Nondestructive testing : a curriculum developed for industrial education
by Merle Clifford Thomas

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF EDUCATION
Montana State University

Abstract:
This study dealt with the problem of selecting methods of nondestructive testing which met the criteria selected by the writer for this study. This criteria included an evaluation of eddy currents, liquid penetrants, magnetic particles, radiography, and ultrasonics in terms of their: (I) compatibility to existing industrial education programs, (2) ability to satisfy one or more of the present needs of industry, (3) relative simplicity and broad encompassing nature, (4) potential in satisfying what the writer believes to be a weakness of the present industrial education program; the exclusion of nondestructive testing methods from the industrial education program, and (5) the educational requirements and competency levels expected of inspectors. The radiographic and ultrasonic methods of testing did not meet the criteria of this study; therefore, procedures for applying these tests in an industrial education program were not included in the study.

Although numerous articles and books exist which deal with the various aspects of nondestructive testing, there are few which deal with this subject in a form easily understood by industrial education teachers. The writer found that there is a definite need for these testing methods in the industrial education program since they could provide a closer correlation between the goals and objectives of industrial education and the needs of industry. This study points out the requirements for initiating a program of nondestructive testing in the areas of eddy current testing, liquid penetrant testing, and magnetic particle testing.

The conclusions reached as a result of this study were: (1) industrial education should provide individuals with measurable competencies in the area of nondestructive testing; (2) there is a definite need for individuals with these competencies in industry; (3) this type of curriculum can easily and quickly be incorporated into existing educational programs; or (4) new programs could be developed in conjunction with chemistry, science, or industrial education programs.

The major recommendations reached as a result of this study were: (1) the guidelines developed in this study were applicable to teachers as well as individuals considering careers in industrial technology; (2) a curriculum committee should be established to develop goals and objectives which are essential to the success of the program; and (3) the curriculum committee should develop a continuous program of evaluation to determine the degree to which the goals and objectives of the nondestructive testing program are being realized and to recommend changes in the program as the need arises.

NONDESTRUCTIVE TESTING: A CURRICULUM DEVELOPED
FOR INDUSTRIAL EDUCATION

by

MERLE CLIFFORD THOMAS, JR.

A thesis submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF EDUCATION

Approved:

Eric R. Strohmeyer
Chairperson, Graduate Committee

Robert J. Thibault
Head, Major Department

Henry L. Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

July, 1976

ACKNOWLEDGMENT

The writer wishes to express his gratitude and appreciation to the members of the thesis committee: Dr. Eric Strohmeyer, Chairman, Dr. Henry Parsons, Dr. Douglas Herbster, Dr. Gerald Sullivan, Dr. Bruce Jacobsen, and Mr. Francis Sprinkle. He is grateful for their patience, consideration, encouragement, and understanding during the writing of this study. He would like to thank his major advisor, Dr. Eric Strohmeyer, for his personal attention and encouragement during the period this study was in progress. Without his help, this study would not have been completed.

The writer wishes to express his appreciation to Mr. Carl E. Betz of Magnaflux Corporation, Mr. T. W. Judd of Republic Steel Corporation, and the Convair Division of General Dynamics for their personal interest and assistance in the development of this study.

The encouragement shown by his wife, Teresa, and his sons and daughters is deeply appreciated.

Although the writer initiated this study, its successful completion is doubtful without the patience, understanding, and assistance of those mentioned above.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study dealt with the problem of selecting methods of nondestructive testing which met the criteria selected by the writer for this study. This criteria included an evaluation of eddy currents, liquid penetrants, magnetic particles, radiography, and ultrasonics in terms of their: (1) compatibility to existing industrial education programs, (2) ability to satisfy one or more of the present needs of industry, (3) relative simplicity and broad encompassing nature, (4) potential in satisfying what the writer believes to be a weakness of the present industrial education program; the exclusion of nondestructive testing methods from the industrial education program, and (5) the educational requirements and competency levels expected of inspectors. The radiographic and ultrasonic methods of testing did not meet the criteria of this study; therefore, procedures for applying these tests in an industrial education program were not included in the study.

