuracy
2. Known defects vs. the unknown
3. Specification requirements
4. Understanding of basic metallurgy
5. Understanding of nonmetal manufacture
6. Understanding of basic metals manufacture
7. Cognizance of discontinuity development
8. Realization of stress flow vs. load
9. Critical factors in surface stress

B. Appraisal of object inspected

1. Individual ability to appraise
2. Application of rules for acceptance
3. Causes for rejection
4. The point between acceptance and rejection
5. Acceptance of responsibility

CHAPTER IV

MAGNETIC PARTICLE TESTING

Magnetic particle testing is based on the principle of magnets and magnetization of ferromagnetic materials. When a ferromagnetic part has its molecules aligned in a single direction by magnetization, one end of the metal becomes a north pole while the other end becomes a south pole. Magnetic lines of force then flow from pole to pole by leaving one pole and completing the circuit through the surrounding air to the opposite pole. A flux pattern or group of magnetic lines of force then surrounds the magnet. It is on the basis relating to various aspects of the bar and circular shaped magnets that this method of nondestructive testing is conducted.

All metals cannot be magnetized; therefore, the magnetic particle test is reserved for those that are ferromagnetic. Most of the cast irons and steels however, which are used in manufacturing processes are subject to becoming magnetized when brought within the influence of magnetic flux fields. These metals have a high permeability factor. In this respect, the flux field develops a pattern about the magnet whereby surface and near surface tests can be made to determine the mechanical soundness of the surface metal. The technician then is concerned about the continuity of the metal; that is, an indication if solid metal exists which contains no flaws.

Principles of Testing

When a current flows through a conductor, magnetic lines of force are established at right angles to the current flow. According to the right hand rule in electricity, when a current carrying conductor is held in the right hand, the fingers point in the direction of flux flow when the thumb points in the direction of current flow. This rule governs the patterns of flux fields (concentrated magnetic lines of force) with respect to the geometrical shape of the conductor, whether the current flows through the part in a straight line or around it by means of a coil. Flux flow in the wire of a coil is 90 degrees to the flow of current and this results in a grouping of flux lines flowing longitudinally through the coil.

When a bar magnet is broken, several magnets are formed, each having a north and south pole. On the other hand, if a bar magnet is slightly cut at right angles to its axis, a north and south pole will be established at the cut in addition to the existing poles at each end. In other words, the break in the surface contour caused a flux field distortion around the bottom and sides of the break so that a flux leak existed. This leak produced the north-south pole arrangement because the flux field cut the break at 90 degrees. A longitudinal flux field was established when the flux flowed longitudinally through the part.

When a bar magnet is cut along its axis, [illegible] flux field flows parallel to the cut and has little opportunity in establishing a strong north-south pole relationship due to flux lines contacting the ends of the cut instead of the sides. Should the flux field be changed by 90 degrees, a strong north-south pole situation would then exist at the break.

Circular Field

Magnets are produced by surges of electrical current being either passed through the permeable metal or being passed around the metal. When the current flows through the part from end to end, a flux field is established at 90 degrees to the flow of current. The flux field is circular and circulates within and beyond the surface of the magnetized part. This circular technique is used in many ways in the search for discontinuities and other flaws within the metal. The circular flux field utilizes the head shot process. As long as the current flows, the flux field exists, but when the current ceases to flow, the flux field collapses so that most of the magnetic lines of force disappear and no magnetism remains. Appendix L illustrates some of these testing principles.

When two prods are used to allow current to flow through designated regions of a part, the flux field is established around each prod's contact point and within the metal. This circular flux pattern extends to the limits of energy which is governed by the amount of current flow.

Another circular flux field is established when a straight conductor carries a current within, but not in contact with, a hollow part. Current flow through the conductor causes flux lines to be established at 90 degrees to the current flow. Because the hollow part, a pipe or tube for example, exists within the flux pattern, a circular flux field is established within and also surrounding the part.

Longitudinal Field

Another technique is to allow the current to flow through a coil. Because the wire of the coil is no longer straight, but shaped into a helix, the flux field circulates from end to end so that the central portion of the coil is energized with magnetic lines of force. When a ferromagnetic part is inserted within the coil, a longitudinal flux field is established along the axis of the part. Again, the flux field is 90 degrees to the directional flow of current. A modified technique can be used by fabricating a "U" shaped magnet. When the part is placed between the poles, longitudinal flux lines also move along the axis of the part. Appendix L illustrates some of these principles.

Polar Environments

The magnetic particle testing process then utilizes circular and longitudinal techniques to cause changes in direction of flux flow on or near the surface of a metal. Whenever a discontinuity of metal (crack or inclusion) exists in the presence of a flux field, flux leakage will occur and a polar environment will be established. Should the discontinuity exist at approximately 45 degrees from the flux pattern, a weaker indication will be seen. Sometimes, a swinging magnetic field can be utilized to detect discontinuities which rest near the border line zones of circular and longitudinal testing capabilities.

Hard steels will retain magnetism while soft steels will lose it when the current ceases. Because permanent magnets are usually made from hardened steel, a continuous flux pattern surrounds the magnet. When magnetism is established in soft steels, the magnetism disappears when the flux field ceases. On the other hand, some metals have the residual ability to hold a molecular alignment while others have little retention capability. Because of this difference in some metals to retain magnetism, the magnetization process sometimes requires a continuous flow of current to retain the flux field. This continuous process applies particularly to soft metal. When harder metals are magnetized, a momentary surge of current often leaves a residual flux field. The use of hard metals eliminates the need for a continuous flow of current.

Current Use

Magnetization of metals is accomplished by both direct and alternating current. When direct current or pulsating direct current is used, a molecular alignment in the part to be tested quickly establishes a north-south pole arrangement. Any discontinuities on or near the surface of the part will immediately provide north and south poles because of the detouring and leaking flux field. When alternating current is used, the break in part contour at the surface will immediately establish alternating north and south poles at the break. The polar change will be synchroni with the frequency of the current. Geometry of the part, its condition, and location of flaws determine the type of current to use. Alternating current flows closer to the surface whereas direct current flows deeper. Neither current will suffice for testing deep regions within a metal. Defects on or near the part's surface however can be detected by the magnetic particle method.

Inspection Techniques

Even though north and south poles are established on a metal's surface because of discontinuities or surface irregularities, they cannot be detected without the assistance of a ferromagnetic powder. Because a magnet attracts an iron containing powder, a specially prepared iron powder is then spread across the entire surface of the part being tested, while the part is under the influence of a flux field. When the north-south pole situation occurs, the powder arranges itself at the flux leakage and tends to outline the shape of the flaw. The powder may be applied onto the part either dry or wet. The wet method uses a thin oil similar to kerosene as the vehicle for carrying the powder in suspension to the area of flux leakage. Obviously, operators must be positive that the testing medium covers the part in all areas and that both the circular and longitudinal techniques are used to assure the detection of unsatisfactory situations in any position within the metal.

Application of the testing medium to the surface of the magnetized part allows an experienced operator to inspect all surface areas for clues and indications of unsound metal. Magnetization by direct current will provide a pattern of closely held powder particles at the flux leakage or along the detouring flux path. Alternating current causes the particles to vibrate at the flaw due to the constant polar change. Should a fluorescent material be added to the testing powder, an increase in inspection capability is often produced when a black light is focused on the part's surface. The black light provides a greater color contra because of fluorescence while the flux leakage holds the powdery material in an outline form.

Equipment

Equipment for conducting the magnetic particle testing process is produced by several manufacturers. Some equipment is portable in order that field tests can be made, a welded pipeline for example. Other equipment is stationary and fairly fixed because of its bulk and weight. Also, this fixed process lends itself to automation and rapid production of inspected parts. Basically, a bench type arrangement is needed for holding the parts, for manipulation of the electrical contact mechanisms, and for holding the tanks containing the inspection liquid. This type of arrangement allows for ease of inspection. While the part is held between the electrical contact jaws of the machine and while the flux field exists, the inspection liquid is pumped onto the surfaces of the part. Any discontinuities at or near right angles to the flux field will be outlined by the magnetic powder within the liquid. Following this circular testing technique, the part is then placed within the flux field of the coil and subjected to longitudinal inspection. Appendix L represents a fixed testing and inspection installation and provides an illustration of the testing technique. According to this arrangement, both circular and longitudinal techniques can then be accomplished. In order that numerous other testing techniques can be performed, attachments and accessories are necessary.

Evaluation

Again, evaluation of the sight picture is necessary in order to determine serviceability of the part. A familiar knowledge of metallurgy is essential in order to form a decision. Should wrong judgement be made, serious consequences may result. As an example, if a small fatigue crack is evaluated as a tool mark, part failure and disaster will ultimately follow. Should human life be dependent on proper stress reaction in a metal, the metal must favorably react to the load when called upon or life may be endangered. Unsatisfactory discontinuities and irregularities found in the metal are cause for rejection.

Demagnetization

Following the inspection process, all parts are demagnetized by subjecting them to the vibrating and weakening flux fields of alternating current. Following demagnetization, parts are cleaned.

Saftey Precautions

The main safety precautions related to this testing process are associated with the fundamentals of electricity. Care must be exercised to prevent electrical shock and burn. In some instances, fumes from the inspection liquid are unhealthy. In addition, the liquid can often be a fire hazard.

Objectives

Objectives of the magnetic particle method of nondestructive testing are stated below.

I. The trainee should:

A. Understand the principles governing the magnetic particle testing and inspection process.

B. Be familiar with the various types of parts which are commonly tested by use of magnetic lines of force.

C. Be cognizant of the routine procedures involved in accomplishing the test.

D. Understand the requirements for a specific technique and be able to select the proper technique.

E. Understand the advantages and disadvantages of a specific test.

F. Comprehend the reason for surface and sub-surface indications.

II. The trainee will be able to:

A. Use typical equipment pertinent to magnetic particle testing.

B. Use the needed equipment attachments and accessories related to specific techniques.

C. Follow an authorized testing procedure.

D. Use circular and longitudinal techniques in searching for discontinuities.

E. Differentiate among the several discontinuity patterns at the surface.

F. Evaluate a sub-surface indication.

G. Analyze specific and total inspection results.

H. Evaluate the total inspection situation.

I. Accept or reject the individual indications.

Outline of Key Points

I. Equipment

   A. Operator's ability to use

      1. Understanding of test principles
      2. Knowledge of test purposes
      3. Types of equipment and functions
      4. Attachments and accessories
      5. Exercises in use of equipment

   B. Portable type

      1. Reason for portable equipment
      2. Capabilities of portable types
      3. Similarity to stationary equipment
      4. Need for increased capabilities

   C. Stationary type

      1. Capability to handle large and heavy parts
      2. Flexibility in use
      3. Need for stationary types
      4. Automation needs
      5. Use of accessories and attachments

   D. Automatic type

      1. Requirements for automation
      2. The flow process
      3. Sequential operations
      4. Setting of tolerances
      5. Control and operation factors
      6. Alarm and rejection mechanisms

   E. Liquids and powders

      1. Liquid requirements as a vehicle
      2. Viscosity and flash points
      3. Safety precautions
      4. Temperature needs
      5. Flow mechanisms
      6. Powder and paste contents
      7. Mixing procedures
      8. Need for accurate proportions
      9. Actions of the powders and dyes

F. Black light type

1. Black light and fluorescence
2. Fluorescent material in the liquid
3. Visible and black light comparisons
4. Requirements in the testing cycle
5. Techniques in use

G. Light sensitive instruments

1. Need for instrumentation
2. Light characteristics

II. Principles and purposes

A. Theory of magnetism

1. Ferromagnetic materials
2. Crystalline nature of metals
3. Permeability factors in metal
4. Alpha and gamma iron
5. Molecular alignments
6. North-south polar effects
7. Flux patterns
8. Induced electricity
9. Alternating and direct currents
10. Frequency and voltage factors
11. Current calculations and needs

B. Purpose of magnetic fields

1. The magnetic line of force
2. Bending of force fields
3. Direction of travel of the field
4. Flux line concentrations
5. Polar requirements
6. Surface flux strength
7. Sub-surface effects

C. Ferromagnetic materials

1. The permeability factor and influence
2. Body-centered cubic iron
3. Wrought irons
4. Steels - magnetic vs. the nonmagnetic
5. Cast irons
6. Temperature of part limits for testing

D. Magnets and magnetism

1. The basis for magnetism
2. North and south poles

   3. Current flow and flux fields
   4. Distance factors vs. strength of flux
   5. Attraction properties of opposite poles
   6. Internal and external flux patterns
   7. Phenomenon action at the discontinuity
   8. Permanent and temporary magnets
   9. Heat effects on magnetism
   10. Material hardness vs. magnetic retention

E. Dry method

   1. Need for dry method processes
   2. Procedures
   3. Types of dry powders
   4. Surface irregularities, flux, and powder

F. Wet method

   1. Need for wet procedures in testing
   2. Procedures
   3. Liquid vehicle and the paste or powder
   4. Application processes
   5. Liquid flow with the powder
   6. Liquid contact in presence of flux

G. Filtered particle

   1. Relationship to conventional tests
   2. Need for test

III. Flux fields

A. Rules of field

   1. Right hand rule
   2. Current flow and flow pattern
   3. Density of field
   4. Distance factors

B. Direct current

   1. The steady flux field
   2. Directional patterns
   3. Depth or penetration factors
   4. Polar effects
   5. Source of current

C. Direct pulsating current

   1. Similarity to direct
   2. Source of current production

3. The pulsating factor
4. Advantages
5. Typical fields

D. Alternating current

1. Polar effects
2. Cyclic effects
3. Surface strength characteristics
4. Safety precautions
5. Voltage and current factors
6. Source of current

E. Bar magnet principles

1. Induced flux patterns
2. Internal current flow
3. External current flow
4. Straight and curved magnets
5. Flux strength
6. D.C. - A.C. influences on poles
7. Distance and strength factors
8. Residual magnetism
9. Discontinuity effects

F. Ring magnet principles

1. The internal flux pattern
2. Surface discontinuity effects
3. Field strengths
4. The induced field

G. Continuous field

1. Life of continuous field
2. Source of field
3. Need for continuous field
4. Characteristics of field
5. Strength patterns

H. Residual field

1. Retention characteristics
2. Retention problems
3. Disadvantages and advantages
4. Need for residual field
5. Strength of field
6. Procedures involved with field

I. Swinging field

1. The changing flux pattern
2. Need for swinging field

3. Polar effects
4. Comparison with stationary field

J. Length-diameter ratios

1. Dimensional understanding
2. Current characteristics
3. Efficiency

K. Meters and strength of field

1. Flux measurements
2. Current and voltage factors
3. Frequency effects
4. Need for instruments

IV. Surface discontinuities

A. Cleaning processes

1. Need for surface cleaning
2. Types of cleaners
3. Cleaning procedures
4. Safety precautions
5. Fire hazards
6. Fumes

B. North-south pole factors

1. Need for opposite poles
2. Characteristics of pole flux
3. Flux patterns and strengths
4. Directional factors
5. Surface and sub-surface factors

C. Crack types

1. Metallurgical basis
2. Casting effects
3. Heat treating effects
4. Fabrication process effects
5. Grinding and welding effects
6. Fatigue effects
7. The jagged pattern
8. Relationship of part history to crack

D. Laps, seams, and pits

1. The surface characteristics
2. Straight line factors of the seam
3. Forging and rolling irregularities

4. The casting or welding irregularities
5. Discontinuity patterns

E. Machine marks

1. Contrast to the discontinuity
2. Depth vs. discontinuity similarity
3. Types of marks - from sliding and whirling tools
4. Recognition factors

F. Geometric effects

1. Geometry of the part
2. Mass of material under flux influence
3. Depth characteristics of flux
4. Depth of discontinuity recognition
5. Solid and hollow objects
6. Square and cubical shapes
7. Rounded and rectangular shapes
8. Wire
9. Nonsymmetrical shapes

Surface defects

A. Surface indications

1. Particle concentrations
2. Patterns of particle concentration
3. Directional properties of indications
4. Strong vs. weak patterns
5. Part's geometry effects
6. Discontinuity orientation to flux field
7. Sub-surface indications

B. Holes and porosity

1. Round ended indications
2. Circular patterns with strong centers

C. Metallic discontinuities

1. Metallic separations
2. Voids - holes and cracks
3. Inclusions - chemistry
4. Orientation to flux field
5. Shape of discontinuity

D. Depth from surface relationships

1. Field strength decrease in depth
2. Pattern strengths at surface
3. Indications not open to surface
4. Strength and distance relationship

VI. Circular techniques

A. Procedures

1. Principles of flux flow
2. Current calculations
3. Depth factor considerations
4. Proper contact
5. Precautions - safety
6. Precautions - overheating

B. Right hand rule and flaws

1. Current flow and flux pattern
2. Application of powder or liquid
3. Intensity of flux patterns
4. Direct and indirect current indications
5. Continuous flux
6. Residual flux
7. Part orientation vs. flux patterns
8. Discontinuity indications
9. Flaw identification

C. End-to-end current conduction

1. Part geometry considerations
2. Suitability of contact points
3. Types of discontinuities detected
4. Significance of weak indications
5. Current factors
6. Need for accessories and attachments

D. Contact plates

1. Contact surfaces required
2. Adequacy of current conduction
3. Special shapes and needs

E. Contact prods and yokes

1. Requirements for prods and yokes
2. Current carrying capabilities
3. Cables and attachments
4. Shapes and sizes

F. Current calculations

1. Formulas
2. Current needs
3. Types of current needed

G. Overheating precautions

1. Characteristics of different currents
2. Size of part vs. current need
3. Current saturation
4. Consequences of metal heating

H. Types of irregularities

1. The internal discontinuity
2. The surface discontinuity
3. Theory of discontinuity development
4. Rounded or jagged shaped
5. Long and continuous types

VII. Longitudinal technique

A. Procedures

1. Patterns of flux fields
2. Strength of fields
3. Induced fields
4. Types of discontinuities detected
5. External current flow
6. Shapes and sizes of coils
7. Application of liquid or powder in influence of flux field

B. External flow of current

1. Principles of induced flux fields
2. Geometry of part to be inspected
3. Theory of discontinuity interception

C. Use of coils and cables

1. Current directional flow vs. flux field
2. Strength of field
3. Ampere turns of cable
4. Shapes, sizes, and current capacities

D. Current calculations

1. Formulas
2. Types of current required
3. Current demand

E. Types of irregularities

1. Discontinuities across the axis
2. Voids and inclusions

    3. Shapes, patterns, and orientation
    4. Flux flow and bending

  F. Demagnetization procedures

    1. Need for demagnetization of parts
    2. Current frequency attack on molecular orientation
    3. Heat factors and precautions
    4. Need for collapsing flux fields
    5. Cleaning of parts

VIII. Evaluation techniques

  A. Use of standards

    1. Need for standards and references
    2. Measurement of known with unknown
    3. Specifications and certifications
    4. Employment of locally made standards
    5. Comparison techniques

  B. Defect appraisal

    1. History of part
    2. Manufacturing process
    3. Possible causes for defect
    4. Use of part
    5. Stress reaction capabilities
    6. Acceptance and rejection criteria
    7. Use of tolerances

CHAPTER V

EDDY CURRENT TESTING

Eddy current testing is a recent type of nondestructive test in which an alternating electric current is used to induce a secondary current into a conductor. This induced current is provided by a coil of wire. Because the alternating current reverses its directional flow in the coil with the frequency, the electromagnetic flux patterns and induced currents in the conductor also reverse. In effect, a moving path of induced electrical currents exists within the conductor as long as the influence of the primary effects of the [illegible] xist. When the conductor becomes the part to be tes [illegible] a testing situation is established. Eddy current density is proportional to the coil's magnetic field.

As in other nondestructive testing processes, the test seeks the presence of some type of discontinuity in a material. Although eddy current may be used to determine material thickness and to find some mechanical properties, the primary purpose of its use for material soundness is the detection of discontinuities. Eddy current testing equipment, more than any other type of nondestructive testing equipment, must be especially fabricated to suit the particular test situation. Because many variables exist in eddy current testing which influence the outcome of the test, special consideration must be given to the control and or isolation of these variables. Therefore, the test is reserved for a more restricted type of investigation.

Principles of the Test

When a test coil is energized with an alternating current, flux patterns form about the coil. If the coil is moved in close proximity to a material which provides a flow of electricity, a movement of free electrons in the material will immediately establish a circulating type of organized path. The direction of this path of oscillating electrons is determined by the shape and type of test coil; however, the current flow is parallel to the surface. When the atomic lattice of the material being tested is orderly, no scattering of electrons occurs from the influence of eddy current, but when an unorganized lattice exists (a discontinuity), scattering of certain electrons occurs. In turn, this scattering or opposition from the test part to the test coil's magnetic field occurs and is detectable with proper instrumentation.

