AN INVESTIGATION OF SOME NONDESTRUCTIVE TEST METHODS

By

WILLIAM CALVIN DIEHL, JR.

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
January, 1956

Submitted to the faculty of the Graduate School of the
Oklahoma State University of Agriculture and
Applied Sciences in partial fulfillment
of the requirements for the degree
of MASTER OF SCIENCE
May, 1962

AN INVESTIGATION OF SOME NONDESTRUCTIVE

TEST METHODS

Thesis Approved

R. N. Maddox
Thesis Adviser

John B. West

Lawrence Madeira
Dean of the Graduate School

PREFACE

Brightness and contrast comparisons have been conducted on several fluorescent penetrants. An attempt has been made to develop a method for the radiography of flash-welds. A survey of the literature concerning several nondestructive tests is presented.

I am grateful to Dr. Joseph M. Marchello for his guidance and continued interest during this study. Special thanks go to Dr. Robert N. Maddox and Dr. John B. West for their assistance with the final draft of this thesis.

I greatly appreciate the educational program of the United States Air Force, which made my graduate studies possible.

To my wife, Claire, I extend deepest thanks for her encouragement, suggestions, and assistance during my graduate studies.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF PLATES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

During the summer of 1960, the School of Chemical Engineering at Oklahoma State University was granted Contract AF 34(601)-5470 by the Oklahoma City Air Materiel Area at Tinker AFB, Oklahoma. This contract was for work entitled "An Initial Investigation of Nondestructive Testing." The Oklahoma City Air Materiel Area is vitally interested in keeping abreast of the most recent applications of the methods of Nondestructive Testing to the inspection of aircraft components. In addition, OCAMA is desirous of finding new applications for existing tests. The contract established three main objectives.

1. A survey of applicable literature should be accomplished to provide a sound basis for further investigation.

2. Brightness and contrast comparisons were to be run on several fluorescent penetrants to determine if they met the criteria of acceptability established by existing military specifications.

3. Work was to be done to see if a circumferential flash-weld located in the nose gear of the KC-135 tanker could be easily and reliably radiographed using radioactive isotopes as the source of penetrating radiation.

Objectives

The objectives of this thesis are coincident with the objectives of the contract. The objectives are:

1. To assemble a partial survey of nondestructive testing literature.

2. To compare the brightness and contrast of some fluorescent penetrants following the procedures established by existing military specifications.

3. To conduct experimental work to determine if an easy and reliable method for the radiographic inspection of flash-welds using radioactive isotopes can be developed.

CHAPTER II

A PARTIAL SURVEY OF NONDESTRUCTIVE TESTING LITERATURE

Penetrant Testing

Assembly line production of aircraft components requires many operations which, even when properly applied, introduce surface flaws or discontinuities into the final product. Some of these discontinuities are microscopic in size and have little or no effect on the over-all serviceability of the part. Other flaws present in the finished product are large enough to greatly shorten the service life of the part, particularly if the part is to be subjected to either continuous or periodic intervals of high stress loading.

Flaws or discontinuities that are likely to affect the serviceability of the part can often be sighted by a skilled inspector utilizing purely visual means. This visual inspection is a tedious process and requires well-trained inspectors, so this type of inspection is not desirable when there is a large volume of finished products.

Penetrant inspection of these parts provides a nondestructive test method that is rapid, reliable, and requires less-skilled inspectors than does purely visual inspection (47). Penetrants tend to delineate discontinuities to a greater extent than visual means and much of the human element is thereby eliminated.

Penetrants are relatively inexpensive and the rapidity of penetrant testing makes this type of test completely compatible with assembly line production (11).

The techniques employed in penetrant inspection are essentially the same for all penetrants (24, 25). Basically they include:

1. Cleaning the surface of the part.
2. Applying the penetrant to the part.
3. Removing the excess penetrant.
4. Applying the developer.
5. Inspecting the part and interpreting the indications.