Although numerous articles and books exist which deal with the various aspects of nondestructive testing, there are few which deal with this subject in a form easily understood by industrial education teachers. The writer found that there is a definite need for these testing methods in the industrial education program since they could provide a closer correlation between the goals and objectives of industrial education and the needs of industry. This study points out the requirements for initiating a program of nondestructive testing in the areas of eddy current testing, liquid penetrant testing, and magnetic particle testing.

The conclusions reached as a result of this study were: (1) industrial education should provide individuals with measurable competencies in the area of nondestructive testing; (2) there is a definite need for individuals with these competencies in industry; (3) this type of curriculum can easily and quickly be incorporated into existing educational programs; or (4) new programs could be developed in conjunction with chemistry, science, or industrial education programs.

The major recommendations reached as a result of this study were: (1) the guidelines developed in this study were applicable to teachers as well as individuals considering careers in industrial technology; (2) a curriculum committee should be established to develop goals and objectives which are essential to the success of the program; and (3) the curriculum committee should develop a continuous program of evaluation to determine the degree to which the goals and objectives of the nondestructive testing program are being realized and to recommend changes in the program as the need arises.

Chapter 1

INTRODUCTION

The term "nondestructive testing" as it is used in this study is a term given to all methods of testing which permit the inspection and evaluation of a metal without impairing its future usefulness. There is a common tendency to think of nondestructive testing as being limited to the detection of harmful flaws, but such is not the case since these tests can be designed to measure properties which are not considered flaws in the usual sense (Betz, 1966:19). The eddy current method of inspection can, for example, determine material thickness coatings, sort items according to their composition or alloy and monitor metallurgical conditions such as hardness, grain size, and degree of heat treatment. From a quality control point of view, the results of these tests are most significant.

Nondestructive testing in industrial education is still considered to be in its infancy. If it is expected to satisfy the demanding needs of society, new methods and techniques must be developed, including more sophisticated equipment and materials. To accomplish this goal, basic research should be accelerated and programs developed which insure a steady supply of competent inspectors.

With all of our advanced technology, all of our high specialized processes and all of our devices developed for quality control, industry is still unable to produce materials which possess the high degree of freedom from imperfection that complicated machines and demanding services require. Industry continues to have defective materials, and it should be prepared to evaluate every possible means of locating defects before they can be built into machines and eventually cause them to fail (Betz, 1958:8).

During the period 1930 to 1940, considerable progress was made in the field of nondestructive testing. Industries were coming to regard these methods of inspection with important, if not vital, significance. This was especially true in aircraft maintenance and manufacture. In airframe and engine inspections, nondestructive testing methods were eagerly accepted. The aircraft industry had become so safety conscious that for many years expense was a secondary consideration to any method of testing that would help to assure the integrity and safe life of engines and structures (Betz, 1963:1-2).

Today the acceptance of nondestructive testing methods in industry is practically universal and experience with these methods is now so extensive that complete confidence exists in nondestructive testing methods and in the ability of competent inspectors to interpret the test results (Beta, 1967:59).

Statement of the Problem

Five major methods (Betz, 1966:19) of nondestructive testing are in use today, and it is to these methods that this study is directed. The problem of this study was twofold:

1. To evaluate the five major methods, to determine those applicable to industrial education in a high school situations, and

2. To describe procedures for applying the methods selected in a form more easily understood by high school teachers.

Importance of the Study

McGonnagle (1961:vii) states that ". . . one of the primary requirements in expanding the technology demanded for the solution of tomorrow's problems is education in the field of nondestructive testing."

The writer believes that industrial education has values which apply to all levels of education and in a continuous program these values should become progressively more intensive and cumulative in their effect. It appears to the writer that the statement by Jacobsen (1968:4) can no longer be ignored: "Industrial education too often reflects the revolution of the past century rather than the technological evolution which has taken place since 1940. Much of the relevant content to which we must relate did not exist at that time."