The depth of penetration of eddy current flow is governed by the conductivity of the material being tested and the frequency of the test coil. The depth of penetration or distribution of eddy current flow increases as frequency is lowered, within limits, and decreases as frequency is increased. This is a general rule because other factors help to influence the net result of distribution such as the closeness of coil to the part (coupling) and magnetic (permeability) properties of the material. Magnetic materials cause a decrease in penetration.

The heart of the eddy current test system is the test coil. The wire in the coil has a resistance to a flow of electric current and when the wire is formed into a coil, an additional factor is introduced within and around the coil. This total electromagnetic factor or impedance provides the basis for a common testing technique.

From the coil, induction of eddy current in the part results. Because the part to be tested may exist in any shape, condition, and size, test coils also require fabrication in a shape and size commensurate with the part's geometry. Basically, the test coil is an extension of the electronic system for purposes of investigating specific volumes of material. Because eddy currents in the part being tested cause flux lines which oppose the coil's flux lines, an effective electromagnetic value results in the test coil.

Testing Techniques

For discontinuity detection when using eddy currents, the searching coil must be closely associated with the part to be tested; that is, the test coil is either inside the part, around the part, or on the part's surface. Appendix M illustrates some of these principles. As coupling of the part to the coil increases, strength of eddy current increases; therefore, coils are manufactured to suit the specific geometry of the part. Eddy currents flow in the direction of the coil's windings. If the coil is placed in a hole or a cylinder, eddy currents circulate around the inside surface of the part. If the coil surrounds the part, eddy currents flow around the perimeter of the part. If the coil is placed against the part, eddy currents flow at and near the surface under the constant influence of the coil. Another technique is accomplished with the use of a gap probe coil. In this procedure, a north-south pole relationship exists on the face of the coil. Eddy currents are then induced when the part is placed within the flux field of the coil.

Types of Tests

The common types of eddy current tests are impedance, modulation, and phase analysis. Impedance testing uses a static situation for the test while the other types of testing become involved with complexities, such as moving parts or interpretation of phase changes as displayed on the oscilloscope. In the impedance test, voltage, amperage, and impedance provide the basic situation within the coil for the test when the coil's frequency induces eddy currents in the material. Impedance testing is based on total change occurring in the impedance of a test coil. Appendix M shows a schematic arrangement of an impedance coil and its relationship to the voltage and current factors.

Specific procedures for conducting an eddy current test depend on the technique to be used and a means for controlling variables. As an example, magnetic material requires saturation with direct current to prevent flux change, as a result of the direct current, in the part while testing is being conducted. In this situation, the impedance coil is frequently placed between direct current coils. Another factor to be considered is the shallow depth of eddy current penetration. Penetrations in excess of three-eights inch are not common; consequently, thick materials are reserved for other types of testing. Also, because eddy currents flow at or near the surface, center portions of a part are not influenced during the test. As depth of penetration increases, eddy currents become weaker and are less effective in carrying out their function. Further, density of eddy current increases as coupling distance is decreased. Eddy current test equipment is shown in Appendix N.

Need for References

In order to perform an eddy current test, some means should be available for establishing a standard or reference. Reference blocks with known defects can be used. If the eddy current equipment is adjusted to the reaction of a defective specimen, the test coil will then have a reference for comparison. Or, if the test coil is adjusted to a homogeneous material, the test coil will also have this sound material as a reference when a discontinuity is detected. The reference may be part of the material being tested or it may be separate.

Reference blocks assist in locating flaws, irregularities, and discontinuities.

Eddy Current Characteristics

Eddy currents have properties of a compressible fluid in that they bend and compress about a discontinuity. When a discontinuity disturbs the path of a circulating eddy current, the path will divide, detour around the flaw, and then join together again in a pattern. The discontinuity therefore impedes the eddy current flow. Density of current fluxuations are then detected and relayed to an indicator. Much of the impedance testing equipment includes meters and scales for flaw indication. Howeve the oscilloscope is used frequently in other testing techniques such as in phase analysis. The part to be tested has an influence on phase changes as well as on impedance in the test coil as shown by the difference in current and voltage factors. Phase differences are displayed on the oscilloscope's screen. Basically, the conductivity variable is separated from the dimensional and permeability variables when using this technique. Three common techniques in this area include linear time-base, ellipse, and vector point.

In modulation analysis testing, more variables can be separated than by impedance and phase analysis techniques. The presence of a discontinuity in the test coil's field modulates the field. Because the test part is moving through the field, static testing is not performed. The discontinuity's frequency of modulation depends on transit time through the magnetic field of the coil. Indication of changes are then relayed to some type of indicating or marking device.

Eddy Current in Automation

Eddy current testing techniques support automation in many excellent ways. Fast moving steel sheets, for example, can be constantly monitored for thickness. Deviations in tolerances immediately provide marked areas on the metal sheet where measurement deviation occurred. Also, automatic alarms are sounded when unsatisfactory situations occur within the material being tested and inspected.

Safety Precautions

Because eddy current testing involves the use of electricity, safety precautions to prevent [illegible] are recommended.

Objectives

Objectives of the eddy current method of nondestructive testing are stated below.

I. <u>The trainee should</u>:

A. Understand the principles governing the eddy current testing and inspection process.

B. Be familiar with the various types of parts which are commonly tested with eddy current.

C. Be aware of the routine procedures involved in accomplishing the test.

D. Understand the requirements for a specific nique and be able to select the proper technique.

E. Understand the advantages, limitations, and disadvantages of the test.

F. Understand the forces causing meter indications.

II. <u>The trainee will be able to</u>:

A. Use typical equipment pertinent to eddy current procedures.

B. Use needed attachments and accessories perculiar to a specific technique.

C. Follow an authorized testing procedure.

D. Use the several types of eddy current testing techniques in accordance with the situation.

E. Differentiate among the several discontinuity patterns, realizing the limited depth characteristics of the test.

F. Analyze the total inspection situation.

G. Evaluate the total inspection situation.

H. Accept or reject the individual indications.

Outline of Key Points

I. Equipment

  A. Operator's ability to use

    1. Understanding of test principles
    2. Knowledge of material to be tested
    3. Familiarization with types of equipment
    4. Functions of equipment
    5. Experience in use of equipment
    6. Safety precautions
    7. Understanding of basic electronics

  B. Purpose of various types

    1. Types of eddy current tests
    2. Principles of tests
    3. Equipment to match the test
    4. Permeability and non-permeability factors

  C. Automatic equipment

    1. Purpose of automation
    2. Speed of tests
    3. Alarms and rejection mechanisms
    4. Simplicity and sophistication of automation
    5. Rapid production possibilities

  D. Design characteristics

    1. Ease of design to fit need
    2. Flexibility of coil adaptation
    3. Testing capabilities and potentials

  E. Indicators and meters

    1. Direct and indirect indications of discontinuities
    2. Oscilloscope and CRT
    3. Scales and direct reading instruments

II. Test coil arrangements

  A. Feed through

    1. Geometry of part vs. geometry of coil
    2. Shapes and sizes of coils

3. Purpose of feeding through
4. Speed capabilities for testing

B. Inside test

1. Geometry of part vs. geometry of coil
2. Design of coils
3. Purpose of inside test
4. Principles of inside test
5. Comparison with feed through

C. Probe

1. Need for probes
2. Length-diameter part factors
3. Probe capabilities

D. Forked

1. Need for forks
2. Part geometry

E. Other shapes and sizes

1. Need for increased capabilities
2. Design potentials
3. Increased automation potentials

III. Impedance Plane Response

A. Feed back

1. Inductance and resistance ratios
2. Self-excited circuits
3. Energy losses
4. Oscillator circuit and voltage
5. Energy loss effects

B. Reactance

1. Permeability variations
2. Frequency ratios
3. Specimen diameter variations
4. Frequency response limitations
5. Oppositions to current flow
6. Reactive components

C. Magnitude

1. Test and limit frequencies
2. Discontinuity variations

3. Surface cracks effects
4. Oscillation frequency influences

D. Vector analyses

1. Voltage variations due to specimen in coil
2. Horizontal and vertical deflection voltages
3. Phase angle
4. Characteristics of resultant pattern
5. Specimen discontinuity influences
6. Amplitude and phase values

E. Effects suppression

1. Influence of diameter variations
2. Optimum frequencies
3. Differences in ferrous and nonferrous materials
4. Effective permeability

F. Cathode ray

1. Vertical and horizontal factors
2. Specimen waveform
3. Slit values
4. Straight line and ripple effects
5. Screen displays

G. Linear time base

1. Fundamental frequencies
2. Mixed frequency effects
3. Amplitude
4. Phase shifts
5. Absolute values and the test coil
6. Wave signals
7. Linear sweep
8. Dimensional variations

IV. Eddy current principles

A. Principles of eddy current

1. Induced circulating electrical current
2. Surface parallel travel
3. Density decreases in penetration
4. Variables problems
5. Coil relationships
6. Frequency effects

B. Alternating current field

1. Build up and collapse of flux fields
2. Frequency spread
3. Coil shape effects
4. Frequency and depth density factors
5. Coil reactions

C. Empty coil voltage

1. Magnetic lines of force
2. Flux density
3. Current magnitude
4. Basic voltage
5. Insertion effects on voltage

D. Object influence in coil

1. Coils magnetizing force
2. Magnetic and nonmagnetic materials
3. Part's electrical conductivity
4. Primary-secondary coil relationships

E. Primary coil characteristics

1. Basis for flux field
2. Coil shape, size, and current flow
3. Coil purpose
4. Eddy current flow
5. Permeability factors

F. Secondary coil characteristics

1. Relationship to primary coil
2. The induced flux pattern
3. Residual effects in ferrous and nonferrous metals
4. Rules of current and flux flow
5. The coupling factor and its importance
6. The outside and inside coil relationships
7. Relationships to reference and standards
8. Variable effects
9. Meter readings

G. Coupling factors

1. Purpose of the couple
2. Distance and strength factors
3. Geometry of part and coil
4. Flux direction
5. Relationship to type of coil
6. Permeability factor

H. Signal-noise ratio

1. Impedance and voltage plane
2. Control of voltages
3. Signal direction
4. Conductivity and discontinuity effects

I. Choice of coil

1. Part geometry
2. Coupling distances
3. Use of coil
4. Frequency and inspection speed
5. Design criteria

J. Circular direction characteristics

1. Inside and outside coil purposes
2. Probes and forks
3. Part geometry and frequency penetration
4. Eddy current density
5. Diameter of flux and current patterns
6. Strength needs
7. Materials conductivity
8. Discontinuity effects
9. Variable control

K. Surface to center factors

1. Characteristics of alternating current
2. Frequency effects in depth
3. Surface maximums to center minimums
4. Orientation of discontinuity relationships
5. Standards and calibration
6. References

L. Constants

1. Analysis of variables
2. Artificial and natural factors
3. Known factors as basis
4. Comparison techniques
5. The complete coil environment

M. Amplitude and phase angle

1. Waveform and adjustment
2. Vectors
3. Hysteresis
4. Phase changes
5. CRT screen displays
6. Voltage factors

N. Depth penetration

1. Material resistance to eddy current
2. Conductivity constants
3. Geometry and the flux pattern
4. Need to know depth of penetration
5. Sub-surface effects are weak
6. High frequencies and shallow penetration
7. Shallow penetration
8. Technique partially controlled by depth factor

O. Temperature compensation

1. Frequency requirements and ratios
2. Temperature coefficients of expansion
3. Variations in part diameter
4. Heating effects and inductance

V. Impedance

A. Impedance changes

1. Chemistry of part and impedance effects
2. Coil oppositions to current flow
3. Straight wire and coiled wire comparisons
4. Current flow
5. Voltage, current, and impedance relationships
6. Part's constants influence coil impedance

B. Circuit arrangements

1. Comparison techniques
2. Standard and reference areas
3. Coupling relationships
4. Magnetic fields of the coils
5. Frequency vs. impedance
6. Lift off and fill effects

C. Variation of object arrangement

1. Field relationship to part
2. Impedance effects
3. Secondary coil arrangements
4. Coil output and part variables

D. Properties of test object

1. Reference and part compared
2. Primary-secondary coil arrangement
3. Field intensities
4. Coupling significance
5. Discontinuity detection techniques

E. Coil - object characteristics

   1. Voltage influence from reference
   2. Voltage influence from part
   3. Equal reference and part properties produce no voltage
   4. Discontinuity in part changes voltage
   5. Impedance changes

VI. Permeability

A. Fundamentals

   1. Magnetic lines of force
   2. The flux field
   3. Ratio of coil force to part flux density
   4. Flux strength variable effects
   5. Molecular relationship to domain
   6. Ferrous (magnetic) and nonmagnetic metals
   7. Alignment factors in magnetic domain
   8. Saturation magnetic points by direct current
   9. Residual magnetism
   10. Coercive forces in opposite directions of field
   11. Hysteresis
   12. Ferromagnetic metals and permeability

B. Ferromagnetic objects

   1. The alpha molecular arrangement
   2. Molecular magnetic alignment
   3. Iron base and ease of magnetism
   4. Irons, steels, and cast irons
   5. Hardness of part factors
   6. Residual magnetism

C. Nonferromagnetic objects

   1. Relative differences with ferromagnetic
   2. Hysteresis facts in nonmagnetic materials
   3. Lack of quantity of residual magnetism
   4. Mechanical properties influence permeability

D. Selection of frequency

   1. Relationship to velocity, permeability, and conductivity
   2. Electromagnetic waves
   3. Wave speeds and discontinuity data

VII. Field strength

A. Strength factors

1. Coupling distance
2. Frequency and depth effects
3. Coil types, shapes, and current flow
4. Part composition and conductivit

B. Distribution and penetration

1. Internal and external coils
2. Primary and secondary coils
3. Eddy current and inductance
4. Permeability
5. Frequency and conductivity
6. Discontinuity orientation
7. Skin effect of alternating current

C. Internal and external coils

1. Part's geometry
2. Encircling coils; part inside
3. Inside coil; part outside
4. Probes for holes, pipe, and tube
5. Relationship with references

VIII. Test indications

A. Conductivity

1. Material's molecular condition
2. Electron flow capability
3. The International Annealed Copper Standards
4. IACS standards and comparison techniques
5. Constants vs. chemistry
6. Calibration factors

B. Comparator

1. Relationships of part to standard
2. Chemical and mechanical properties
3. Calibration requirements
4. Specifications

C. Hysteresis

1. The hysteresis loop
2. The horizontal and vertical axes
3. Reversing magnetic fields
4. Residual magnetism and saturation
5. Material magnetic characteristics
6. Loop shapes and sizes
7. Sight pictures on the CRT

IX. Test object and circuitry

A. Geometry of shape

1. Cast parts and chemistry
2. Wrought parts; chemistry and mechanical properties
3. Hollow and solid parts
4. Symmetrical and nonsymmetrical parts
5. Ferrous and nonferrous parts
6. Dimensional ratios

B. Cylinder test

1. Part's shape, material, and dimensions
2. Test frequencies required
3. Permeability factors
4. Fill factors and the coil
5. Conductivity
6. Field strengths and distribution
7. Coil requirements
8. Testing techniques
9. Discontinuity detection
10. Instrumentation

C. Tube tests

1. Dimensions and compositions
2. Wall thickness and length
3. Conductivity and permeability
4. Solid and hollow parts relationships
5. Voltage factors
6. Frequency scales
7. Discontinuity locations; inside and outside

D. Sphere test

1. Part geometry and end effects
2. Conductivity and permeability effects
3. Symmetrical factors of geometry
4. Limit frequencies
5. Voltages
6. Secondary coil reactions
7. Discontinuity detection

E. Sheet test

1. Primary and secondary coil arrangements
2. Arrangements for fast production
3. Forked coils
4. Basic constants and variables

5. Sheet insertion into coil effects
6. Discontinuity detection

X. Irregularity recognition

A. Flaw detection and identification

1. Application of principles of the test
2. Coil relationship to part
3. Flaw orientation in part
4. Part geometry and dimensions
5. Compression and bending abilities of eddy currents
6. Coil reactions
7. Instrumentation

B. Mechanical properties of object

1. Eddy current capabilities
2. Types of mechanical properties
3. Calibration and standards
4. Principles of constants and variables
5. Identification techniques

XI. Evaluation techniques

A. Use of standards

1. Requirements for reference and standards
2. Specifications
3. National standards and local standards
4. Types, shapes, and sizes
5. Comparison techniques
6. Acceptable and unacceptable parts
7. Acceptance and rejection criteria

B. Appraisal of object

1. History of object
2. Use of object or part
3. Loading factors
4. Stress reaction capabilities
5. Safety factors in design
6. Type of discontinuity and size or shape
7. Acceptance or rejection

CHAPTER VI

ULTRASONIC TESTING

One of the most sophisticated methods used in nondestructive testing is the ultrasonic test. Because sound waves of exceptionally high frequencies are beamed into materials of different densities and elasticities and of different shapes, complicated equipment is often required to perform the test. Many techniques are used in the search processes because of the numerous variables encountered. The ultrasonic beam is commonly pulsed into the test specimen at frequencies in excess of 18,000 cycles per second. Cycles below this frequency may be detected by the human ear; consequently, those higher than 18,000 are called ultrasonic. The usual testing scale runs from 20,000 to 25,000,000 cycles per second.

The ultrasonic test is becoming more useful because discontinuities existing at the surface of the test specimen or those resting deep within the specimen can be identified through the numerous combinations of inspection techniques. Because the flaw may be oriented in any direction relative to the path of the penetrating sound beam, certain principles must be understood prior to the search. The principle of the pulse-echo system, for example, is based on reflected sound from pulsating energy.

Principles of the Test

An examination of these principles can be performed with illustrations involved in the use of the pulse-echo type unit. Although each manufacturer designs equipment to his particular specifications, similar circuitry exists in many models. Basically, there is a power supply with controls, a transducer, a couplant, an electrical pulser generator and receiver, and a display for visual image including some type of timer for the pulser. A typical ultrasonic testing unit is shown in Appendix O.

In order for the ultrasonic wave to penetrate a material, there must be a means for converting high frequency electrical impulses into mechanical vibrations. This conversion is accomplished by means of a transducer. One of the most common types of transducer materials used in obtaining this energy conversion is the quartz crystal, usually cut on the X axis. This crystal has piezoelectrical properties; that is, the ability to transform electrical impulses into mechanical vibrations and in turn, the ability to receive these vibrations as a signal and change them back into electrical energy. Appendix P illustrates how the transducer is placed against the test specimen in preparation for an ultrasonic test. Energy is also converted by other transducer materials. These materials include ceramics and lithium sulfate. The ceramic transducer, lead zirconate titanate for example, is an excellent transmitter of sound energy while lithium sulfate is an excellent receiver.

Testing Techniques

Contact between the transducer and the test material is essential in order that signals will be transmitted. Good contact materials include grease, oil, and water. The use of one of these materials acts as a couplant or connector between the transducer and the test material and assures proper functioning of the transducer. The transducer is used in both contact testing and immersion testing.

The generation of high energy bursts of electrical energy come from a thyratron tube which is governed by a timer for timing the pulses. Because materials vary in density and in elastic properties, the wave's speed or velocity of travel through the material is predetermined. Volume or intensity of the wave determines the maximum distance of vibrations. As the amplitude changes, the vibrations in the material become more pronounced because amplitude is the highest point of the wave and relates to strength of the impulse.

Ultrasonic waves pulse through materials at different frequencies. When greater depth of penetration within the material is required, the lower frequencies are used. However, low frequencies do not always detect the discontinuity. When small discontinuities exist within the test specimen, higher frequencies are needed to identify them, but penetration is shallow. The wave frequency acts as a ripple moving into the material. The sound wave compresses matter ahead of its movement and leaves a less dense area behind it. This ripple or succession of molecular movements occurs as a stretch away from the energy pulse and then as a quick return. The lattice network of the material acts as a barrier to energy penetration. When struck by a burst of energy, the line of atoms moves beckwards from a fixed position and releases the impact to the next line and so on in ripple form. The elastic nature of the material's molecules then establishes this tolerance of the shifting action.

When ultrasonic waves are beamed into a homogeneous material, they move in the direction of the beam's path until a material differential is contacted or until attenuation occurs. Collision with the opposite side of the homogeneous material (material differential) causes the wave to bounce or reflect back to the transducer. Collision with a discontinuity causes part or all of the wave to reflect back into the transducer. When a receiver transducer is used in addition to a transmitting transducer (through transmission), a loss of energy is indicated when a discontinuity is contacted. Energy pulses are then relayed to the display unit once they enter a material.

Signal Characteristics

One of the most universal devices used in the display of pulsating energy is the oscilloscope. Because the oscilloscope is part of the electronic circuitry, a quick and accurate visual presentation of the wave's actions is shown.

Appendix Q illustrates the presence of a discontinuity in the test specimen. The three pips shown on the screen of the oscilloscope indicate the initial pulse, the discontinuity, and the material's back side reflection. When time becomes a measured distance along the base line of the viewing screen, location of discontinuities is established.