When the penetrant being used is the postemulsifier type, an additional step must be included. The postemulsification type of penetrant is not water washable and an emulsifier must be applied to the penetrant after it has had time to penetrate the surface discontinuities. After emulsification, the penetrant becomes water washable and steps 3, 4, and 5 apply.

Cleaning the Surface of the Part

An absolute prerequisite is that the surface of the part be thoroughly cleaned. An unclean surface may contain discontinuities that have become clogged by dirt, grease, paint, scale, or other materials. The penetrant will not fill these clogged discontinuities and as a result the flaw may go undetected. The dirt or other material might also absorb the penetrant and give a false flaw indication. Liquid solvents, vapor blasting, vapor degreasing, and acid etching are methods normally used to clean the surface. Sandblasting the surface of the part is not

recommended, since this has a tendency to close small surface openings.

Applying the Penetrant to the Part

The penetrant may be applied to the surface of the part by immersion, brushing, or spraying. The latter method will undoubtedly give the most uniform coat of penetrant and this method is recommended if conditions permit (24, 25). After the penetrant has been applied to the surface of the part to be inspected, it is drawn into any small surface openings by capillary action. If the part is warm when the penetrant is applied, the surface openings will be slightly expanded and better results will be obtained. The rate of penetration may be increased by raising the temperature of the penetrant, but care should be taken to insure that the flash point of the penetrant is not approached. Each penetrant supplier will recommend the temperature that is best suited for his penetrant.

Residence time for the penetrant on the surface of the part is a function of the material, the type and size of the defect, and the penetrant used. It is absolutely necessary that the penetrant be allowed to remain on the surface of the part long enough to enable a sufficient amount to enter the defect to produce a visible indication upon development. If the flaws are very small it may be necessary to apply the penetrant more than once to insure that the flaws have every opportunity to fill with penetrant. The exact penetration time for the part being inspected will necessarily need to be determined by experimentation. By

varying the penetration time, the optimum time for a particular size and kind of defect can be determined.

Removing the Excess Penetrant

Tap water and some recommended solvents may be used to remove the excess penetrant from the surface of the part. Penetrant removal is an especially critical operation. Too much washing may not only remove the penetrant from the surface of the part but may also remove the penetrant from some of the flaws. Insufficient washing may leave surface collections of penetrant which may either give false indications of flaws or mask some of the true flaw indications. After the excess penetrant has been removed, the part is dried in a hot-air drier, by a blast of clean dry air, or by standing in air.

Applying the Developer

The developer is applied to the dried surface of the part. This developer generally consists of a finely divided powder, such as talc. The developer acts much like a blotter in that it draws the penetrant from the discontinuity by a blotting action. The withdrawn penetrant is spread on the surface of the part around the defect that contained it. The indication of the defect is thus magnified and easier to discern. Heating the part, or striking or vibrating the part aids in increasing the rate of seepage of penetrant out of the flaw.

Inspecting the Part and Interpreting the Indications

This is the most important step. Improper implementation of any of the foregoing steps will result in a reduction of the reliability of the indications and reduce the effectiveness of this step. The interpretation of characterisitic patterns indicating the types of flaws is extremely important. A crack or cold shut will be indicated by a line of penetrant. Dots of penetrant indicate pits or porosity. A series of dots indicates a tight crack, cold shut, or partially welded lap. A rough estimate of the size of the opening may be gained by noting the width of the indication or the spreading of the penetrant in the developer. Proper interpretation must be learned and the more experience that an inspector has, the more reliable will be his interpretation. Experienced inspectors can often tell from the size of the indication the approximate dimensions of the flaw as well as its type.

Fluorescent Penetrants

Many requirements must be satisfied by a material before it can be satisfactorily used as a penetrant. It must be able to enter extremely fine surface openings. It must have properties that make it subject to removal from the surface of the part after the penetration period has taken place. It must be easily visible after the development step has been performed. In addition, the flash point and toxicity of the penetrant must allow it to be safely used in industrial locations without elaborate equipment.