The need to include these methods of testing in the industrial education program becomes increasingly apparent as one considers the statement by Mr. F. B. Stern, Director of Nondestructive Testing, Magnaflux Corporation (1970 personal letter to the writer): "Training in all areas of nondestructive testing is desperately needed by industry. The initial training of prospective operators must be initiated by the schools."

Further justification for including these testing methods in the educational curriculum can be found in the statement by Mr. T. W. Judd, Assistant Division Head of Nondestructive Testing, Republic Steel Corporation (1974:personal letter to the writer):

> . . . at Republic, nondestructive testing is extensively employed to control manufacturing costs and processes, to maintain a uniformly high level of quality and to assure product compliance with technical specifications. Toward this end we employ three to four hundred personnel in nondestructive testing research, product testing, and equipment maintenance and repair. The majority of these prople have had no more than a high school education and probably none have had the type of training you are suggesting. However, such training would be most valuable to one working in this field.

The significance of including nondestructive testing methods in the industrial education curriculum has been stated by those who are most knowledgeable in this field. Mr. Carl E. Betz, Nondestructive Testing Consultant and past Vice President, Magnaflux Corporation (1974: personal letter to the writer), makes his opinion quite clear in the following statement:

> . . . I believe the high school senior, in general, is quite capable of understanding the basic concepts of nondestructive testing if they are presented without the complex theoretical details. If they are interested in a program which is orientated toward any of the branches of engineering or mechanics, the subject of nondestructive testing would be most useful and interesting. But it must be a carefully planned program which should, if possible, include some laboratory work with either the actual equipment or some simple demonstrations.
>
> For many years I have advocated the teaching of this subject at an early age in the education of young persons who are following a program leading to any branch of engineering or mechanics. Just how early it is considered profitable to begin such

instruction however, may depend upon the ability of the instructor to create interest in the subject and upon the capability of the students to assimilate these methods.

Further evidence of the importance of including these methods in the industrial education curriculum have been stated by Mr. Bruce D. Taylor, Director of Training, Magnaflux Corporation (1974: personal letter to the writer):

> . . . who says this method of testing should be included in the high school curriculum? There is not really one single source or even a large group that can make that statement. But my question to them might be, who says that auto mechanics, woodworking, metalworking or welding should be taught in the high schools? Who is to say where anything should have its start? I cannot give one good reason for not teaching nondestructive testing in the high school other than the mental laziness on the part of the instructor. It does require work preparation on the part of the instructor presenting the course.
>
> Trained nondestructive testing personnel are in great demand, especially in the nuclear inspection field. It can be a great advantage to a youth coming out of high school to have this specialized training. This is especially true if he is going directly to work in industry.

These statements are reinforced by Mr. Roy L. Odell, Western Manager, Automation Industrial Incorporated, Sperry Division (1974: personal letter to the writer):

> . . . as a salesman, I encountered many applications for nondestructive testing in industry and it is extremely evident that there is a manpower shortage for trained and qualified personnel.
>
> At the present time there are a few community colleges in the northwest which have nondestructive testing programs in their curriculums. But, there is in my opinion a definite need for new people in this field.

It has been stated that the principles of nondestructive testing date back to the period prior to World War II (Betz, 1963:47).

However, in the opinion of the writer, very little effort has been made to include these methods of testing in the industrial education curriculum. This is particularly disheartening in light of the statement of Mr. J. E. Hinkel, Manager, Application Engineering, Lincoln Electric Company (1974: personal letter to the writer):

> . . . all of the processes used in nondestructive testing operate on sound and relatively simple principles of physics, electricity and science. As such they are extremely interesting to students who are so-minded. A casual exposure to these principles could be very rewarding to at least a few of these students. If the curriculum could support it time-wise, I would be in favor of including it.

As an educator in the field of industrial education, David M. Goin (1968:33-34) indicated that nondestructive testing methods could be incorporated into existing metal working programs without disrupting them. It is his opinion that these methods of testing could do much to enhance the present industrial education program.