The presence of discontinuities in a material is unknown until a test is made. Because discontinuities may rest at any angle relative to the ultrasonic beam's path, several searching processes are usually used. When the beam is directed into the material at 90 degrees from the material's surface, a longitudinal beam searches the mass of material. A discontinuity existing within the beam's path acts as a barrier to further penetration and beam energy is reflected back to the transducer when the pulse-echo process is used. When the discontinuity rests in a plane parallel to the beam's path, little indication of a discontinuity is reflected; therefore, a different process should be used to better identify the flaw. If the transducer is oriented at an angle other than 90 degrees from the material's surface, a transverse or shear wave will be beamed into the material at an angle from the longitudinal path. Shear waves move slower through material than longitudinal waves, but are very effective in locating discontinuities beyond the capability of the longitudinal search. Should the discontinuity be close to the material's surface or be open to the surface, a surface wave can be made to ripple across the material by adjusting the transducer to a steeper angle. The wave may be a lamb or Rayleigh.

The Search Process

An organized coverage of the material's surface is necessary to assure accuracy of the search. Several scanning processes are used such as the A, B, and C scans. An important factor however, associated with the scan is that all areas of the material be searched. A succession of straight line passes at intervals across the material provides uniform scanning and may be accomplished manually by the contact process or with automation in which immersion techniques are used.

By varying the searching techniques, the ultrasonic testing and inspection process may be used to locate discontinuities in any area of the material. The geometry of the material's shape, the manufacturing process, the chemical analysis of the material, and other factors such as stress, necessitate a proper plan of search to assure a valid evaluation of the condition of the material.

Testing equipment is available for many different testing techniques. Due to the high cost of some models of ultrasonic equipment, consideration should be given to the types of inspection processes needed. In order that this equipment be calibrated for proper testing techniques, special standards or reference blocks are used. These refer-being available from the American Society for Testing and Materials.

Safety Precautions

Because electricity is the initial source of energy used in ultrasonic testing, safety precautions pertinent to electrical apparatus must be observed.

Objectives

Objectives of the ultrasonic method of nondestructive testing are stated below.

I. <u>The trainee should</u>:

A. Understand the principles governing the ultrasonic testing and inspection process.

B. Be familiar with the various types of parts which are commonly tested with ultrasonics.

C. Be aware of the routine procedures involved in completing the test.

D. Understand the requirements for a specific test and be able to select the proper test.

E. Understand the advantages and disadvantages of the test.

F. Understand the forces causing meter indications.

II. <u>The trainee will be able to</u>:

A. Use typical equipment pertinent to ultrasonic testing.

B. Use the several scan systems.

C. Follow authorized testing procedures.

D. Use the longitudinal, shear, lamb, and Rayleigh wave techniques.

E. Use the contact and immersion techniques.

F. Differentiate among the several discontinuity indications.

G. Analyze the specific and total situation.

H. Evaluate the total situation.

I. Accept or reject the specific indications.

Outline of Key Points

I. Equipment categories

- A. Operator's ability to use
    1. Purposes and principles of equipment types
    2. Functions of equipment
    3. Variations to suit needs
    4. Safety precautions
    5. Experience in using equipment
- B. Purposes of different equipment
    1. Particular needs for inspection
    2. Types and shapes of parts
- C. Amplitude and through energy transmission types
    1. Discontinuity and beam interception
    2. Continuous
    3. Pulsed
    4. Modulated
    5. Frequency
- D. Amplitude and transit time type
    1. Signal amplitude
    2. Discontinuity location and distance
    3. Elapsed time
    4. Frequency, phasing, and pulsing
- E. Transducer loading factors
    1. Specimen thickness and resonance
    2. Resonance and impedance
- F. Design requirements
    1. Inspection needs
    2. Size, shape, and symmetry of part
    3. Speed of test requirements

II. Equipment functions

- A. Frequency modulation
    1. Limitations in testing techniques
    2. Special applications

B. Continuous oscillator

  1. Need for this function
  2. Comparison to other types

C. Time pulsed

  1. Source of electrical energy
  2. Pulsating mechanism
  3. Echo and elapsed time factors
  4. Signal (discontinuity) receipt
  5. CRT display

D. Modulated oscillator

  1. Comparison with other units
  2. Need for this system

E. Resonance

  1. Frequency modulations
  2. Material thickness measurements

F. A-scan system

  1. Cathode ray tube display
  2. Time-distance-linear factor
  3. Discontinuity indication
  4. Back side reflection
  5. Signal amplitude
  6. Velocity factors
  7. Reflected intensity and discontinuity
  8. Location and size of discontinuity

G. B-scan system

  1. Modified A-scan search
  2. Interception factors and screen display
  3. Longer viewing time to study discontinuity

H. C-scan system

  1. Visual and written presentations
  2. Depth problem
  3. Two dimensional display of discontinuity
  4. Includes features of the A-scan

I. Bridges

  1. Manipulation devices
  2. Circuit patterns

3. Balancing media
4. Signal and adjustment capabilities

III. Test systems

A. Through transmission

1. Amplitude relation to discontinuity
2. Beam intensities
3. Beam transmission through part
4. Limited in use
5. Energy loss at discontinuity

B. Reflected transmission

1. Pulse-echo principles
2. Discontinuity orientation to beam
3. Most common technique in testing
4. Initial pulse, discontinuity, back reflection
5. Elapsed time

C. Single search

1. Reflection testing
2. Material coverage from side to side
3. Beam interception with discontinuity
4. Initial and back side indications
5. CRT presentation

D. Double search

1. Two transducer technique
2. Common techniques used in Europe

E. Straight beam

1. Transducer face on part
2. Flat surfaced parts
3. Traditional uses
4. Wear plates
5. Beam directed straight from part's surface
6. Longitudinal wave

F. Angle beam

1. Beam aimed away from normal angle
2. Wedge effects in obtaining angle of beam
3. Production of shear and surface waves
4. Curved contacts for cylinders

G. Generators

1. Variable frequency oscillator
2. Very high frequencies
3. Continuous input of energy
4. Resonance or energy surges
5. Battery or conventional line voltage
6. Tube generation and pulser

H. Transducers

1. Piezoelectric factors
2. Electrical-mechanical and mechanical-electrical
3. Mechanical pulsed vibrations into part
4. Straight and angle beam types
5. Construction materials and shapes
6. Uses; through and reflected energy
7. Safety precautions

I. Couplants

1. Purpose and principles
2. Materials; oils, water, grease
3. Uses and efficiency factors
4. Types of techniques

J. Indicators and meters

1. Cathode ray tube (CRT)
2. Oscilloscope and controls
3. Screen displays
4. Meters
5. Recorders
6. Alarms
7. Automatic testing systems

IV. Wave propagation

A. Characteristics and principles

1. Mechanical vibrations
2. Ultra high frequencies
3. Directional travel at velocity
4. Time, distance, and attenuation
5. Reflection and penetration capabilities

B. Frequencies and ranges

1. Usually from 200,000 to 25,000,000 cycles per second
2. Geometry and shape of part
3. Material of part - elastic nature

C. Stress ranges

1. High energy levels vs. low stress ranges
2. No mechanical damage to parts
3. Frequency and magnitude
4. Low amplitude vibrations

D. Wavelengths

1. Elastic modulus factors
2. Waves as fronts in movement
3. Velocity and oscillations
4. Variables and constants
5. Reference tables of wavelengths

E. Vibrations

1. Mechanical from electrical pulses
2. Low in amplitude
3. Non-damaging to part

F. Velocity

1. Measured in centimeters per second multiplied by a constant
2. As material varies, velocity varies
3. Velocity a function mainly of elastic modulus or density
4. Attenuation factors in gas, liquid, and solid
5. Motion is longitudinal, compound, or transverse

G. Impedance

1. Acoustic impedance factors
2. Density times wavelength
3. Impedance in various materials

H. Attenuation

1. Energy loss in a material
2. Constants
3. Difficulty to isolate, yet present
4. Penetration capabilities in materials
5. Echo time factors
6. Noise generation factors

I. Reflection

1. Incidence angles
2. Impedance factors
3. Time-distance relationships

4. Discontinuity reflection time
5. Reflection coefficients
6. Transmission coefficients

J. Refraction

1. Incidence of non-normal beam between two different materials
2. Differences in material's sound velocities
3. New angles generated - refracted
4. Generation of secondary beams
5. Refracted beam intensity

K. Diffraction

1. Diverging effects of beams
2. Wave fronts
3. Wave interferences
4. Beam spreading characteristics
5. Need for accuracy in flaw detection
6. Discontinuity evaluation factors

L. Dispersion

1. Characteristics
2. Energy spread

M. Mode conversion

1. Materials and velocities
2. Energy dispersion and propagation
3. Surface, shear, and longitudinal waves
4. Interception of beam with a different material
5. Conversion of one type of wave to another
6. Beam spreads
7. Conversion factors and effects

N. Special effects

1. Beam spread effects
2. Added indications

O. Undesirables

1. False indications
2. Variables

V. Testing techniques

A. Contact

1. Straight beam longitudinal wave
2. Angle beam shear wave
3. Surface wave
4. Transducer contact with part or wedge use
5. Couplants needed
6. Pulse-echo transmission
7. Through transmission
8. Oscilloscope indications

B. Immersion

1. Transducer submerged in water
2. Water column or tank
3. Submerged test part
4. Sound beam path - water to part
5. Oscilloscope indications
6. Comparisons with contact techniques

VI. Calibration

A. Need for calibration

1. Variable effects
2. Transmission accuracy
3. Calibration requirements
4. Reference blocks

B. Standards

1. Comparisons with standard reference blocks
2. Pulse-echo variables
3. Types, shapes, and sizes
4. References for planned tests

C. Major parameters

1. Transmission factors
2. Transducers
3. Couplants
4. Materials
5. Receiving factors
6. Circuitry components and relationships

VII. Defect detection

A. Sensitiveness to reflections

1. Size, type, and location of defect
2. Techniques used in detection
3. Wave characteristics
4. Material and velocity
5. Defect orientation to sound beam

B. Resolution processes

1. Standard reference comparisons
2. History of part
3. Probability of type of defect
4. Degrees of operator discrimination
5. Band width factors
6. Frequency effects

C. Energy-noise discrimination

1. Widening characteristics of CRT base line
2. Malfunctioning of circuitry
3. Irregular patterns and non-cyclic effects
4. Attenuation factors vs. materials
5. Probe and coupling factors
6. Surface conditions of part
7. Refraction factors and effects
8. Part geometry and reflections

D. Size of defect determination

1. CRT display and meter indications
2. Transducer movement vs. display
3. Two-dimensional testing techniques
4. Signal patterns

E. Location of defect factors

1. CRT display and meter indications
2. Amplitude and linear time
3. Search techniques
4. Wave forms and scanning areas

F. Kind of defect determination

1. Manufacturing processes relationship
2. Heat treating effects
3. Chemistry of part
4. CRT display
5. Scanning techniques

VIII. Evaluation

A. Defect comparison procedures

1. Standards and references
2. Calibration techniques
3. Comparison techniques
4. Inspection of transducers
5. Inspection of amplitude, area, and distance relationships

B. Object appraisal

1. Part's history in manufacture
2. Use of part
3. Environment of part in use
4. Loading vs. stressing factors
5. The stress pattern in reaction
6. Type of flaw and location
7. Criteria for acceptance or rejection

CHAPTER VII

RADIOGRAPHIC TESTING

The radiographic process is the oldest method used in nondestructive testing. Techniques used in this method are based on powerful rays of energy penetrating a mass of solid material and then recording their results on a special type of film. A homogeneous material to be tested provides for a uniform penetration of energy, whereas a material containing discontinuities provides an uneven distribution. When the rays completely penetrate a material and make contact with a specially prepared film, a shadow picture of the material's inside results. This shadow picture is similar to "seeing through the material." Uneveness of ray distribution results in light and dark areas on the developed film. Basically, the criteria for radiographic testing includes a source of penetrating rays of energy, a part to be inspected, and the film. The part is placed between the source of energy and the film.

Characteristics of Radiation

Radiant energy used in radiographic testing includes the X-ray and gamma ray. Both rays have similar physical characteristics and they obey the laws of light with regard to their straight-line paths. These high energy waves are electromagnetic, have no weight, mass, or electrical charge, travel at the speed of light, ionize matter, and expose film. Their energy is indirectly proportioned to their wavelength while their penetration power depends on their intensity. Because matter absorbs these rays, their depth of penetration is greatly governed by the density and thickness of the material to be inspected. When thickness of material varies, results are recorded on the film. Likewise, when density of material varies (discontinuity), results are recorded on the film.

Because silver bromide is coated on the thin sheet of plastic film, exposure to radiation causes black silver to appear in such proportions (radiation intensity differentials) that the image is outlined with its interior density differences projected onto the film. In order that the image will be clear and adequate, a test piece is frequently placed on the source side of the part to be radiographed. This test piece, a penetrameter, is usually made of the same material as the specimen to be tested and its geometrical proportions are related to the specimen. A satisfactory image of the penetremeter is evidence of an acceptable technique.

An unusual aspect of radiation is that man's senses cannot detect it. Man can see ordinary light and follow the trajectory of its expanding beam, but man has no means of "seeing" the X and gamma rays. However, the ray's effects on man can be disastrous and deadly when exposure has lasted over a period of time. Consequently, the process of radiography includes hazards to health. Personnel who are engaged in radiographic processes must be cognizant of radiation capability and act according to safety practices recommended by the Atomic Energy Commission.

Techniques in Radiography

Often, a discontinuity may be suspected deep within a thick slab of steel. Radiant energy is frequently called upon to locate this type of flaw. In this respect, two or more radiographs from different positions will usually show the location of the flaw when proper techniques are used. As the ray penetrates the thickness of the metal, ray absorption occurs which results in a loss of ray intensity. If intensity is great enough, however, penetration occurs. Should the flaw intercept the radiant beam, a density differential will be reflected on the film. The developed film will then indicate light and dark areas which portray the image of the flaw.

Different techniques are necessary for proper production of radiographs. As the geometry of the part varies, variations in the shadow picture also vary. As an example, when the plane of the part and the plane of the film are not parallel, distortion of the shadow picture will occur and the true shape of the part will be lost. Sharpness of the part's image depends on the distance between the part and the film and between the part and the source of energy. Also, smaller energy sources give sharper images by decreasing the size of the penumbra. Appendix R illustrates some of these techniques.

Because X and gamma rays diverge as distance from source increases, greater areas are covered by the rays, but with a loss of intensity. Consequently, the Inverse Square Law is used in calculating safety practices and exposure factors. This means that the beam's intensity varies inversely with the square of the distance from the energy source and a spreading of the beam occurs much like a beam of visible light. When an increase in intensity is required, the source's voltage factor is increased so as to produce rays having shorter wavelengths for greater penetration capabilities. However, a straight-line beam will scatter as it collides with atoms along the path. Scattering results because of directional changes from the straight-line path when the collision occurred. Scattering of beams also results from a part's uneven geometry and from objects in close proximity to the part being radiographed. Beam scattering causes images to be blurred.

Precautions in Radiography

The radiographic method of nondestructive testing requires special housing for equipment such as a lead lined room, in order that most of the radiation will be contained within the room. Room walls may be lead lined or they may be produced from very thick walls of poured concrete. Because shielding is often difficult in some instances, soft lead sheets are usually used to absorb most of the radiation in the area of the source. The density of the lead serves as a barrier to penetrating radiation. Lead is also very malleable and can be easily folded into any shape to contain the radiation if the sheet is thick enough. In these respects, some radiographic equipment is built within a large lead lined box in order to remove the major shielding complexities. These box-like radiographic units can be safely used in a typically constructed building when their energy outputs remain below a specified level. However, radiological checks from time to time with counters are necessary to assure a safety zone around the radiation source.

Large parts, on the other hand, require intricate portable and fixed equipment which demand either a special type of shielded room capable of containing and absorbing the radiation or an open area where distance acts as the final barrier. Because radiography includes the radiation hazard, all personnel working in a specified radius of the source must conform to the rules for handling radioactive sources which are issued by the local, state, and federal governments.

Emission of Penetrating Rays of Energy

The radiographer will be confronted with the need for X and gamma radiation facilities. In these respects, alpha and beta particles are relatively insignificant, but X and gamma rays are powerful and penetrating rays. The X-ray is generated within a special electronic tube. A high voltage input to the cathode provides an abundance of electrons and as electrons increase in numbers, intensity of the rays increases. When a high voltage is applied to the tungsten anode, the negative particles are quickly drawn to the anode. Because the collisions occur at an angle, much like a billiard ball's bouncing actions, the particles of energy shoot into straight-line paths in all directions. The X-ray tube's shielding prevents radiation from being beamed in unwanted directions, however, a window in the tube acts as a means for focusing the source of energy at the target (material to be inspected). The X-ray can be turned on and off by the radiographer by flipping a switch. The X-ray source is rated in milliamperes and is directly related to the quantity of free electrons emitted at the cathode's filament.

The other type of penetrating ray is the gamma ray which is energy moving away from a decaying radioactive material. The nuclei of the radiant material constantly disintegrate and the rate of disintegration is measured in half-life quantities which is an activity measure. Common isotopes used in this technique of nondestructive testing are Iridium 192, Thulium 170, and Cobalt 60. These isotopes result from nuclear bombardment while Cesium 137 is produced by nuclear fission. Thulium 170 and Iridium 192 are commonly used in radiography because of their lower energy radiation and their requirements for less shielding. Cobalt 60, on the other hand, has the equivalent energy emission of an extremely powerful X-ray machine (mev) whereby thick plates of steel can be radiographed.

Ray Measurements

Wavelengths of radioactive materials are determined by the specific material. Intensity of the gamma ray is measured in roentgens which means the radiation emitted at a set distance during a given period of time. In other words, the intensity of energy is measured in roentgens per hour at a set distance while the measure of energy activity or amount of source energy is measured in curies. Radioactive materials are contained in lead jugs or pigs. The thick walls of the lead container absorb and contain nearly all of the radiating energy. Therefore, these containers often become very heavy. The gamma ray cannot be turned off however, only the container's window can be adjusted for escape of the rays when focused on the target.

Because man cannot detect radiation with his senses, special detection equipment is required wherever radiation processes are conducted. An example of detection equipment includes the badge which is worn by all personnel engaged in radiographic processes. The badge is measured periodically to determine exposure of the wearer. A dosimeter is also carried by the person who works in the radiography area. This instrument, pencil shaped, indicates the accumulation of radiation. Another important instrument is the Geiger counter. This counter acts as an alarm in the presence of radiation and can be used in detecting gross radiant contamination. However, other safety devices must be used when high radiation intensity is present because of the possible inaccuracy of the counter at saturation levels of radiation. Because radiation cannot always be completely confined, the radiographer (or other personnel) may be exposed to small quantities. Therefore, all personnel are subject to a permissable dose of radiation. This means that the dose of radiation received should not be harmful during the person's lifetime. Doses beyond the acceptable amount require severance from further exposure.

Determine the Source Need

Prior to requisition of radiographic and radiological equipment, the radiographer should decide on the type of needed source material. The box type of X-ray apparatus provides good radiographs within certain limits without the requirement for a large additional shielding arrangement. However, this type of installation is severely limited in energy output and is unsuitable for inspection of large parts. When increased levels of radiant energy are produced, shielding becomes a necessity. If the gamma ray is needed for intricate inspections or for deep penetration, the isotope is used. Either radiographic process requires strict compliance with established codes, rules, and regulations. Appendix R illustrates a typical box unit for limited radiographic inspections.

Objectives

Objectives of the radiographic method of nondestructive testing are stated below.

I. The trainee should:

A. Understand the principles governing the radiographic testing process.

B. Be familiar with the various types of parts which are commonly inspected with radiation.

C. Be cognizant of the routine procedures involved in accomplishing the test.

D. Understand the requirements for a specific technique and be able to select the technique.

E. Understand the advantages and disadvantages of the test.

F. Understand and be familiar with the safety precautions pertinent to radiation hazards.

II. The trainee will be able to:

A. Use typical equipment peculiar to radiographic processes. Use should be confined to the softer ray tests unless special requirements dictate otherwise.

B. Comply with local, state, and federal radiation safety codes.

C. Use the attachments and accessories pertinent to routine testing.

D. Use the X-ray technique in locating discontinuities.

E. Use the gamma ray technique when this technique is required.

Note: The trainee should be familiarized with the gamma ray test and should be given the opportunity to perform some of these tests.