No iron-clad set of rules exists that makes a material a satisfactory penetrant for all applications. Surface tension appears to be of less significance than viscosity but it is desirable that the penetrant have good wetting properties. At the same time, the penetrant must not attack the material being inspected and should not have a tendency to spread. In practice, experimentation is used to determine the penetrant to be used for a given material and a given flaw size (10, 25).

Volatility is a factor in that penetrants that are highly volatile are undesirable. As the more volatile constituents vaporize, concentration changes occur in the liquid and possible performance characteristic changes will be introduced. However, some degree of volatility is desirable since a small amount of evaporation at the defect helps intensify the indication.

The visibility of the surface indication presented by the developed penetrant is probably the most important single property of a penetrant. The smaller the flaw, the better the penetrant must be at providing a visible indication.

Fluorescent materials are often added to the penetrant base material to aid in increasing the visibility of the surface indications. These materials are carried into the surface flaw by the carrier liquid and then are brought to the surface of the part during development. During the inspection phase, an ultraviolet light is used to excite the fluorescent material and make the indications discernible (6, 40, 45, 46). The most effective way to increase the visibility of a fluorescent penetrant is to increase its fluorescent brightness.

Gamma Radiography of Flash Welds

Radioactivity

The beginning knowledge of radioactivity dates from 1896, and was an indirect consequence of the discovery of the X-ray. Roentgen had discovered X-rays in 1895. It was known that when X-rays were produced in a vacuum tube, a strong phosphorescence of the glass was noted, and it occurred to several investigators that perhaps some ordinary substances which were made phosphorescent by visible light might possibly emit a penetrating radiation similar to X-rays.

Following upon this idea, Henri Becquerel, a French Scientist, exposed a photographic plate to uranium-potassium sulfate. When the plate was developed, a weak photographic effect was observed. After further investigation, Becquerel discovered that this photographic action was exhibited by all compounds of uranium and by the metal itself. Compounds of uranium are naturally radioactive. Elements which are naturally radioactive spontaneously emit radiations without the addition of energy to them. Some originally stable elements may be raised to excited states by the addition of energy to them. These elements return to the stable state by the emission of radiation of the same types emitted by naturally radioactive elements. Elements made radioactive by the addition of energy to an originally stable element are termed artificially radioactive.

Rutherford showed that there are three distinct types of radiation that are emitted from radioactive elements. These

are alpha particles, beta particles, and gamma rays.

An alpha particle carries a positive electric charge equal to twice the electron charge. It has mass equal to that of the helium nucleus. Alpha particles can be absorbed by a few sheets of ordinary paper and are of little consequence in radiography.

Beta particles have a negative electrical charge equal to that of an electron. Beta particles can be absorbed by a few millimeters of sheet aluminum.

Gamma rays are electromagnetic radiations or photons emitted by a nucleus in an excited state. The emission of these photons allows the unstable nucleus to go to its lowest energy, or ground state. There are many possible excited states in the nucleus of an atom, and consequently, gamma rays are emitted with discrete energies. The gamma ray energies range from several thousand electron volts (Kev) to several million electron volts (Mev). The most powerful gamma rays are capable of penetrating several feet of lead or steel. It is the gamma ray that finds wide application in industrial radiography.

Early in the history of radioactivity it was discovered that the activity of a radioactive material decreases with time at a rate characteristic for each isotope. The time in which a radioisotope loses 50% of its activity is called its half life. The length of a half life can vary from several milliseconds to as much as 10^9 years, depending on the radioisotope.

Before the large-scale production of artificial radioisotopes, radium (Ra 226) had become a standard of comparison for radioactive measurements. Radium, although a relatively

rare element, could be prepared in adequate quantitites in a highly purified state. Its long half life (1612 years) permitted the preparation of standards whose activity changed slowly with time and could be accurately corrected for decay. The rate of decay for one gram of radium in equilibrium with its daughter products is 3.7×10^{10} disintegrating atoms per seond. A radioactive element that decays with a disintegration rate of 3.7×10^{10} disintegrating atoms per second is said to have an activity of one curie. The curie is used to define the activity of all radioactive substances. Since the curie is a relatively large unit, the millicurie, mc, (10^{-3} curie) and the microcurie, μc, (10^{-6} curie) are more often used.