> . . . in the metal industry today, nondestructive testing is of great importance in design and quality control. These methods can be integrated into the curriculum of the machine shop, welding shop and general metals shop or they could be taught as a separate testing and metallurgy unit involving different tests, heat treating, or the study of metals in general. I sincerely hope that other industrial arts teachers will see the need for this type of program and will work to initiate it in different parts of our country, to try and get away from the old "manual training" concept of teaching metal working in our high schools.

Since industrial education has been charged with the formidable task of reflecting the current image of one of the most important aspects of our present culture: the correlation between education, technology, and industry, the writer believes industrial education teachers cannot be expected to satisfy the needs of their profession until they have developed a certain measure of competency in the area of nondestructive testing. This includes an awareness and knowledge of:

1. The basic theories and principles of these tests
2. The advantages and limitations of these tests
3. The potential safety hazards of the tests, and
4. The skills required to satisfactorily perform these methods of testing

This belief is reinforced by the American Vocational Education Association in their report, <u>A Guide to Improving Instruction in Industrial Education</u> (1968:9-11). In this report, their stated goals and objectives for industrial education were:

A. To develop an insight and understanding of industry and its place in our culture
B. To discover and develop talents, aptitudes, interests and potentialities of individuals interested in technical pursuits
C. To develop an understanding of industrial processes and the practical applications of scientific principles
D. To develop basic skills in the proper care and use of common industrial tools, machines and processes, and
E. To develop problem solving and creative abilities involving materials, processes and products of industry

Methods of Collecting Data

The general procedures which the writer used to gain background knowledge for this study were:

A. An extensive and thorough review of existing published literature as it pertained to past and present methods of conducting nondestructive tests. Professional journals of scientific and trade associations, United States Government publications, current industrial texts and selected publications from manufacturers of nondestructive test equipment and materials were analyzed for relevant data.

B. Personal letters were written to selected specialists in the field of nondestructive testing who were considered to have first-hand knowledge and technical experience in the field of nondestructive testing. A copy of this letter has been included in Appendix C, page 374. Authoritative data were obtained from:

1. Automation Industries Incorporated, Sperry Division, Renton, Washington

2. General Dynamics, San Diego, California

3. Magnaflux Corporation, Chicago, Illinois

4. Office of the Assistant Secretary of Defense, Washington, District of Columbia

5. Pacific Northwest Laboratories, Richland, Washington

6. Republic Steel Corporation, Cleveland, Ohio

7. The Lincoln Electric Company, Cleveland, Ohio

C. In addition to the authoritative knowledge from selected specialists in the field of nondestructive testing, certain knowledge was available to the writer as a direct result of:

1. Completion of a certified Class (C) school of nondestructive testing at the Naval Air Station, Pensacola, Florida

in 1962

2. His past position as supervisor of the nondestructive testing department at Ellyson Field, Pensacola, Florida from 1962-1964

3. Feedback from personal discussions with other members of the United States Navy who were actively engaged in testing aircraft parts with nondestructive testing processes and other civilian personnel who worked in the nondestructive testing division of the overhaul and repair department at the Naval Air Station, Pensacola, Florida

Methods of Organizing Data

Chapters 2 through 6 of this study deal with a critical analysis and evaluation by the writer of the five major nondestructive methods of testing metals. Each of these chapters include:

1. A brief history of one testing process

2. A description of one testing process, the materials, and equipment required to perform the test, the types of discontinuities which could be located with the test and the advantages and limitations of the test

3. The principles of the test

4. The purpose of the test

5. The types of test materials and test equipment commercially available

6. An evaluation of the testing process by the five criteria set forth in the analysis of data section of this chapter

When a testing process met the five criteria, procedures for applying the test in an industrial education program at the high school level were described in depth. These descriptions included:

1. The preparation of the parts prior to the actual test

2. The application of the test materials, if any, to the part being tested

3. The inspection procedures and the methods used to evaluate the parts

4. The methods used to establish acceptable inspection standards

5. The various factors which could adversely affect thest tests

Chapter 7 provides a summary of the study and the conclusions and recommendations of the writer.