F. Differentiate among the several patterns of discontinuities.

G. Analyze the specific and total situation.

H. Evaluate the total inspection situation.

I. Accept or reject the specific indications.

Outline of Key Points

I. Equipment

  A. Operator's ability to use

    1. The X and gamma ray principles
    2. Purpose and objectives of tests
    3. Safety precautions
    4. Safety code compliances
    5. Operational techniques
    6. Experience in equipment use

  B. Purpose of types

    1. Purpose of test
    2. Objectives to be obtained
    3. Fixed and mobile types

  C. Fixed installations

    1. Self shielded
    2. Semi-mobile
    3. Higher energy systems
    4. Special designs
    5. Large and heavy parts

  D. Mobile types

    1. Mobility needs
    2. Shielding factors
    3. Special designs

  E. X-ray type

    1. Low energy machine
    2. 150 KV machines (possible limit of low energy)
    3. High and very high voltage machines
    4. Shielding factors and codes
    5. Safety precautions
    6. Radiation detection devices
    7. Inspection needs

  F. Gamma ray type

    1. Common isotopes
    2. Curie factors and source shape

    3. Shielding needs and problems
    4. Safety precautions and codes
    5. Radiation detection devices
    6. Inspection needs
    7. Decay factors and cost

  G. Design requirements

    1. Inspection needs
    2. Part geometry
    3. Shielding requirements

  H. Safety precautions and practices

    1. Local, state, and federal codes
    2. Manufacturers' codes and specifications
    3. Atomic Energy Commission codes
    4. American Society for Testing and Materials codes
       American Society for Nondestructive Testing codes
       Interstate Commerce Commission codes
    7. Shielding and radiation detection factors
    8. Exposure values
    9. Radiological equipment

II. Radiation

  A. Principles

    1. X-ray sources
    2. Gamma ray sources
    3. Intensity and strength factors
    4. Materials impervious to radiation
    5. Existence factors

  B. Types of rays

    1. X-rays
    2. Alpha and beta rays
    3. Gamma rays

  C. Electronic sources

    1. The X-ray tube
    2. Cathode-anode arrangements
    3. Electron flow and quantity
    4. Anode potential
    5. Deflection pattern
    6. Window and shadow picture
    7. Shielding
    8. On and off existence of source
    9. Penetration capabilities

D. Isotopic sources

1. Radioactive materials
2. Half life values of isotopes
3. Decay phenomena
4. Alpha, beta, and gamma ray emissions
5. Curie factors and effects
6. Roentgen factors and effects
7. Shielding needs
8. Intensity focus control
9. Penetration capabilities
10. Cannot turn rays off

E. Sensitivity

1. Insensity factors and energy levels
2. Velocity
3. Source to film distance
4. Part to film distance

F. Intensity distribution

1. Quantity of electrons
2. Voltage variables
3. Electron acceleration
4. Current and filament temperature
5. Anode voltage
6. Intensity in milliamperes

G. Detection devices

1. Badges for wear
2. Dosimeters
3. Geiger counters
4. Radiological safety standards

H. Handling procedures

1. Known energy levels
2. Shielding uses and requirements
3. Curie and roentgen factors
4. Ray focus, beam spread, and scattering
5. Distance factors vs. energy levels

I. Primary effects

1. Penetration and ionization effects
2. Spread and scatter variables
3. Absorption characteristics
4. Film exposure effects
5. Human exposure and dose levels

J. Secondary effects

1. Exposure factors
2. Molecular change potentials

K. Shielding procedures

1. X-ray and gamma ray requirements
2. Machine source existence of ray
3. Area shielding needs and specifications
4. Container thickness and access window
5. Window control of different rays
6. Code requirements

L. Absorption characteristics

1. Molecular crystalline structure
2. Density factors
3. Thickness of shielding values
4. Shielding materials
5. Molecular collision patterns
6. Radiation effects on materials

M. Scatter effects

1. Internal nature of ray path and divergence
2. Part geometry and side effects
3. Near-by object influences

N. Pair production

1. Limited to extremely high energy levels
2. Electromagnetic radiation collisions with atom
3. Radiant energy conversion
4. Positron and electron pair
5. Collision path and convergence
6. Additional effects of pair uniting

O. Protection and safety codes

1. Radiological monitoring criteria and standards
2. Area detection and alarm devices
3. Local, state, and federal codes
4. Professional organization codes and specifications

P. Radiation dose control

1. Radiation measurement
2. Human dose accumulation
3. Maximum permissable dose
4. Atomic Energy Commission Guides

5. Time and distance factors
6. Exposure factors
7. Construction techniques for protection
8. Permissible levels of radiation
9. The radiation survey team
10. Radiological testing and monitoring
11. Instrument and device protection

III. Procedures

A. Shadow picture and geometry

1. Radiation source
2. Size of source and shape (gamma)
3. Focal spot and distance
4. Part geometry
5. The image-source triangle
6. Image sharpness
7. Penumbra
8. Distortion effects and characteristics

B. Focal spot and window

1. Geometry of ray travels
2. Intensity and projection characteristics
3. Source size and shape (gamma)
4. Rectangular opening of X-ray window
5. Angle of electron collision at anode
6. Actual and effective focal spots
7. Temperature factor, anode material and focus

C. Electromagnetic waves

1. Gamma ray and X-ray characteristics
2. Applications of the laws of white light
3. Absence of mass and electrical charge
4. Wavelength vs. energy
5. Human senses cannot detect
6. Ionization of matter capability
7. Film exposure capability
8. Matter penetration capability
9. Discontinuity in material detection

D. Techniques

1. Conventional radiographic procedures
2. Stereoradiography
3. Xeroradiography
4. Fluoroscopy

E. Voltage and amperage factors

1. Line voltage and input to X-ray machine
2. Transformer action
3. Circuitry
4. X-ray tube and shielding
5. Current and voltage input
6. Cathode current
7. Anode voltage
8. Milliampere ratings

F. Exposure factors and contrast

1. Time of exposure and radiation intensity
2. Radiation intensity differences in a material
3. Homogeneous materials' effects

G. Screens and filters

1. Material types for screens
2. Purpose and principles of screens
3. Lead alloys and fluorescent materials
4. Filter materials
5. Principles of filtering
6. Absorbing characteristics

H. Film characteristics and types

1. Film structure and chemical content
2. Purpose of silver bromide
3. Radiation and film exposure
4. Use of penetrameters
5. Contrast effects and functions
6. Types
7. Techniques in radiography
8. Film holders
9. Dark room procedures and processing
10. Dark room equipment

I. Laws and rules

1. Physics of X and gamma rays
2. Penetration capabilities in solid materials
3. Matter response to radiation
4. Safety observance and precautions
5. Shielding vs. exposure
6. Life and health hazards
7. Governing codes

J. Object material and density

    1. Physical constants of elements
    2. Velocity vs. density
    3. Penetration vs. density
    4. Thickness and penetration

K. Image quality factors

    1. Sharpness of part image
    2. Source-part-film distance relationships
    3. Geometry of planes during exposure
    4. Distortion factors
    5. Contrast effects

L. Penetrameters

    1. Image clarity testing
    2. Purpose of penetrameters
    3. Geometry of penetrameters
    4. Materials

M. Film processing

    1. Potential image after exposure to radiation
    2. Sequential procedures
    3. Equipment in the dark room
    4. Developing
    5. Neutralizing of developer
    6. Excess silver bromide removal
    7. Water washing and drying

IV. Evaluation techniques

A. Criteria for evaluation

    1. Objectives of tests
    2. Standards and references
    3. Penetrameters
    4. Comparisons

B. Defect identification

    1. Standards for comparison
    2. Image clarity and shadow picture
    3. Contrast and completeness
    4. Types of discontinuities
    5. Shapes and sizes of discontinuities
    6. Location of discontinuities

C. Appraisal of object

1. History of part
2. Loading factors and stress
3. Use of part
4. Location of discontinuity
5. Acceptance and rejection criteria

CHAPTER VIII

OTHER NONDESTRUCTIVE TESTING METHODS

The five main methods of nondestructive testing provide the majority of tests needed in quality control of manufactured parts. However, there are several additional tests which provide a greater coverage for the total manufacturing process. These additional methods are summarized below.

Magnetic Rubber Test

A prepared mixture of ferrous powder and liquid rubber can be used to supplement the magnetic particle test. When the liquid mixture is placed and held in contact with a ferrous area, that appears receptive for discontinuities, in the presence of a magnetizing current (prods), the ferrous powder and syrup are attracted into the discontinuity. The principle is very similar to the north-south pole relationship of magnetic inspection. Because the syrup encloses the area to be inspected, any discontinuities will immediately absorb the syrup due to the polar condition. This polar environment then attracts the syrup deeply into any discontinuity or irregularity which is in proximity of the syrup.

The electrical prods are placed on each side of the suspected area and the area between the prods then becomes the inspection zone. The current is allowed to flow until a good flux is established. In turn, the syrup enters all discontinuities, remaining in the discontinuity until solidification of the syrup occurs. When solid rubber forms, it is then removed and examined under a microscope (low magnification) for uneven areas and other clues which may be indicative of discontinuities.

The magnetic rubber test is ideal as a supplement to eddy current testing techniques, but may often be used as the primary test. Holes and corners of ferrous parts are ideal areas for inspection by this test.

Infrared Test

This nondestructive testing method provides inspection of materials by use of the infrared heat principle. When the source of energy is focused across the part to be inspected, a pattern of heat absorption occurs in the material. Homogeneous material will provide a uniform indication of heat absorption. This indication, through electronic circuitry, is relayed to a meter or an oscilloscope. As long as sound material is contacted, a uniform signal will be established. However, when a discontinuity is contacted, a temperature differential exists at the discontinuity and this differential is then displayed at the meter or oscilloscope. The oscilloscope's base line, in this case, on the screen can be arranged to present the discontinuity in two-dimensional shape.

The two basic infrared testing systems include the pointing radiometer, for line scanning, and the raster scanning type. The heat generated requires control; therefore, air is normally used to cool the pointing radiometer while liquid nitrogen is used in the raster type. Because these types of inspection devices are often used for inspecting parts where different materials make up the assembly, the aircraft industry finds them advantageous. Assemblies such as bonded laminations are inspected by this process.

Acoustic Emission Test

When parts are highly stressed and discontinuities begin to form, a reflection of the metal's separation sound pattern is detectable in the acoustic emission testing process. Cracks especially are detectable during the process of metal failure. Research has shown that the noise generated by the separating metal is indicative of a stress factor. As stress increases and decreases, noise changes its pitch and because of its containment, reflects itself repetitiously within the material.

Emission noises are sound frequencies and are detected by the transducer. Because of containment in the material, a varying pitch results. The frequency variation apparently is loudest from the crack and weakest from very small irregularities. As a material is stressed and the discontinuity expands, emission also increases. As a crack, for example, begins to increase, emission increases an appreciable amount to the failing point.

The acoustic emission process of nondestructive testing is in the stage of further development. Tests have shown that grain pattern and other microstructural factors influence the emissions. From an operational point of view, this process has tremendous potentials in that emissions are warnings.

Other Techniques Used in Nondestructive Testing

Electrical systems variations
Electromagnetic ray variations
Frequency variations
Heat variations
Holographic
Laser
Light variations
Optics and visual examinations
Photoelastic stress cycling
Sonic
Strain systems
Vibrational

CHAPTER IX

CURRICULUM

This proposed curriculum for training nondestructive testing and inspection technicians is the result of an intensive search for information. Contents of this curriculum have been extracted from data obtained in a statewide industrial survey.

The key points in each of the five main methods of nondestructive testing and inspection have been outlined in previous chapters. Educational objectives have also been stated for each of the five methods. The five main methods of testing comprise the core of the curriculum, but this core must be supported with foundation skills and knowledge. Together, the foundation and the core skills are needed to build the complete curriculum.

Foundation knowledge and skill provide for understanding the principles of the core skills. A listing of this foundation subject matter, general education, is shown in Appendix S. These eighteen subjects, when integrated into the total program, should help provide a high level of proficiency in the graduate.

An examination of the core skills shows that electricity, metallurgy, and mathematics comprise the bulk of the knowledge needed in conducting the main methods of testing. Therefore, these subjects should be weighed heavily in the overall training program.

An examination of the subject matter shown in each of the five main outlines of key points, together with the subject matter listed in Appendix S, indicates that most of these subjects can be integrated into less than a dozen specific subjects. Specifically, a training program comprising a dozen technical subjects, supported with a few general educational subjects, will provide the backbone of the curriculum.

After reviewing all data obtained from Part I of this study, it is recommended that a minimum of four semesters be established as the general time requirement for the proposed program. In order to allow for a minimum of general education, the proposed program should consist of seventy-four semester hours of specified subject matter. Because some subjects require prerequisites, a basic and an advanced course will be needed in some areas. Each of the twenty-five subjects shown in the curriculum below must then be patterned to include the knowledge, principles, procedures, and related information necessary to guide the trainee to graduation as a nondestructive testing and inspection technician.

In order to allow for theory and application of theory, technical subjects will be divided into lecture and laboratory periods. Experience has shown, in technical subject areas, that approximately three clock hours of laboratory experience will allow the trainee enough time to apply the principles he learned in the two clock hours of discussion. Also, the five clock hours, extended over a semester, will provide a comprehensive coverage of the area to be covered.

Because a hierarchy of subjects must be provided, from beginning to graduation, a sequence is therefore established. The recommended curriculum in support of this program is shown below. However, flexibility must exist within the two-year period; therefore, subjects may be taken at a time best suited for the trainee, provided he has the prerequisites. A description of each course shown in the curriculum is also provided below.

Even though course descriptions are very general in coverage, the description does include the scope of instruction. In order to ascertain the detailed coverage of each course, the syllabus must be reviewed. In this respect, course planners must give due consideration to proper course coverage by verification that all needed subject items for the course are shown in the syllabus. In effect, reference should be made to previous chapters of this study to assure all needed items are included in the syllabus. It is not intended, however, that previously outlined key points of instruction be all inclusive. The instructor should use his best judgement in organizing his program.

Due to flexibility in industrial needs, some kinds of industry may require the technician to be cognizant of technical information that is not shown in the proposed training outlines. Research has shown that additional knowledge may be required for some technicians, depending on the manufacturer's needs. These additional possible needs are shown in Appendix T. These subjects may be added to proposed programs wherever required.

Curriculum planners must also be aware of the tremendous spread of American manufacturing capability. A training program for an aircraft plant will be different from that needed in a shipbuilding yard. Even though basic principles and procedures apply to programs, specific needs may necessitate curriculum changes. For planning purposes, some of the branches of industry using nondestructive testing processes are shown in Appendix U.

Also, it is interesting to realize the high percentage of manufacturers who recommended nondestructive testing for inclusion in other technology training programs. Appendix V lists seventeen technologies that were recommended to include some form of nondestructive testing processes. This study has shown (Part I) that 70 per cent of respondents queried, indicated that seventeen separate technologies should be supported with some form of instruction in nondestructive testing. The listing indicates results obtained from the industrial survey. Metallurgical technology was checked by 85.8 per cent of the respondents as needing this instruction the most, while Electronics technology was checked by 69.6 per cent as needing this instruction the least. From these statistics, it is evident that a large percentage of the metal manufacturing industries (other than low stressed parts) have some form of nondestructive testing in their production lines.

Another consideration during the curriculum planning phase must include a sharp and continuous look at the total program. Such things as field trips and factory familiarization visits should be included in programs whenever feasible. As an example, many training programs will probably not include gamma radiation testing facilities. In this respect, a visit to a radiation laboratory will make a fine substitute. A short factory indoctrination visit may also provide insight into a specific area of learning.

Reference should be made to the equipment listing in this guide, Appendix W, as an additional source of learning aids. Many manufacturers produce and provide numerous brochures pertaining to specific items of testing equipment. A supply of these brochures can add vitality and reality to a program. In this respect, experience is a wonderful teacher; therefore, equipment should be used as much as possible in order to learn the testing process.

Appendix W provides a listing of equipment that has been recommended by several manufacturers for use in training nondestructive testing and inspection technicians. This listing provides several choices in the same types of equipment and includes units for use in all areas of nondestructive testing.

Obviously, there are many types of equipment not listed due to the impracticability of publishing a large volume of items. It is recommended that course planners contact the manufacturer and obtain brochures pertinent to specific types of equipment prior to requisitioning.

Due to the high cost of equipment, it is recommended that the laboratory group of trainees be divided into sections and then rotated through each method of testing. Once the basic principles of the several tests are learned, rotation can be accomplished in an effective manner. Appendix X suggests a typical laboratory arrangement.

PROPOSED CURRICULUM

in

NONDESTRUCTIVE TESTING

Nondestructive Testing Technology

Curriculum

First Year

First Semester

	Credit	Lecture	Lab
Applied Communications I	3	3	0
Applied Physics and Mathematics I	4	3	3
Basic Principles of Nondestructive Testing	3	2	3
Manufacturing Materials and Processes I	3	2	3
Metrology	3	2	3
Physical Education	1	1	2
	17	13	14

Second Semester

	Credit	Lecture	Lab
Applied Communications II	3	3	0
Applied Physics and Mathematics II	4	3	3
Manufacturing Materials and Processes II	3	2	3
Basic Electronics	3	2	3
Applied Penetrant and Magnetic Particle Testing	3	2	3
Physical Education	1	1	2
	17	13	14

Summer

	Credit	Lecture	Lab
United States Government	3	3	0
Texas State and Local Government	3	3	0
	6	6	0

Second Year

First Semester

	Credit	Lecture	Lab
Applied Physics and Mathematics III	4	3	3
Basic Radiography in Nondestructive Testing	3	3	0
Basic Ultrasonic Nondestructive Testing	3	2	3
Introduction to Quality Control	3	2	3
Strength of Materials	3	2	3
	16	12	12

Second Semester

	Credit	Lecture	Lab
Industrial Psychology	3	3	0
Advanced Radiography in Nondestructive Testing	3	2	3
Advanced Ultrasonic Nondestructive Testing	3	2	3
Inspection Standards	3	2	3
Practical Problems in Nondestructive Testing	3	2	3
Eddy Current Testing	3	2	3
	18	13	15

al Semester Hours: 74

Applied Communications I. (3-3-0). Language study involving grammar, punctuation, and spelling skills with frequent exercises in the development of accurate and precise sentences and paragraphs. Emphasis on composition is given in the area of practical application.
Prerequisite: A grade of C or better in Developmental English or equivalent, or satisfactory score on placement test.

Applied Physics and Mathematics I. (4-3-3). A basic course for occupational programs including whole numbers, fractions, decimals, units, exponents, operational algebra, stated problems and geometry. Applications are made utilizing the slide rule and calculator. Laboratory fee charged.

Basic Principles of Nondestructive Testing. (3-2-3). This is a basic course which investigates the purposes, principles, and main methods of nondestructive testing. Also studied will be the origin and significance of discontinuities in manufactured parts.

Manufacturing Materials and Processes I. (3-2-3). This is a study of the various materials used in the metals and plastics industries. The course is designed to familiarize the student with the several materials used in manufacturing and to acquaint him with the chemical, physical, and mechanical properties of these materials.

A study of the various types of manufactured parts will be accomplished. Laboratory fee charged.

Metrology. (3-2-3). This course is designed to provide proficiency in the use of standard measuring tools, fixtures, and instruments in support of inspection activities during manufacturing processes. Techniques for achieving accurate measurements will be investigated to include the use of standards and references.

Health Concepts of Physical Activity. (1-1-2). A general course in college physical education designed to teach the biophysical values of muscular activity through lecture and laboratory periods. In the laboratory periods, a swimming proficiency test and a physical fitness test are given to determine the student's future physical education program. Required for full time, first semester freshman. Laboratory fee charged.

Applied Communications II. (3-3-0). Composition slanted toward writing technical reports, brochures, promotional materials, surveys, and similar projects. Attention will be given to the preparation and delivery of speeches pertaining to technical or business interest. Prerequisite: Applied Communications I.

Applied Physics and Mathematics II. (4-3-3). Topics covered are review of operational algebra, coordinate geometry, vectors, trigonometry, statics, forces, quadratic equations, heat and properties of matter.

Applications are made in demonstrations and laboratory. Laboratory fee charged.

Prerequisite: Physics and Mathematics I or equivalent.

Manufacturing Materials and Processes II. (3-2-3). Fundamental and advanced manufacturing processes will be discussed including the processing of materials through the various stages of production. Testing, inspection, and quality control procedures will be accomplished. Laboratory fee charged.

Prerequisite: Manufacturing Materials and Processes I.

Applied Penetrant and Magnetic Particle Testing. (3-2-3). Included in this course is practice in penetrant and magnetic particle testing principles, procedures, applications, and capabilities. Students will be familarized with the use of equipment and accessories relative to these testing methods.

Prerequisite: Basic Principles of Nondestructive Testing.

Physical Education. (1-1-2) A Continuation of Physical Education I.

Basic Electronics. (3-2-3). This is a beginning course in electronics and includes the fundamental principles of direct and alternating currents used in typical electronic circuitry. Special emphasis will be given to circuitry principles involved in the use of nondestructive testing equipment such as magnetizing currents, eddy currents, transducers, and X-ray circuits.

United States Government. (3-3-0). United States constitutional and governmental systems are studied for the purpose of understanding good citizen attributes.

Texas State and Local Government. (3-3-0). Texas state, county, and municipal governments are investigated and contrasted with other states in the union.

Applied Physics and Mathematics III. (4-3-3). Continuation of Physical Science II with emphasis on trigonometry, solutions to equations, complex numbers, radicals, logarithms, energy and motion, electricity and circuits. Applications are made in demonstration and laboratory. Laboratory fee charged.
Prerequisite: Physics and Mathematics II or equivalent.

Radiography in Nondestructive Testing. (3-3-0). luction to Radiography theory is studied, including discussions and demonstrations. Field trips to industrial X-ray and gamma ray laboratories will be accomplished. Course covers fundamentals of radiation safety and protection; radiation measurement doses, exposure factors and biological effects; instrumentation and basic equipment used in X-ray and Isotope Radiography; requirements of state and federal regulations; and basic radiographic and radiological techniques.
Prerequisite: Basic Principles of Nondestructive Testing, Manufacturing Materials and Processes II, and Basic Electronics.

Basic Ultrasonic Nondestructive Testing. (3-2-3). This is a laboratory course which includes basic ultrasonic testing principles, procedures, applications, and search capabilities. Equipment will be used to explore the several testing techniques. Calibration of test units will be included.

Prerequisite: Basic Principles of Nondestructive Testing, Manufacturing Materials and Processes II, and Basic Electronics.

Introduction to Quality Control. (3-2-3). This study provides an investigation into manufacturing processes with a view toward quality assurance and reliability through management, nondestructive and destructive testing techniques, and statistical control procedures.

Prerequisite: Basic Principles of Nondestructive Testing and Manufacturing Materials and Processes II.

Strength of Materials. (3-2-3). This is a study of the several mechanical properties of materials. The course is intended to provide technical and design students with a basic understanding of strength of materials as related to parts designed. Included in this study will be relationships among materials, loads, and stresses pertaining to parts manufactured by means of casting, forming, welding, and machining processes. Laboratory work includes material inspection and the use of testing equipment. Laboratory fee charged.

Prerequisite: Manufacturing Materials and Processes II and Applied Physics and Mathematics II.

Industrial Psychology. (3-3-0). This is a study of industrial organization and management, line and staff functions, employee-employer relations, control techniques, labor-management policy and procedure, effective supervision, and industrial planning. This course is also designed to assist the student to make the adjustment from college to employment.

Advanced Radiography in Nondestructive Testing. (3-2-3). This course is designed as a continuation of basic radiography and includes theory of radiographic image formation, exposure calculation, radiographic techniques, darkroom procedures, and film reading. Procedures are accomplished in advanced radiography including the use of X-rays and isotopes applicable to various materials and situations.

Prerequisite: Basic Radiography in Nondestructive Testing.

Advanced Ultrasonic Nondestructive Testing. (3-2-3). Advanced ultrasonic theory and testing techniques will be investigated for the purpose of illustrating the use of equipment in flaw detection processes. Both contact and immersion testing systems will be studied to include the use of the several wave searching techniques.

Prerequisite: Basic Ultrasonic Nondestructive Testing.

Inspection Standards. (3-2-3). Included in this course will be a review of inspection standards related to manufacturing processes and quality assurance, including a survey of pertinent specifications. Inspection tools, gages, instruments, and mechanisms will be used in illustrating the need for maintaining quality control in industry.

Practical Problems in Nondestructive Testing. (3-2-3). This is a laboratory problems course involving the use of the main methods of nondestructive testing in the search for discontinuities. Problems are related to typical manufacturing processes.

Prerequisite: Course or experience in Penetrant, Magnetic Particle, Eddy Current, Ultrasonic, and Radiographic testing methods or permission of instructor.

Eddy Current Testing. (3-2-3). This is a study of eddy current principles and electrical concepts related to nondestructive testing. Included in this study will be eddy current testing techniques to include conductivity measurements and discontinuity and thickness testing. Also, phase and modulation analysis will be investigated along with special applications.

Prerequisite: Introduction to Basic Principles of Nondestructive Testing, Manufacturing and Materials Processes II, and Basic Electronics.

APPENDIX

APPENDIX A

TYPICAL PARTS THAT ARE TESTED BY NDT PROCESSES*

Agricultural Tools
Aircraft Parts
Arbors
Armor Plate
Arms
Assemblies and Sub-Assemblies
Automotive Stressed Parts
Axles
Bars
Beams
Bearings
Beds
Billets
Blades
Blooms
Boiler Parts
Bolts
Boxes
Brackets
Brazed Fittings
Bulkheads
Busses - Stressed Parts
Cams
Cannon
Castings - All Types
Ceramics - Powder Metallurgy
Chain
Clamp
Columns
Compressor Parts
Conduits
Connectors
Containers
Controls
Couplings
Crankshafts
Cutters
Cylinders
Dies
Discs
Drives
Ducts
Electrical Fittings
Electronic Fittings
Engine Blocks
Extensions
Extrusions
Flanges
Foils
Forgings
Forks
Formed Parts
Flywheels
Gears
Guides
Guns
Handles
Hinges
Holes - Surfaces
Honeycomb
Housings
Hydraulic Fittings
Impact Parts
Ingots
Instrument Parts
Joints - All Types
Keys
Keyways
Knuckles
Linkage
Longerons
Machinery - All Types
Mechanisms - All Types
Microstructures
Missiles
Mounts
Munitions
Nuts
Orifices
Pins
Pipe
Pistol Parts

APPENDIX A --Continued

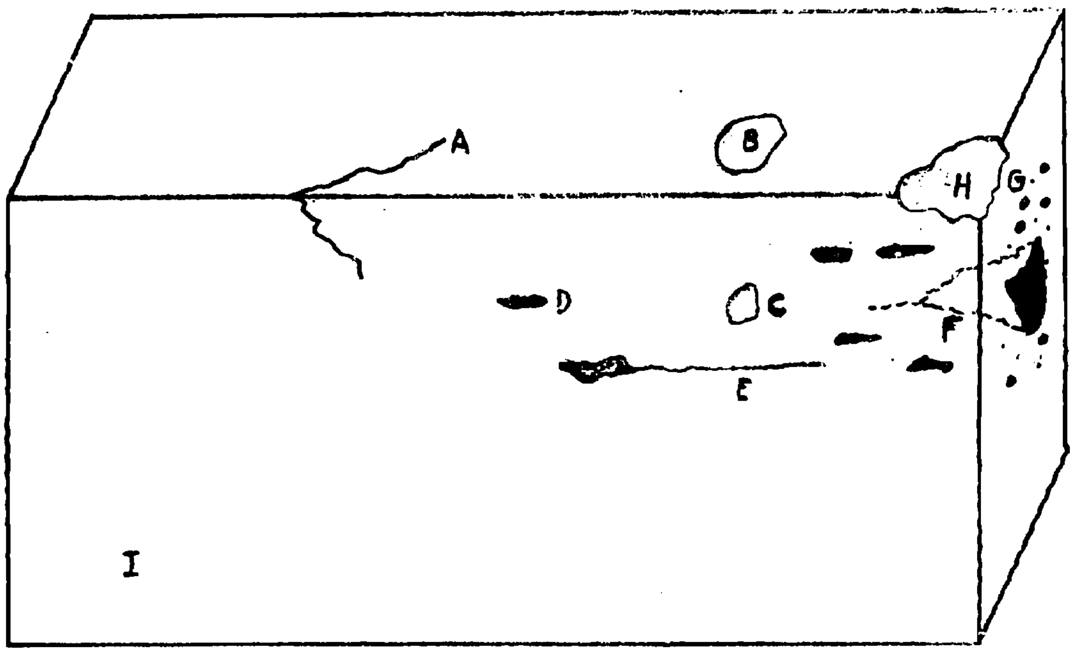
Pistons
Plastics - All Types
Plate
Pressure Containers
Projectiles
Propellers
Pulleys
Pump
Punches
Raceways
Racks
Railroad Locomotive Parts
  and Cars
Rails
Rams
Retainers
Rifle Parts
Rings
Rivets
Rockers
Rods
Rollers
Rotors
Saws
Screws
Seats
Shafting
Sheet
Ship Parts
Shoes - Machinery
Slides
Soldered Fittings
Solid Materials
Space Hardware
Space Vehicles
Spacers
Spars
Splines
Spokes
Spindles
Springs
Sprockets
Steering Parts
Stressed Fittings - All
Stringers
Supports

Tools
Trunnions
Tubing
Turbines
Valves
Washers
Ways
Welds
Wheels
Wire
Wrenches

*Inspections depend on degree of use, stress, safety, and cost. Highly stressed parts are inspected by NDT processes.

APPENDIX B

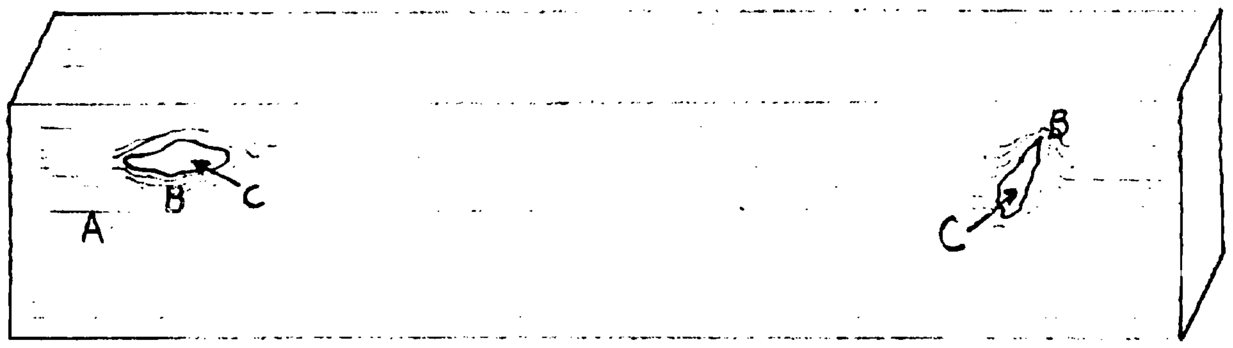
TYPICAL DISCONTINUITIES



A	Surface crack	F	Pipe
B	Blow hole	G	Porosity
C	Cavity, internal	H	Inclusion
D	Inclusion, internal	I	Ingot
E	Inclusion		

APPENDIX C

THE STRESS PATTERN AND DISCONTINUITIES



A Stress, internal flow

B Stress concentration

C Discontinuity

APPENDIX D

DISCONTINUITIES IN THE INGOT

A Pipe

B Porosity

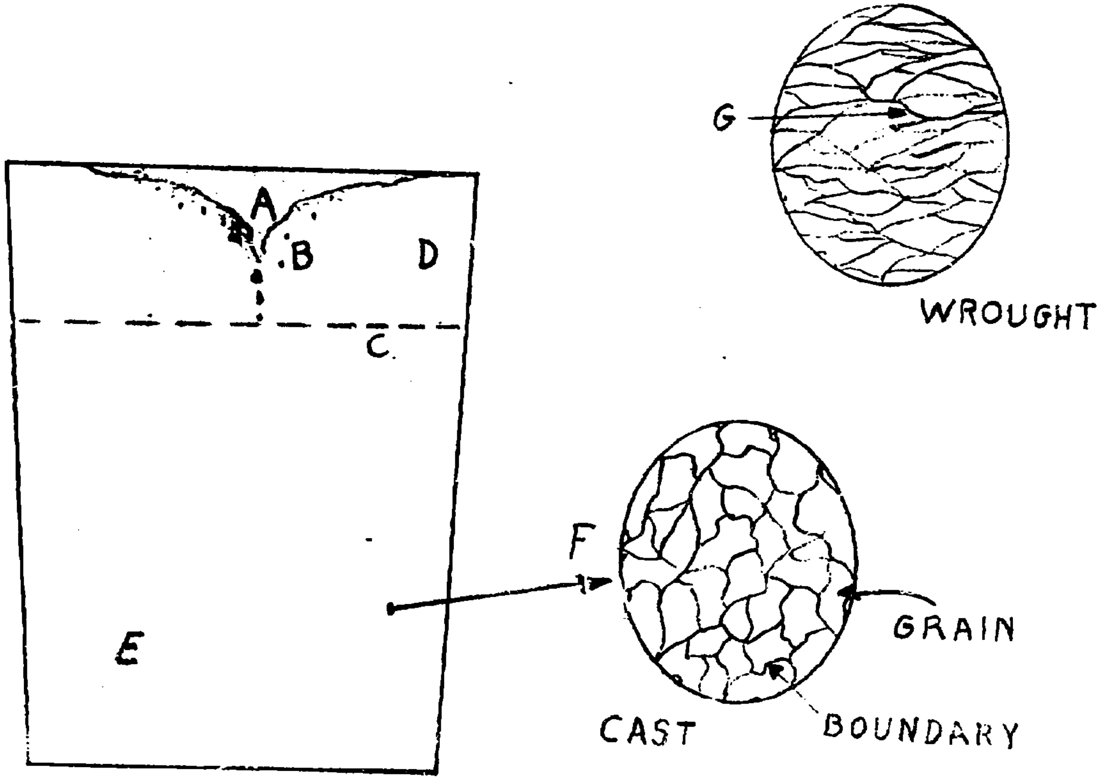
C Crop line

D Scrap

E To be rolled

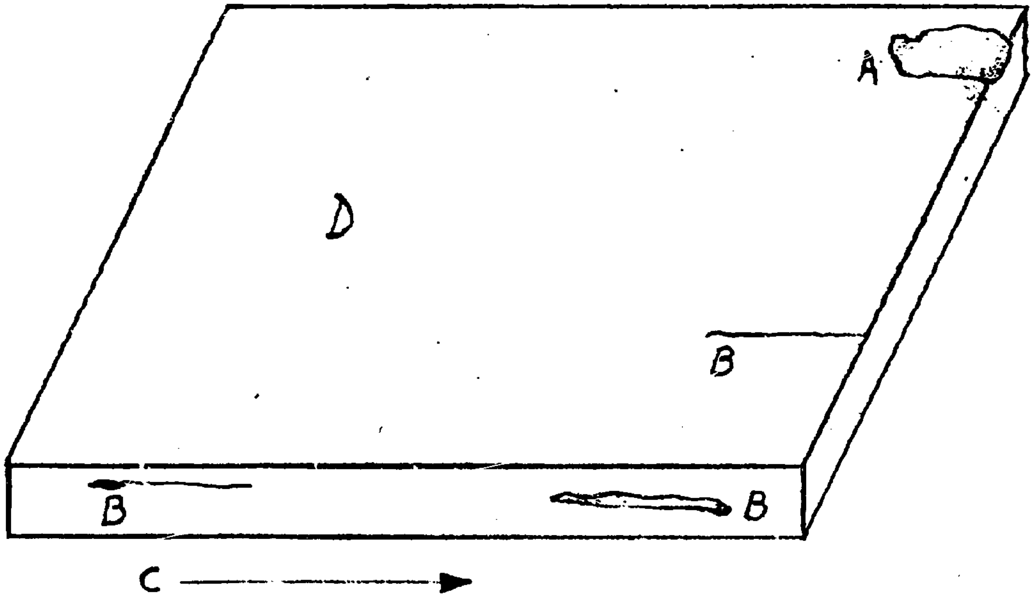
F Cast - coarse grain
(as cast)
Microscopic view

G Rolled (as rolled)
Microscopic view
Grain boundary overlaps



APPENDIX E

FLATTENED AND ELONGATED DISCONTINUITIES



A Inclusion, flattened

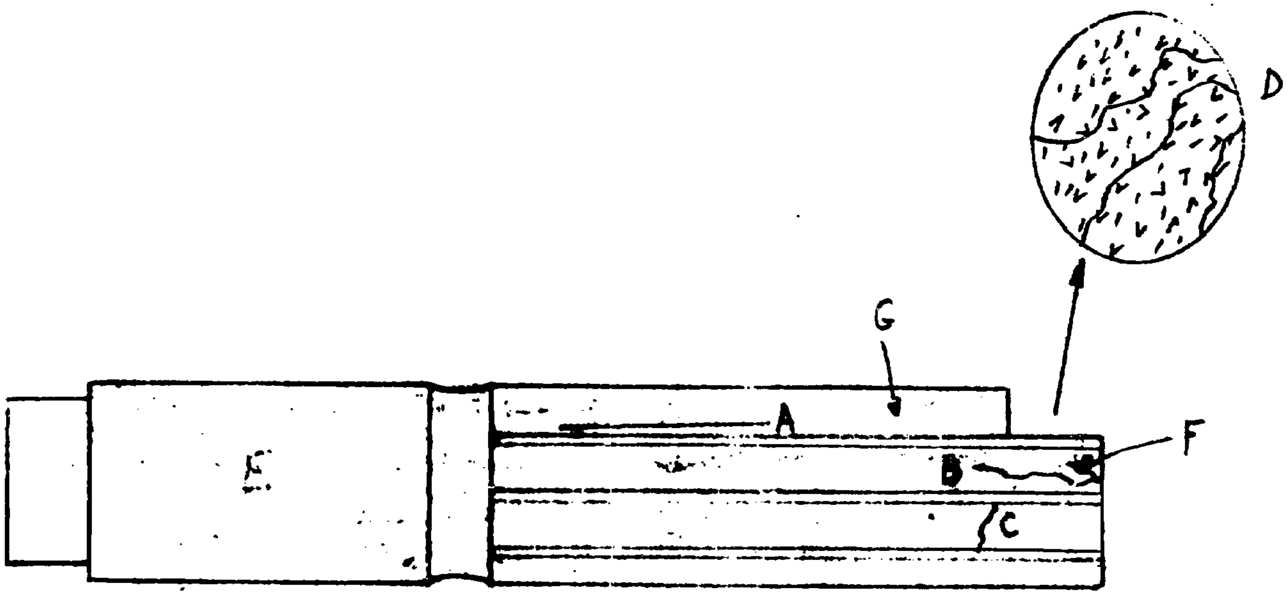
B Inclusion, elongated

C Direction of rolling

D Steel plate

APPENDIX F

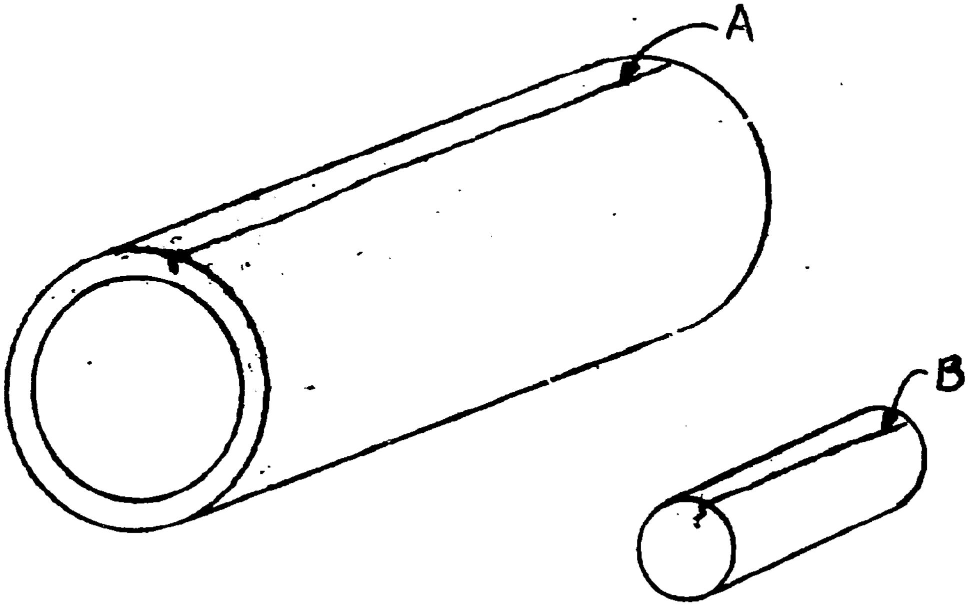
HEAT TREATING CRACKS



A,B,C	Quench cracks
D	Microstructure, 500 X Martensite (Section removed)
E	Reamer
F	Stress was greater than strength
G	Rockwell C 63 (satisfactory) Cracks resulted from overstress Tool must be scrapped