Analysis of the Data

Once the data had been collected and organized, each of the testing processes was analyzed and evaluated in terms of its:

1. Compatibility to existing industrial education programs

2. Ability to satisfy one or more of the present needs of industry

3. Relative simplicity and broad encompassing nature

4. Potential in satisfying what the writer believes to be a

weakness of the present industrial education program: the exclusion of nondestructive testing methods from the industrial education program

5. The educational requirements and competency levels expected of inspectors

When a test satisfactorily met the five criteria, procedures for applying the test in an industrial education program was described. The premise of the writer was, that once suitable nondestructive testing guidelines had been described, teachers would be encouraged by the availability of these guidelines to include these testing processes in their programs.

Questions to be Answered

It was stated earlier in this study that the acceptance of nondestructive testing by industry is practically universal, that there is no question as to the usefulness of nondestructive testing and that experience with these methods of inspection is now so extensive that confidence in its indications and in the ability of experienced inspectors to interpret these indications is now the rule in those industries where nondestructive methods of inspection are applicable. Since this study was written specifically for teachers in the area of industrial education, the following question was answered: did the eddy current liquid penetrant, magnetic particle, radiographic and ultrasonic method of inspection meet the evaluative criteria for inclusion in the industrial education program?

Limitations of the Study

1. No attempt was made in this study to provide the reader with information pertinent to the development of the various types of nondestructive test equipment. Emphasis was placed on the description of procedures which the writer considered "need to know."

2. Only those processes, procedures, methods of inspection, and evaluation which were applicable to the nondestructive testing of metals were included in this study.

3. Procedures for applying the nondestructive testing processes were described only when a test process met the five criteria set by the writer.

Delimitations of the Study

This study was further limited to the study of:

1. The five major methods of nondestructive testing. No attempt was made by the writer to examine or evaluate the more than sixty variations of these five major testing methods.

2. Each of the methods selected was examined in terms of whether or not it could specifically meet the five criteria set by the writer for inclusion in the industrial education program.

SUMMARY

The term "nondestructive testing" as it is used in this study is a general term given to all methods of testing which permit the inspection and evaluation of a metal without impairing its future usefulness.

With all of our advanced technology and all of the devices industry has developed for quality control, our nation is still unable to produce materials which possess the high degree from imperfection that our highly complicated machines and demanding services require. The acceptance of nondestructive testing by industry is practically universal today, and experience with these methods is now so extensive that complete confidence exists in these testing processes and in the ability of competent inspectors to interpret the results.

Statements by Betz, Goin, Stern, and Tyler indicated a growing awareness on the part of industry and education that nondestructive testing methods should become an integral part of the educational program. In their opinion, it is the responsibility of the schools to initiate methods of instruction and provide the means for the practical application of these methods of testing.

Numerous volumes have been written on the subject of nondestructive testing, but the writer believes that large amounts of this data were not available in a form easily understood by industrial education teachers.

The problem of this study was twofold: (1) to evaluate the five major methods of nondestructive testing according to the criteria set by the writer for inclusion in industrial education programs; and

(2) to describe procedures for applying those testing processes found acceptable to the industrial education program in a form more easily understood by teachers. Once the data had been collected and organized, each of the testing processes was evaluated in terms of five criteria:

1. Compatibility to existing industrial education programs

2. Ability to satisfy one or more of the present needs of industry

3. Relative simplicity of the test and its broad encompassing nature

4. Potential in satisfying what the writer believes to be a weakness of the present industrial education program: the exclusion of nondestructive testing methods from the industrial education program

5. The educational requirements and the competency levels expected of entry-level inspectors

An in-depth description for applying these tests in industrial education programs was included only when a test satisfactorily met the five criteria set by the writer. The premise of the writer was, that once suitable nondestructive testing guidelines had been described, teachers would be encouraged by the availability of these guidelines to include these testing processes in their industrial education program.

No attempt was made by the writer to provide the reader with data pertinent to the development of test equipment or materials.

Emphasis was placed on the description of "need to know" data in a form more easily understood by industrial education teachers.

Chapter 2

LIQUID PENETRANT TEST

The liquid penetrant method of nondestructive testing is a method used to locate discontinuities which are open to the surface in solid and essentially nonporous metals. The method employes a penetrating liquid which is applied evenly over the surface and subsequently enters the discontinuity or crack. After the excess penetrant has been removed from the surface, the penetrant which exudes or is drawn out of the crack by the developer is observed thus indicating the presence and the location of the discontinuity (Betz, 1963:17).

History of the Liquid Penetrant Process

The forerunner of the present day liquid penetrant testing process was the oil and whiting method. This process was effectively used by the railroad industry in the Nineteenth Century for a maintenance of steam locomotives. The penetrant, a heavy and usually dirty lubricating oil was thinned with kerosene or a light oil to make it more functional. Locomotive parts, such as rods, axles, and crank pins were cleaned by immersing them in a caustic soda solution, allowing them to dry, and then immersing them in the diluted lubricating oil. The inspection was performed by wiping the part clean and then applying a mixture of chalk and denatured alcohol. This mixture dried rapidly leaving a dead-white uniform surface. The oil entrapped by the discontinuity would then seep out leaving a dark stain as an indication of a possible defect.

In 1938, as a direct result of the defense effort, experimentation was conducted with colored dyes in an attempt to increase the contract of the indications. Maximum sensitivity was achieved by using a penetrant mixed with a dye to produce a high degree of color contrast. A red dye was most generally used, because the deep red color presented an excellent contrast with the white background of the developer.

In 1941 a greatly improved liquid penetrant containing fluorescent rather than visible dye was introduced on the industrial market. This fluorescent dye gave superior contrast when it was used in conjunction with an ultra violet light. This so called "black light" caused the dye to fluoresce. Through continued experimentation with these fluorescent dyes, ranging in color from red to blue, it was discovered that maximum visibility or effect on the human eye was obtained when a yellow-green dye was used. That is, maximum standout was obtained using a yellow-green luminescence which was viewed under an ultra violet light in an otherwise dark area (Lomerson, 1972:2.1-2.2).

With the expanding use of nonmagnetic materials such as aluminum, magnesium, and some grades of stainless steel, the lack of an acceptable method of nondestructive testing to effectively locate critical surface defects was felt by industry. Since the magnetic particle testing process is limited to ferro-magnetic materials, what was desperately needed by industry was a quick, easy, and inexpensive method of testing nonmagnetic materials.

Today, the automotive industry uses the liquid penetrant process to inspect aluminum castings and forgings, plastic components, bonded joints, automatic transmissions and housings, running gears, and welds. Overhaul and rebuild shops are heavy users of this method of inspection when they test components for trucks, busses, sport, and racing cars.

Description of the Liquid Penetrant Process

A basic description of the liquid penetrant methods of inspection is provided in Figure 1, page 19 (General Dynamics, 1967:7.5-7.6). The equipment required, types of discontinuities detected with the penetrant method, and the limitations of this method of testing are (Hinkel, n.d.:13):

1. Equipment required: Commerical kits containing fluorescent dyes, dye penetrants and developers, application equipment for the developer, and a source of ultra violet light when the fluorescent method is used.

2. Enables the detection of: Surface cracks not readily visible to the unaided eye, and the location of leaks in weldments.