APPENDIX F -- Continued

SEAMS

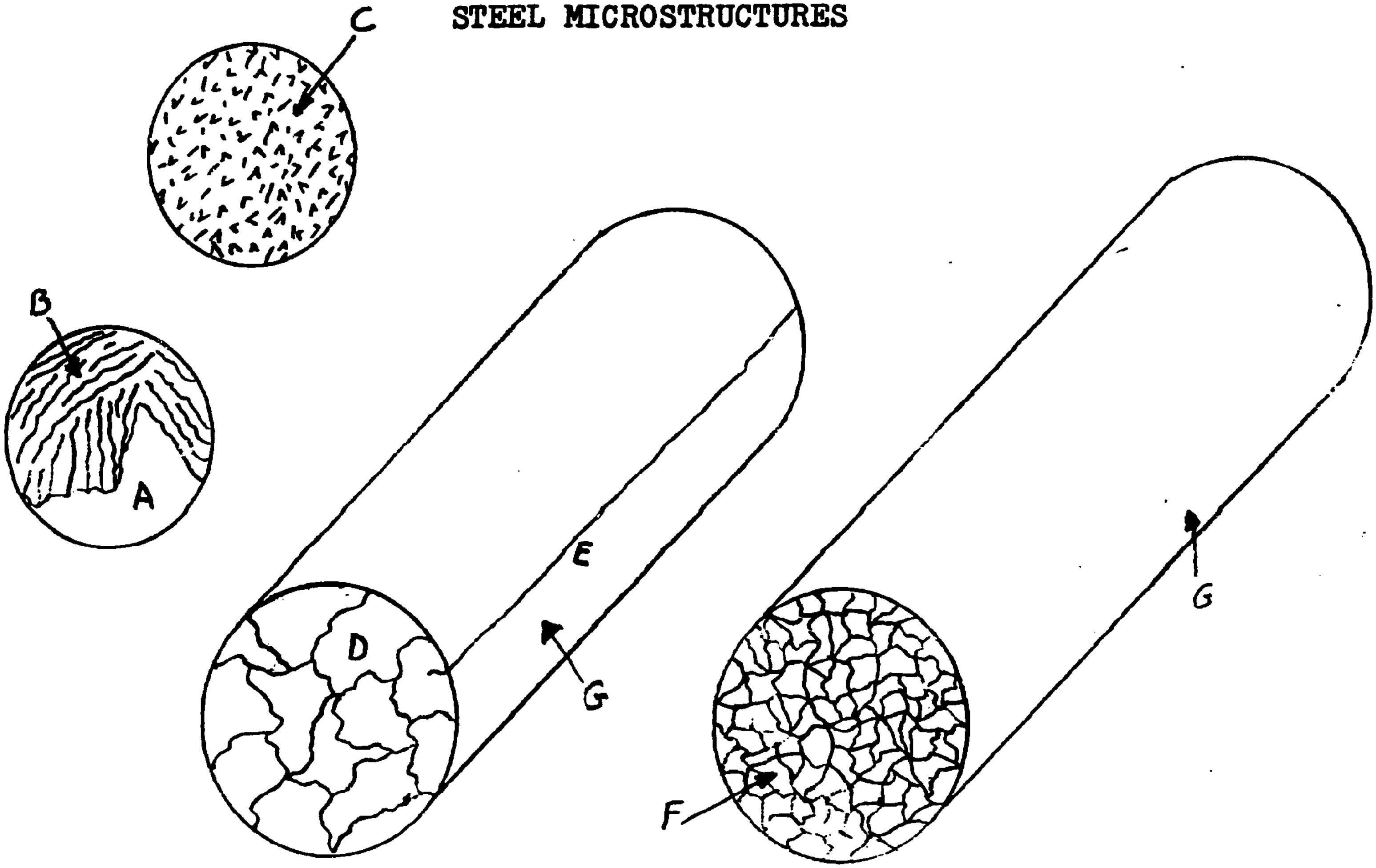


A Seam in pipe

B Seam in rod from which reamer was made

APPENDIX F-1

STEEL MICROSTRUCTURES



A Ferrite, 500 X

B Pearlite, 500 X RB 82

C Martensite, 500 X RC 64

D Coarse grain

E Seam, inherent from ingot

F Fine grain

G Rolled from ingot stock

APPENDIX G

FATIGUE CRACK IN BEAM

A Load, variable

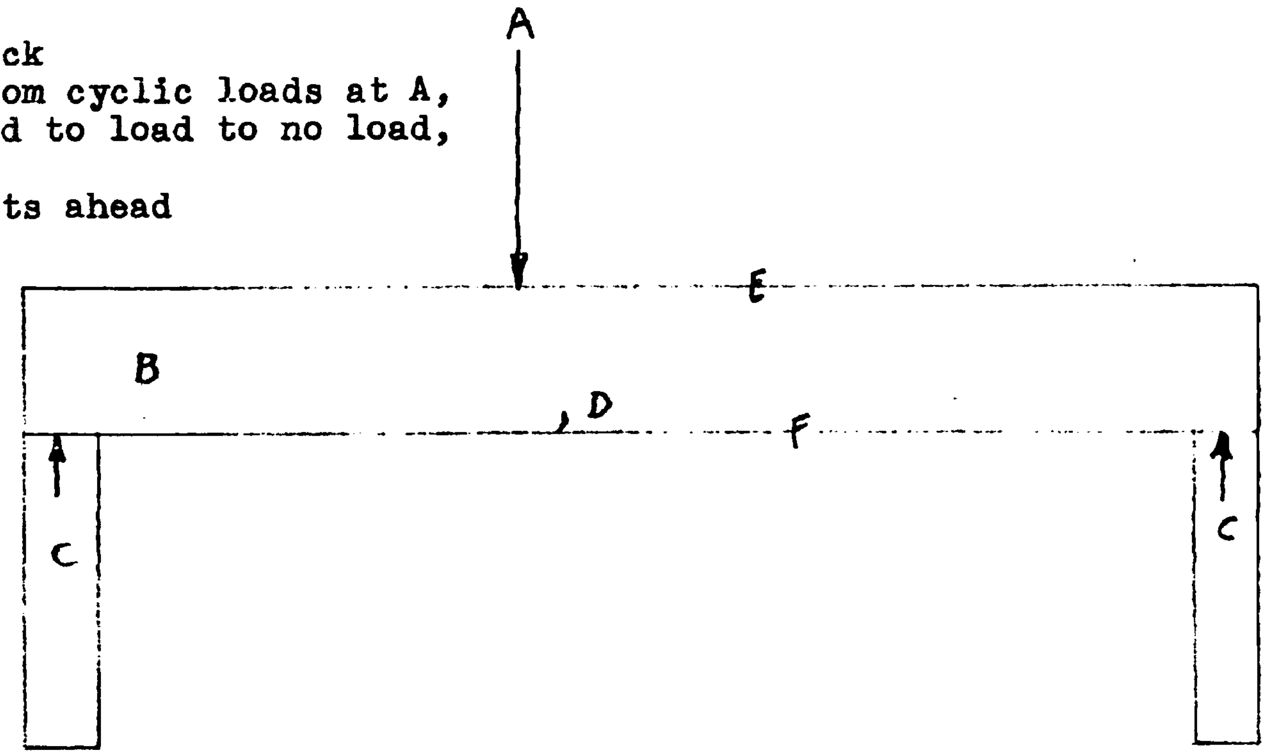
B Beam

C Column

D Fatigue crack
Resulted from cyclic loads at A, from no load to load to no load, etc.
Failure rests ahead

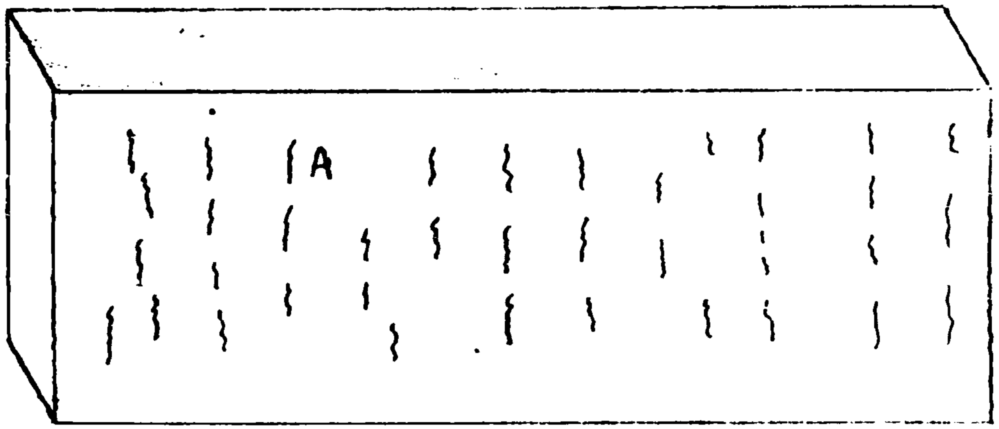
E Compression stress

F Tensile stress



APPENDIX H

CHECKS IN GROUND PART



A Checks (cracks)
Bar was surface ground; checks appeared while and after grinding

APPENDIX H-1

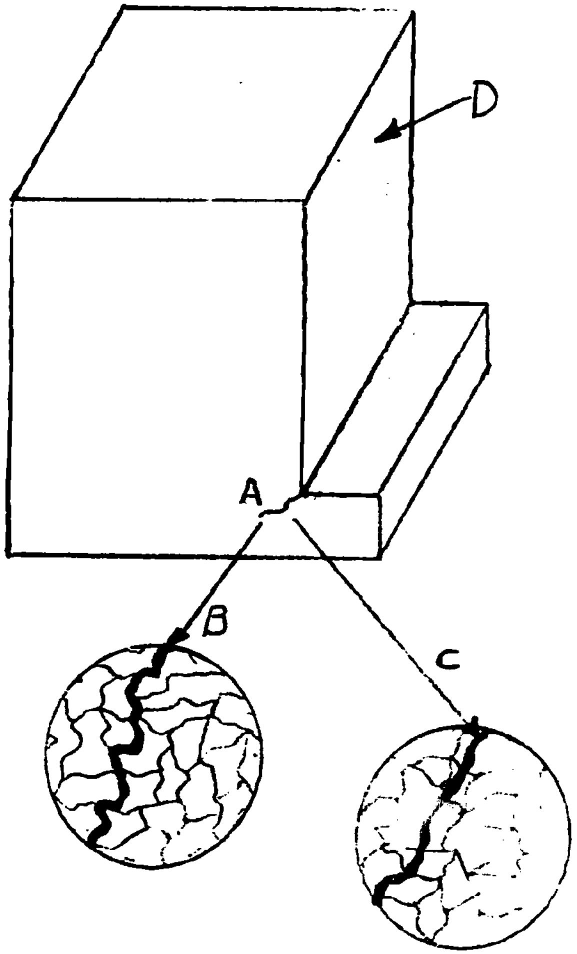
DESIGN CRACK

A Crack - Uneven mass and 90 degree corner with no fillet

B Intergranular crack, 200X

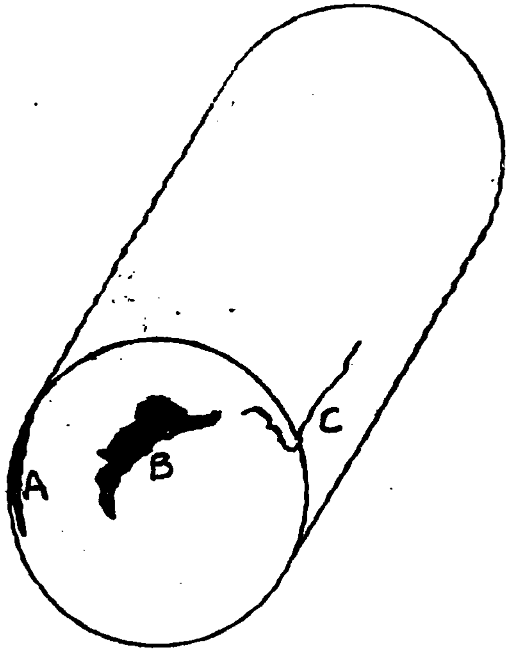
C Intragranular crack, 20

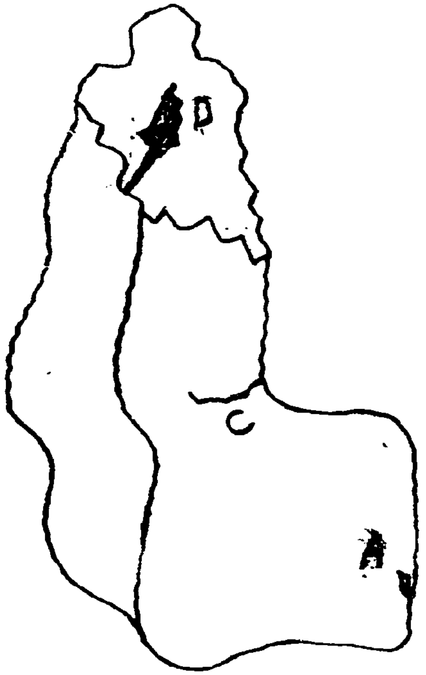
D Hardened steel, martensite, RC 64



APPENDIX I

FORGING LAPS AND CRACKS





A Lap, oxide caught between layers of metal

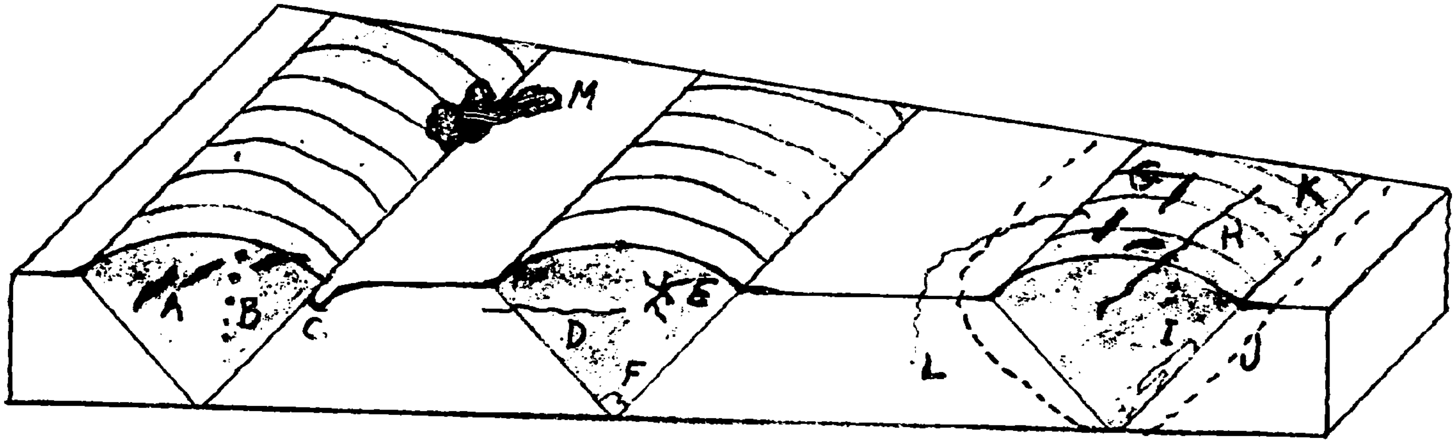
B Burst, surface

C Cracks

D Burst, internal

APPENDIX J

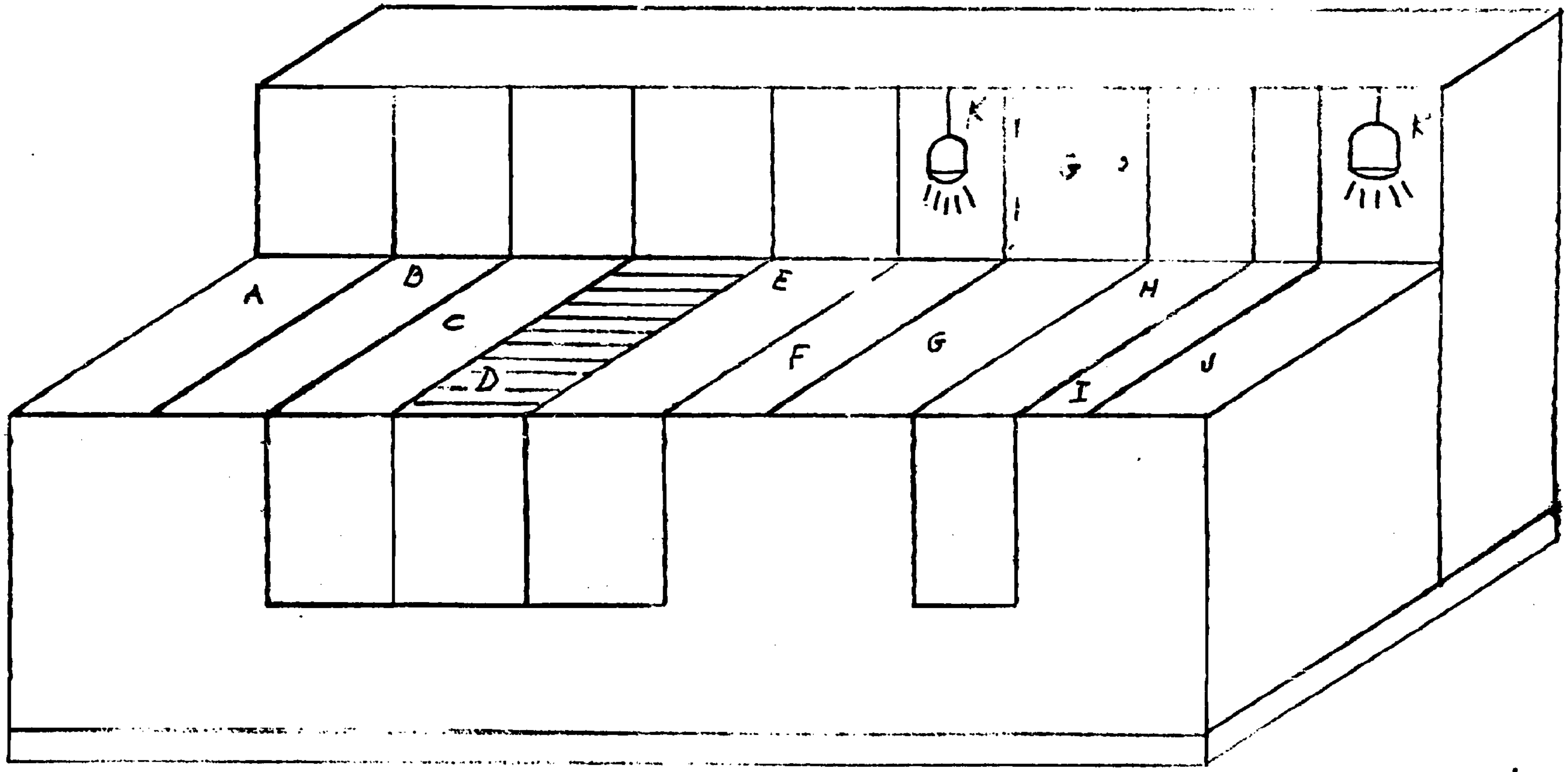
DISCONTINUITIES IN WELDS



A	Inclusion
B	Porosity
C	Undercut
D	Transverse crack
E	Star crack
F	Lack of penetration
G	Surface inclusion
H	Longitudinal crack
I	Lack of fusion
J	Weld zone
K	Bead
L	Fusion zone crack
M	Scale or slag

APPENDIX K

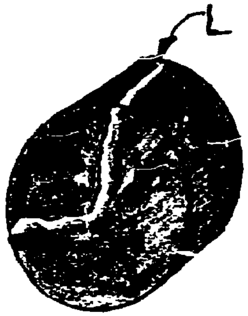
LIQUID PENETRANT TESTING UNIT*



A Bench
B Bench
C Penetrant tank
D Drain

E Washing
F Examination
G Drying
H Developer

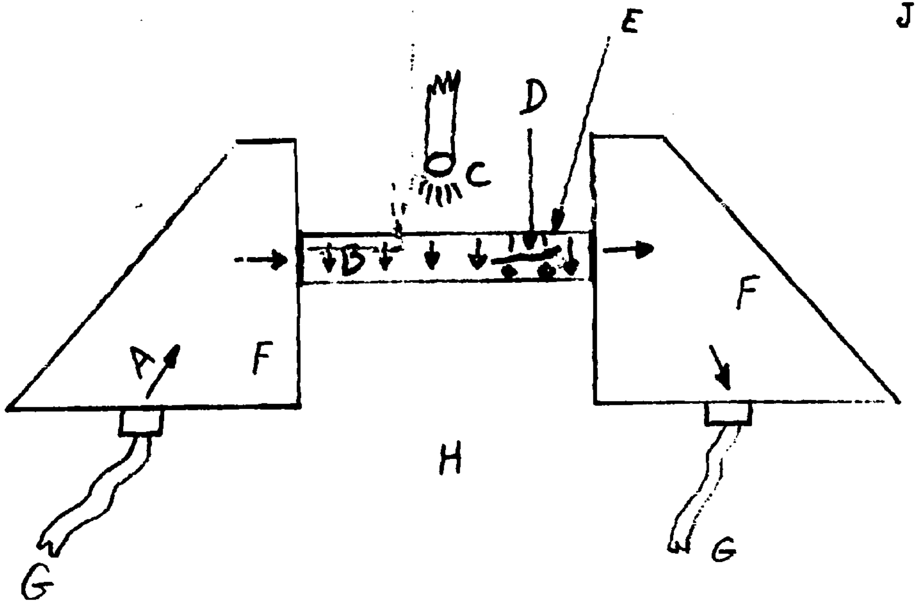
I Visual inspection
J Final inspection
K Black light
*Locally manufactured
L Crack (black light)

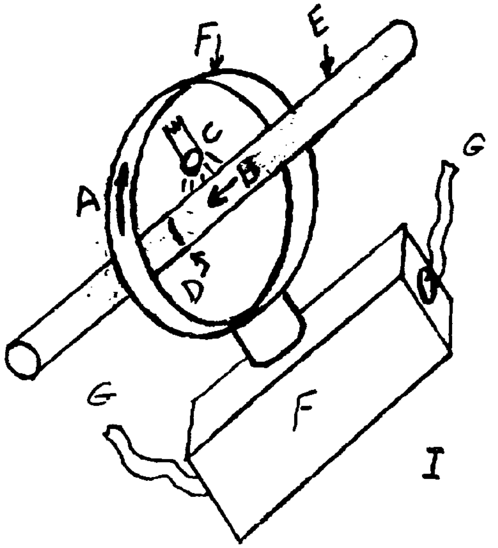


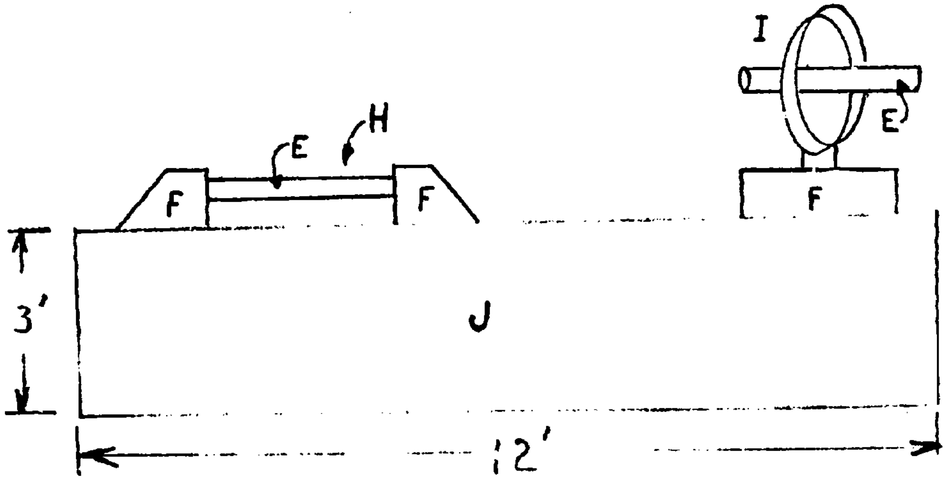
APPENDIX L

MAGNETIC PARTICLE TESTER

A	Current flow
B	Flux
C	Inspection liquid
D	Crack
E	Part
F	Part holder
G	Electric cable
H	Circular
I	Longitudinal
J	Magnetic particle tester

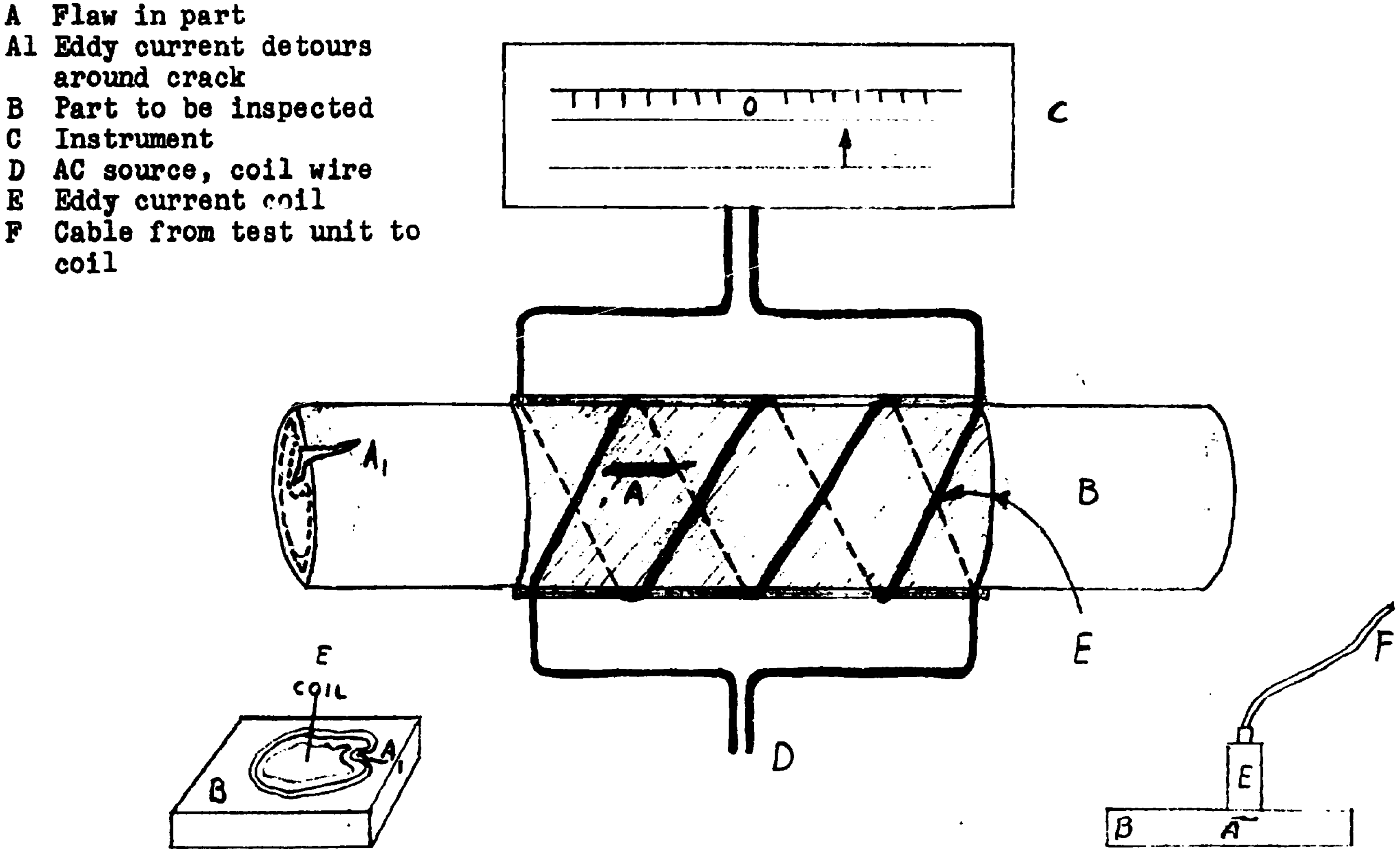




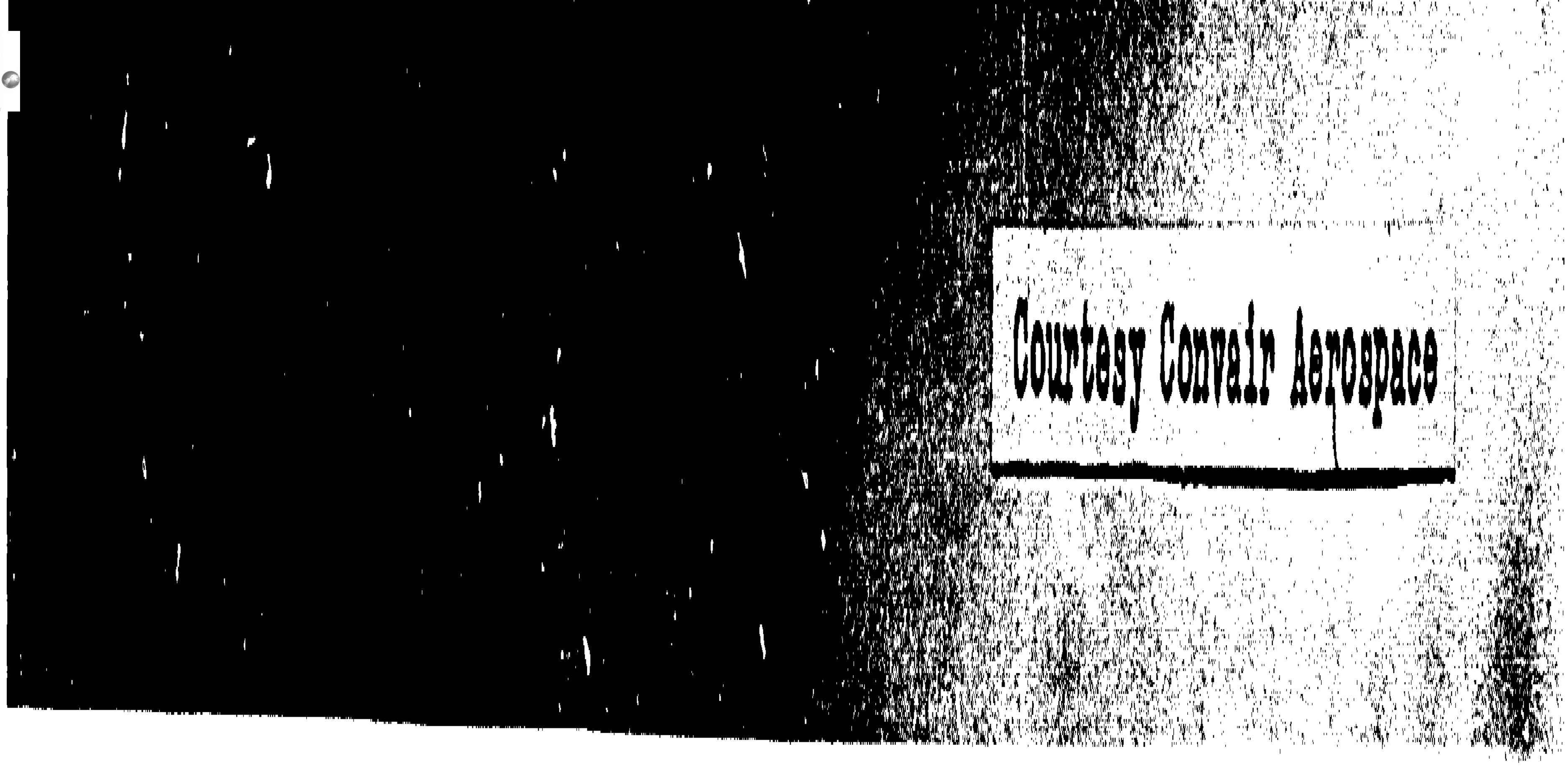


APPENDIX M

EDDY CURRENT COIL
(Schematic)



A Flaw in part
A1 Eddy current detours around crack
B Part to be inspected
C Instrument
D AC source, coil wire
E Eddy current coil
F Cable from test unit to coil

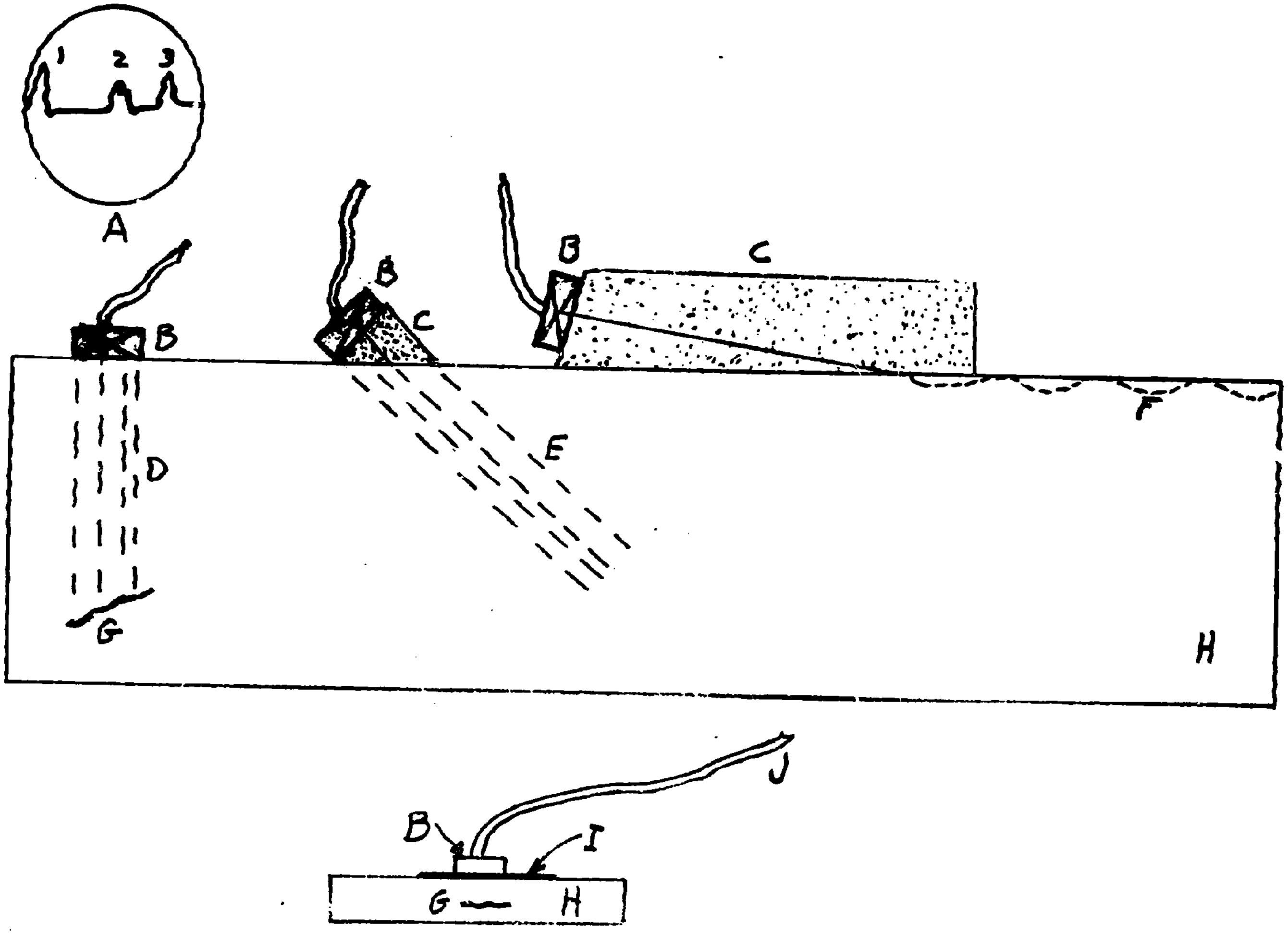


Courtesy Convair Aerospace


DIX N-1
ELECTRONICS
30
40
50
ED
ASTER
FINE
LIFTOFF

APPENDIX P

TRANSDUCERS AND WAVES*



*Continued

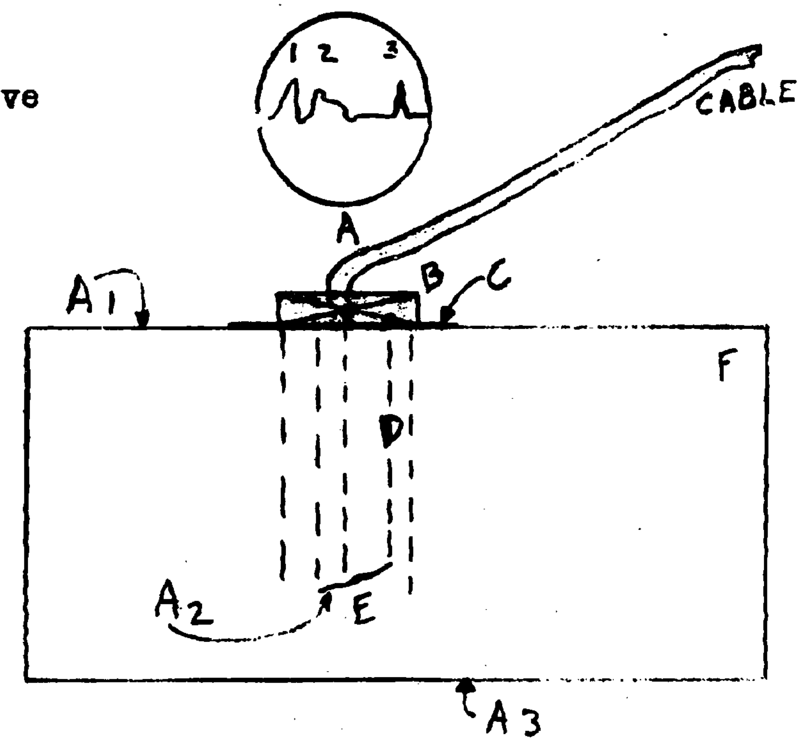
APPENDIX P --*Continued*

A	Oscilloscope picture and pips
A1	Initial impulse
A2	Discontinuity
A3	Back side reflection
B	Transducer (ultrasonic)
C	Wedge
D	Longitudinal wave
E	Shear wave
F	Surface wave
G	Discontinuity
H	Part to be inspected
I	Couplant
J	Cable from unit to transducer

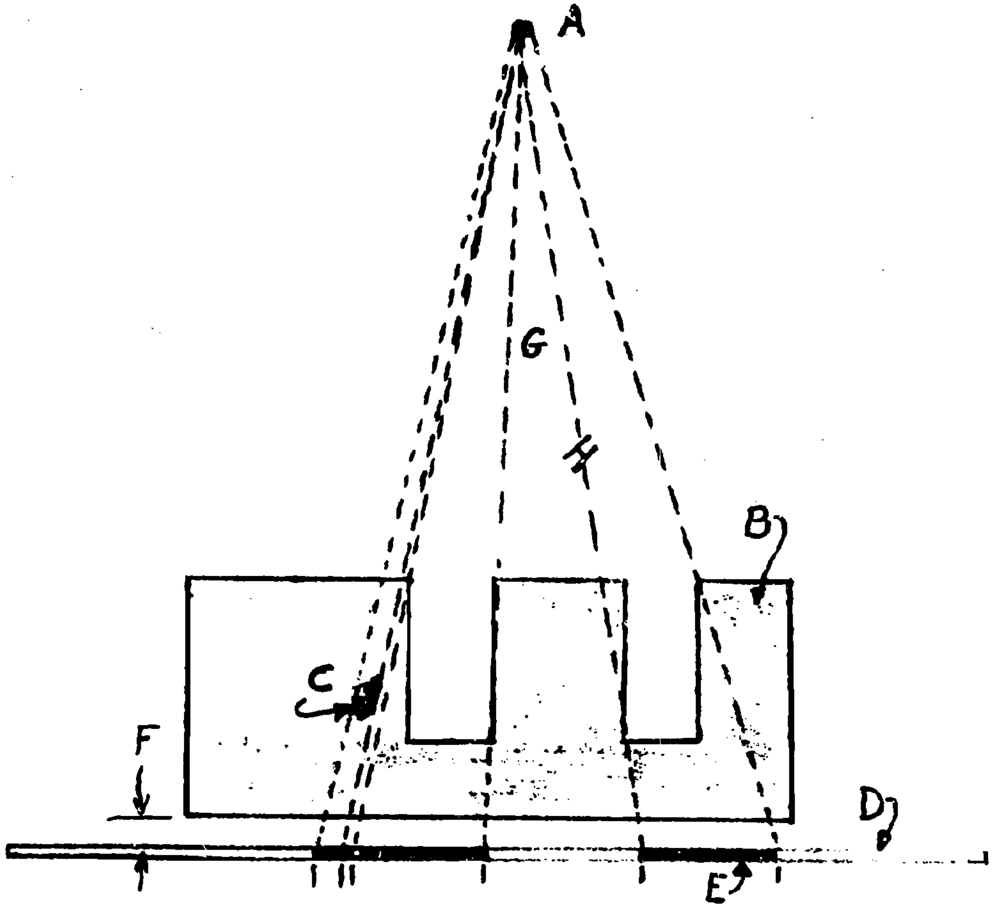
APPENDIX Q

OSCILLOSCOPE PICTURE OF DISCONTINUITY

A	Oscilloscope pips
A1	Initial ultrasonic impulse
A2	Discontinuity
A3	Back reflection
B	Transducer
C	Couplant
D	Longitudinal beam wave
E	Discontinuity
F	Part to be inspected



APPENDIX R--continued



A	Source of radiation
B	Part
C	Discontinuity
D	Film
E	Dark areas on film
F	Part and film distance
G	Part and source distance
H	Ray lines enclose mass differential only; other areas of part will show on film as lighter areas

APPENDIX S

GENERAL EDUCATION SUBJECT MATTER

Oral communication

Technical writing

Fundamentals of physics

Industrial chemistry

Fundamentals of electronics

Applied electronics

Applied algebra

Applied geometry

Applied trigonometry

Quality control

Metrology

Basic statistics

Manufacturing processes

Basic metallurgy

Heat treatment of metals

Specifications and standards

Operator equipment maintenance

Safety precautions

APPENDIX T

ADDITIONAL SUBJECT MATTER RECOMMENDED IN THE TRAINING OF NDT TECHNICIANS

Acoustic Emission
Automation Possibilities
Blueprint Reading
Codes and Specifications
Combined Systems
Computer Support
Equipment Maintenance and Familiarization
Factory Training
Field Trips
Hardness Testing
Holographic
Legislative Laws and Proposals
Magnetic Rubber
Microstructure Correlations
Responsibility in Detection
Safety Factors and Practices
Sensitive Detection Methods
Sensitive Instrumentation
Set-up Procedures
Signal Synthesis
Present Shortage of NDT Technicians
Standards and Specifications
Support from Professional Organizations
Swinging Field
Updating Equipment
Vibration Analysis