3. Advantages: Applicable to magnetic and non-magnetic

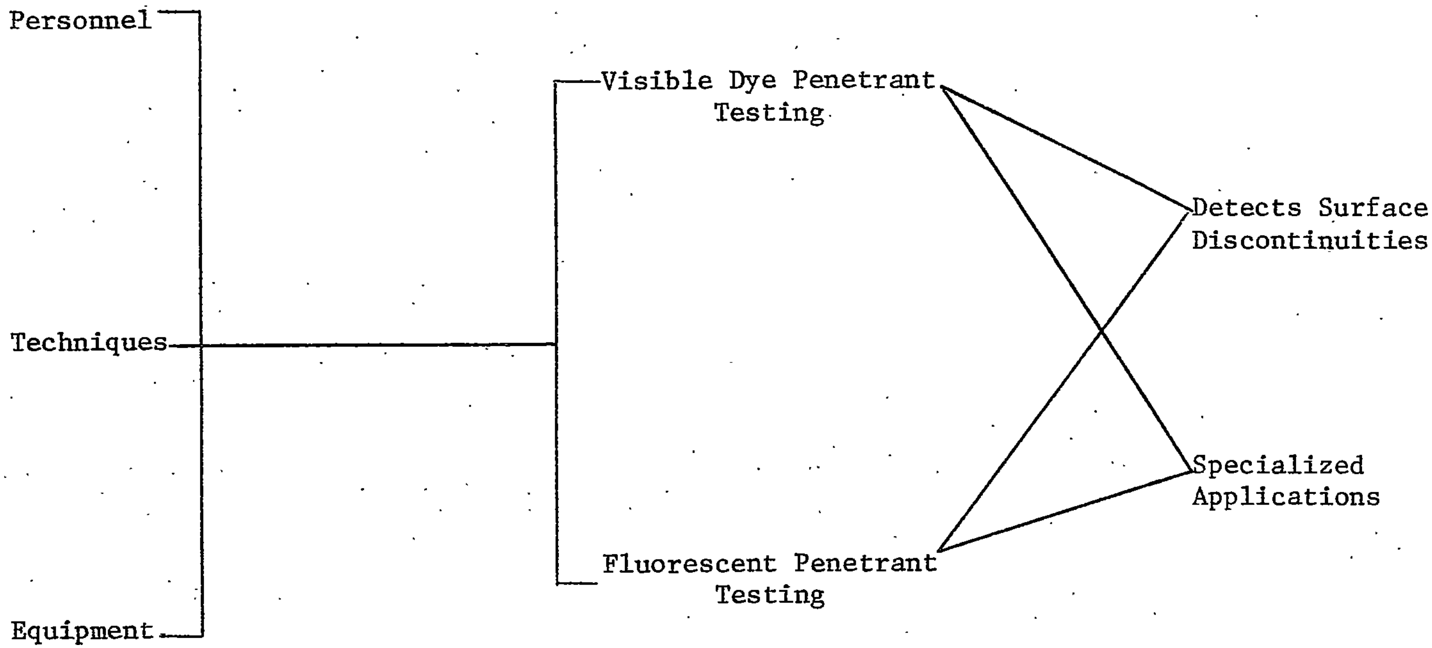

Figure 1

Liquid Penetrant Testing

Reprinted by permission of General Dynamics-Convair Division, San Diego, California, 1975 materials, easy to use, and relatively low in cost.

4. Limitations: Only surface defects are detectable and the process cannot be used on hot surfaces.

Principles of Liquid Penetrant Testing

Liquid penetrants depend for their success upon the principle that a penetrating liquid entering a surface opening and remaining in that opening will be made clearly visible to the inspector when the proper developer is applied. This process can be used successfully to detect discontinuities caused by shrinkage, porosity, fatigue, seams, cold shuts, forging bursts, and heat treating processes. The liquid penetrant method also provides an excellent means of detecting a lack of bond between joined metals.

The principles involved in the liquid penetrant inspection process are simple. They involve three basic steps: (1) application of the penetrant; (2) removal of the excess penetrant; and (3) application of a suitable developer. These basic concepts are illustrated in Figure 2, page 21 (McMaster, 1959:8.1).

Regardless of the type of penetrant being used, the inspector should adhere closely to the procedures listed for the type of penetrant inspection being performed.