APPENDIX U

BRANCHES OF INDUSTRY THAT ARE SUPPORTED WITH NONDESTRUCTIVE TESTING PROCESSES

Aerospace Activities
Air Conditioning Equipment
Aircraft Manufacturers (complete)
Aircraft Manufacturers (parts and sub-assemblies)
Aircraft Pilot Training
Air Force Bases
Airlines (freight)
Airlines (passenger)
Appliance Inspections
Architectural
Army
Arsenals
Automotive Parts
Aviation Agencies
Bonded Surfaces
Bridges
Casting
Chemical Producers
Civil Engineering
Compressors
Communications
Corrosion Control
Drilling Companies
Electric Companies
Electro-mechanical
Electronics
Engine Manufacturers
Engineering Testing Laboratories
Farm Equipment
Forging and Rolling Mills
Gasoline and Oil Refiners
Gas Transmission Companies
General Engineering
General Manufacture
Ground Support Equipment (aircraft)
Heat Treating Plants
Heavy Manufacturing
Helicopter Maintenance
Helicopter Manufacturers
Iron and Steel Producers (mills)
Leasing Companies

APPENDIX U --Continued

Machinery Producers
Machine Shops
Manufacturers (general)
Marine Products
Mechanical Fabricators
Medical
Metal Containers
Metal Foundries
Metallurgical Companies
Metal Parts Manufacturers
Metal Shapes Fabricators
Mining Equipment Manufacturers
Missiles Manufacturers
Munitions Manufacturers
National Aeronautics and Space Administration
Naval Air Stations
Nondestructive Testing Equipment Manufacturers
Nonferrous Metal Producers
Nuclear Plants Parts
Oil and Gas Industries
Ordnance Plants
Pipeline Installations
Plastic Manufacturers
Plating Plants
Power Transmission
Pressure Vessels
Railroads
Railroad Parts Manufacturers
Refrigeration
Research Centers
Road Machinery Manufacturers
Scientific Equipment Manufacturers
Sheet Metal and Fittings
Shipbuilders and Shipyards
Space Hardware
Steel Production
Tank Manufacturers
Tool Manufacturers
Turbine Manufacturers
Valves and Related Parts
Vehicle Manufacturers (passenger)
Vehicle Manufacturers (private)
Weapons
Welding Fabricators, Brazed, and Soldered Parts

APPENDIX V

TECHNOLOGIES RECOMMENDED FOR INSTRUCTION IN NONDESTRUCTIVE TESTING*

Technology	Response	
	No.	%
Metallurgy	170	85.8
Automotive	163	82.3
Welding	163	82.3
Aerospace	160	80.8
Bonding	160	80.8
Mechanical	158	79.7
Machine Shop	152	76.7
Refrigeration	152	76.7
Electrical	151	76.2
Plastics	151	76.2
Civil	150	75.7
Power Transmission	149	75.2
Production	149	75.2
Electro-mechanical	148	74.7
Sheet Metal	147	74.2
Plating	145	73.2
Electronic	138	69.6

*198 respondents

APPENDIX W

NONDESTRUCTIVE TESTING EQUIPMENT

Several items of testing equipment have been selected for each of the main areas of nondestructive testing. These items have been recommended by industry and are available from the indicated manufacturers. Because of the details involved in describing the major items of equipment, no specifications are listed. It is recommended that the manufacturer be contacted so that brochures can be obtained which completely describe the equipment.

All of the following equipment is not required; however, instructors should choose from those items listed which will serve their training objectives. Also, a great quantity of equipment is available; therefore, educational personnel should seek literature from manufacturers prior to requisitioning.

APPENDIX W --Continued

Title	Source	Cost	Type
Accessories for Magnaflux Unit - Model H-710	Magnaflux		Magnetic Particle
Contact Pads #1846C pr.		$ 39.00	
Magnaglo Concentrate No. 14A lb.		46.50	
Accessories - for Magnatest ED 520 Crack Detector	Magnaflux		
General Purpose Probe P/N 62743		35.00	Ultrasonics
Bolt Hole Probe P/N 204623 (3/16" D.)		65.00	
Accessories - for Ultrasonic tester No. PS-702	Magnaflux		Ultrasonics
Model AT-1000 Gate & Attenuation Correction module P/N 207582		375.00	
Transducers - straight or angle beam ea.		145.00	
Acoustic Emission Plug-In Model NDT-101	Nortec	1,295.00	Acoustic Emission
Cabinet - X-ray fluorescent 360 Torr unit with redundant switch on door	W. H. Henken Industries	2,400.00	Radiography
Eddy Current Instrument NDT-8	Nortec	1,145.00	Eddy Current
Conductivity Instrument No. EM2100 8-106% IACS and 26-65% IACS	Automation Industries, Inc.	850.00	Eddy Current

APPENDIX W --Continued

Title	Source	Cost	Type
Conductivity Tester - NDT-5	Nortec	$ 695.00	Eddy Current
Conductivity Tester - NDT-5A	Nortec	995.00	Eddy Current
Conductivity Tester - NDT-5-B	Nortec	1,195.00	Eddy Current
Dark Room Tank - and supplies Picker No. 400167	Picker Industrial	2,150.00	Radiography
Densitometer - McBeth Model TD-100A with voltage regulator	Henken Industries	800.00	Radiography
Differential Hole Probe	Nortec	95.00	Eddy Current
Differential Surface Probe	Nortec	95.00	Eddy Current
Digital Thickness Instrument G-2 with AMC capabilities and 3 transducers 53B172	Automation Industries, Inc.	2,000.00	Ultrasonics
Digital Thickness Instrument G-2S with AMC capabilities and oscilloscope display and 3 transducers 53B177	Automation Industries, Inc.	4,000.00	Ultrasonics
Eddy Current Crack Detection - NDT 2	Nortec	695.00	Eddy Curren
Eddy Current Crack Detection with compensation probe and standard probe No. EM3100	Automation Industries, Inc.	850.00	Eddy Curren

APPENDIX W --Continued

Title	Source	Cost	Type
Eddy Current Instrument - NDT-6	Nortec	$ 4,999.00	Eddy Current
Eddy Current - portable multipurpose No. EM1500 with frequencies from 1-1000 KH with frequency modules and probes	Automation Industries, Inc.	850.00	Eddy Current
Eddy Current Tester NDT-1 solid state	Nortec	4,750.00	Eddy Current
Eddy Current Tester NDT-3	Nortec	1,995.00	Eddy Current
Film - X-ray and polaroid film supplies	W. H. Henken Co.	1,000.00	Radiography
Frequency Modules -Nortec	Nortec	25.00	Eddy Current
Holder - Film No. 545 Polaroid 4 x 5 land	Seymour's Photo	65.00	Radiography
Hole Probe -Eddy Current	Nortec	75.00	Eddy Current
Illuminator - High intensity, Picker No. 240120 with spot view attachment No. 240121	Gilbert X-ray Co.	450.00	Radiography

APPENDIX W --Continued

Title	Source	Cost	Type
Immersion Scanning and Recording System US454 with tank 18x12x36 inches, turntable and drum for disc or drum recordings and C scan. Complete with mounting block, search tube and manipulator.	Automation Industries, Inc.	$10,000.00	Ultrasonics
Isotope Camera - with source tube, drive beamer and tripod with clamp (less isotope) Model 520	Automation Industries, Inc.	1,850.00	Radiography
Inspection Kit - Black light	Automation Industries, Inc.	100.00	Liquid Penetrant
Instruments - Electrical measuring pertinent to testing, inspection and maintenance activities	Local		
Instruments - Metrology support type, complete kit	Local		
Lead Numbers and Letters	Radiation Equipment Co., Inc.	150.00	Radiography
Magnaflux Unit - Model H-710 230V, 60 cyc, 3 phase with tank and demagnitization unit and GD-50 Magnaglo Hood	Magnaflux	11,530.00	Magnetic Particle

APPENDIX W --Continued

Title	Source	Cost	Type
Magnatest - Model ED-520 Crack Detector	Magnaflux	$ 795.00	Ultrasonics
Magnetic Particle Unit - Portable AH-8 with 2 ea. 15 ft. cables 4/0 and prods	Automation Industries, Inc.	950.00	Magnetic Particle
Meter-Survey Victoreen No. 530924 Model 59213	Picker Industrial	415.00	Radiography
Penetrameter - X-ray reference blocks, all standard materials and thickness	Radiation Equipment Co. Inc.	300.00	Radiography
Penetrant - Fluorescent Dye Kit	Automation Industries, Inc.	150.00	Liquid Penetrant
Penetrant - Liquid Visible Dye Kit	Automation Industries, Inc.	150.00	Liquid Penetrant
Penetrant - Zyglo Kit	Magnaflux	140.00	Liquid Penetrant
Penetrant Zyglo - ZA28E 230V, 60 cyc, single phase inspection black light unit complete	Magnaflux	3,290.00	Liquid Penetrant
Probe Cables -Eddy Current	Nortec	15.00	Eddy Current

APPENDIX W --*Continued*

Title	Source	Cost	Type
Probe - Parker No. 200 Kit	Whitson Engineering Co.,Inc.	$ 280.00	Magnetic Particle
Probes - Surface Eddy Current	Nortec	95.00	Eddy Current
Recorder - Ultrasonic No. SR5	Krautkramer	2,111.00	Ultrasonics
Sorting Instrument - Eddy Current No. EM1300-EM1400 with part counter modules linear time base and flying spot CRT presentation with 1,2,3 in. I.D. Coils	Automation Industries, Inc.	4,500.00	Eddy Current
System - Fluorescent penetrant all stations and accessories complete	Automation Industries, Inc.	4,000.00	Liquid Penetrant
Tools - Electronic, small hand for supporting electronic maintenance activities, complete kit	Local		
Tools - Metal working, small hand for supporting small metal working shop, complete kit	Local		
Tools, Power, small pertinent to electrical and metallurgical laboratories	Local		

APPENDIX W --Continued

Title	Source	Cost	Type
Traceable Conductivity Standards -Eddy Current	Nortec	$ 200.00	Eddy Current
Transducers - Ultrasonic set	Automation Industries, Inc.	1,500.00	Ultrasonics
Tube - X-ray 160KV Headstand complete 65C305	Automation Industries, Inc.	750.00	Radiography
Ultrameter - NDT - 116	Nortec	1,500.00	Ultrasonics
Ultrascope - Model NDT-130	Nortec	2,495.00	Ultrasonics
Ultrasonic Flaw Detector Model USK5	Krautkramer	1,950.00	Ultrasonics
Ultrasonic Flaw Detector Model USK 5MR	Krautkramer	2,850.00	Ultrasonics
Ultrasonic Flaw Detector Model USK 5M	Krautkramer	2,350.00	Ultrasonics
Ultrasonic Plug-In Tester - No. NDT-100	Nortec	695.00	Ultrasonics
Ultrasonic Tester - Model PS-702 Complete with Transducer Cable, battery pack, dust cover, cable and manual	Magnaflux	2,000.00	Ultrasonics

APPENDIX W --Continued

Title	Source	Cost	Type
Ultrasonic Tester - Gated Plug-In Model NDT-102	Nortec	$ 1,295.00	Ultrasonics
Ultrasonic Thickness Tester-Model NDT-110	Nortec	995.00	Ultrasonics
Ultrasonic Thickness Gage - Model NDT-120	Nortec	1,145.00	Ultrasonics
Ultrasonic Thickness Gage-NDT 120D	Nortec	605.00	Ultrasonics
Ultrasonic Underwater Thickness Gage - Model - 110V	Nortec	1,495.00	Ultrasonics
Ultrasonic Unit - UM771 with timer AG50D643 AG-IF 50D525 10S db Pulser-Receiver, 50C753 Transigate, 450E641SWB Recording Amplifier	Automation Industries, Inc.	5,500.00	Ultrasonics
Ultrasonic Unit - UM775 with timer AG50D657 and marker 50D571 10W-DAC Pulser-Receiver	Automation Industries, Inc.	4,000.00	Ultrasonics
Unit - Wet Magnetic Particle with black light, hood, contact pads	Automation Industries, Inc.	7,500.00	Magnetic Particle

APPENDIX W --Continued

Title	Source	Cost	Type
X-Ray - Magnaflux Tube Head 150KV, beryllium window 1.5 - 0.5 mm focal spot	Magnaflux	$ 6,000.00	Radiography
X-Ray unit - 160KV, 160-E-8-C, 5 ma 40 degrees with beryllium window, gas filled head water cooled complete with: Power cable 25 ft. Control cable 25 ft. Control cable extension 25 ft. Control cable extension 50 ft. Coolant hose twin 50 ft. Power cable 50 ft.	Automation Industries, Inc.	6,250.00	Radiography
X-Ray unit - Portable Bendix XM105	Picker Industrial	2,795.00	Radiography
Yoke Kit - Portable 50B290	Automation Industries, Inc.	150.00	Magnetic Particle

APPENDIX W-1

NDT EQUIPMENT MANUFACTURERS

Automation Industries, Inc.
10210 Monroe Drive
Dallas, Texas 75229

Branson
Progress Drive
Stamford, Conn. 06904

Cenco X-ray
4401 W. 26th Street
Chicago, Ill. 60623

Custom Machine, Inc.
9200 George Ave.
Cleveland, Ohio 44105

Dayton X-ray Company
1150 W. 2nd Street
Dayton, Ohio 45407

DuPont Company
Room 7353
Wilmington, Delaware 19898

Eldorado Manufacturing Co.
1935 Briarwood
Irving, Texas

GAF Corporation
140 W. 51st Street
New York, N. Y. 10020

Gilbert X-ray Co.
624 Hall St.
Dallas, Texas 75226

Industrial Radiographic
Supply Unlimited
P. O. Box 746
Kenner, La. 70062

Jodon Engineering Associat
145 Enterprise Drive
Ann Arbor, Michigan 48103

Kodak Co.
Rochester, N. Y.

Krautkramer Ultrasonics, Inc.
One Research Drive
Stratford, Conn. 06497

Magnaflux Corporation
6115 Denton Drive
Dallas, Texas 75235

Nat[illegible]l Statham, Inc.
92-91 Corona Ave.
Elmhurst, N. Y. 11373

Nortec
3001 George Washington Way
Richland, Washington 99352

Penetrameters
20903 So. New Hampshire Ave.
Torrance, Calif. 90502

Philips Electronic Instruments
750 So Fulton Ave.
Mt. Vernon, N. Y. 10550

Picker Industrial
1514 Mayfield Ave.
Garland, Texas 75040

Radiation Equipment Co.
1495 Old Deerfield Rd.
Highland Park, Ill. 60035

Seifert X-ray Corporation
P. O. Box 124
King of Prussia, Pa. 19406

Seymour's Photo
6104 Camp Bowie
Fort Worth, Texas 76116

Tac Technical Instrument
Corporation
Scotch Rd.
Trenton, N. J. 08628

APPENDIX W-1 --Continued

Varian
611 Hansen Way
Palo Alto, Calif. 94303

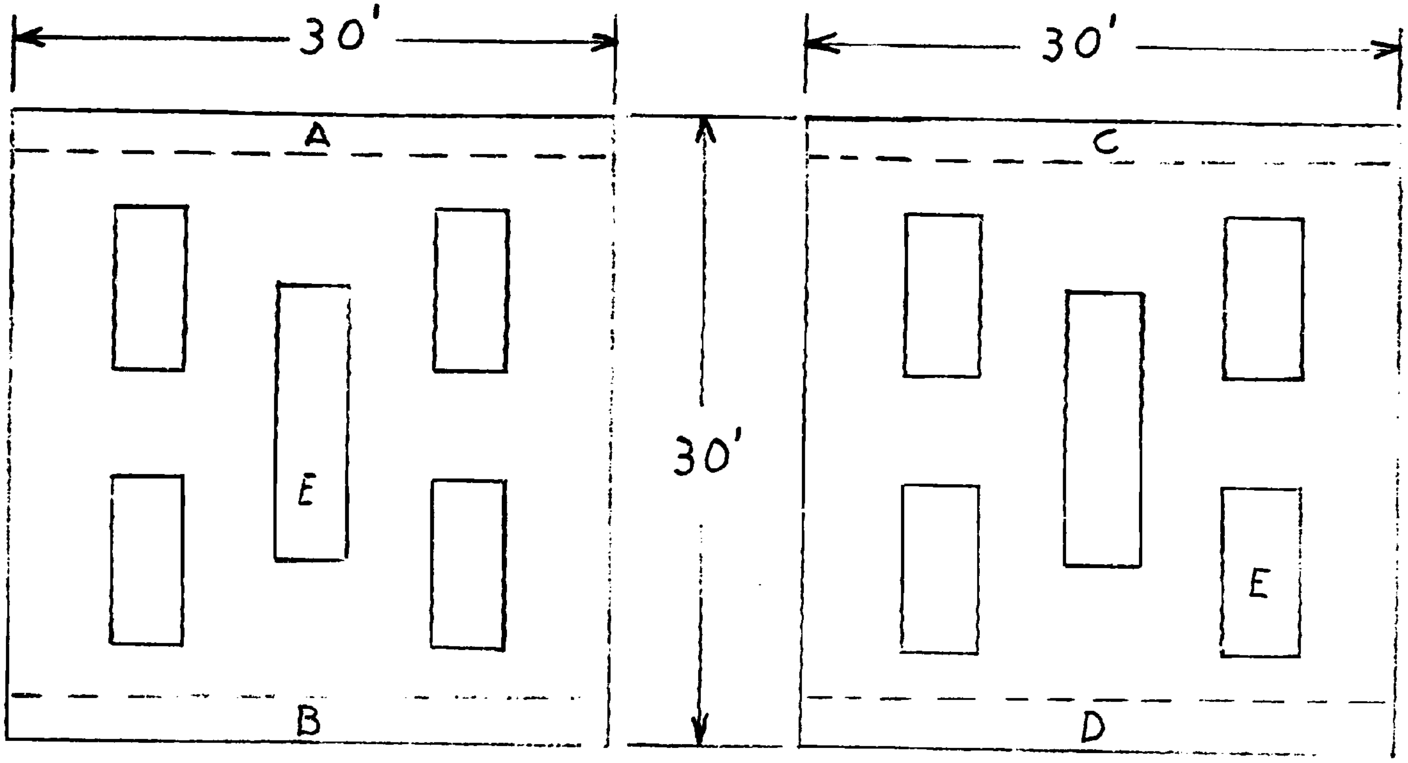
Victoreen Instrument Division
10101 Woodland Ave.
Cleveland, Ohio 44104

W. H. Henken Industries
415 Lillard Lane
Arlington, Texas

APPENDIX X

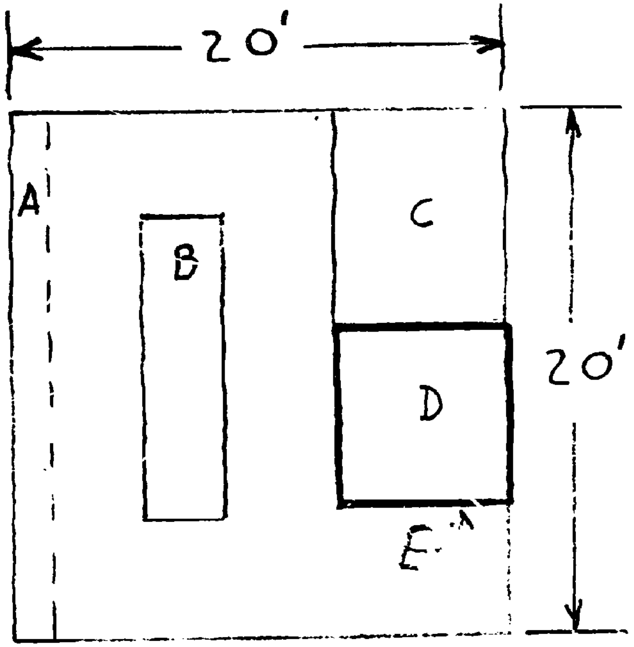
LABORATORY ARRANGEMENT
(Floor Plan)

A	Liquid Penetrant facilities
B	Magnetic Particle facilities
C	Eddy Current facilities
D	Ultrasonic facilities
E	Benches for experiments



APPENDIX X --Continued

LABORATORY ARRANGEMENT
(Floor Plan)



A	Radiographic
B	Benches
C	Dark room
D	Radiation testing
E	Lead shielding, including roof, for X and gamma ray testing

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