The radioisotope used in this work was cobalt 60. The activity of the isotope was approximately 300 millicuries. Cobalt 60 is an artificially produced radioisotope. Cobalt metal (cobalt 59) is placed in a nuclear reactor as the target element for neutron bombardment. Thermal neutrons are used to bombard the cobalt metal. The resulting reaction is known as the neutron, gamma (n,γ) process. In this process a neutron is captured by the nucleus of an atom of the cobalt 59. Simultaneously with this capture, one or more gamma photons are emitted by the nucleus. The atom of cobalt 59 is changed to an atom with one more neutron in the nucleus, that is, to a heavier isotope of the same element. This heavier isotope is cobalt 60.

Cobalt 60 has a half life of 5.27 years. For example, in 5.27 years the 300 millicurie source used in this work will

have an activity of 150 millicuries. The unstable nucleus of an atom of cobalt 60 decays to its ground state by the emission of two gamma rays in casade and the emission of a beta particle. The two gamma photons, whose energies are 1.17 and 1.33 Mev respectively, constitute the penetrating radiation of interest to us for radiography.

Radiography

Radiography is probably the most widely used of all non-destructive tests. A radiograph provides us with a "picture" of the interior of an object. This "picture" is usually recorded on photographic film or another suitable surface which has been exposed to penetrating radiation after that radiation has passed through the object being examined. The primary purpose of a radiograph is to show the presence and nature of defects or discontinuities that are present in the interior of the object.

X- and gamma radiation is referred to as penetrating radiation because of its ability to pass through a material without being completely absorbed. The absorption of the radiation depends on the thickness of the material through which the radiation passes and the nature of the material. If an object is being radiographically checked for homogeneity, and the object contains a cavity or "blowhole" in its interior, the penetrating radiation will be absorbed to a greater extent by the homogeneous material than by the cavity and as a result the radiograph will be darker in the area just under the cavity.

The difference in density, or contrast, of areas of the radiograph beneath the defect and areas beneath homogeneous portions of the object permits a trained observer to identify the flaw and tell something of its nature and location.

Absorption

The absorption of a collimated beam of monoenergetic X- or gamma radiation by a given material follows the relation

$$I = I_o e^{-\mu_l x} \qquad \text{(II-1)}$$

Where:

I_o = the intensity of the radiation at the surface of the material.

x = the thickness of the material through which the radiation passes.

I = the intensity of the radiation after it has passed through a thickness x of the material.

μ_l = the linear absorption coefficient (per cm or per inch)

The expression (II-1) is the basic law governing absorption of a homogeneous beam of X- or gamma radiation.

Other coefficients that find application in the expression (II-1) are the mass absorption coefficient, μ_m

$$\mu_m = \frac{\mu_l}{\rho} \qquad \text{(II-2)}$$

Where:

ρ = density of the absorber

and the atomic absorption coefficient, μ_a

$$\mu_a = \frac{\mu_m}{n} \qquad \text{(II-3)}$$

Where:

n = the number of atoms per gram of absorber

Each of the absorption coefficients just considered is actually the sum of three components.

$$\mu = \mu_{ph} + \mu_c + \mu_p \qquad \text{(II-4)}$$

Where:

μ = total absorption coefficient (linear, mass or atomic)

μ_{ph} = absorption coefficient for photoelectric effect

μ_c = absorption coefficient for Compton effect

μ_p = absorption coefficient for pair production

The three principal interactions between photons and matter which give rise to these three components are the photoelectric effect, the Compton effect, and pair production.

1. The Photoelectric effect. In this effect, a photon impinges upon an orbital electron of an atom of the absorber and transfers all of its energy to this electron by ejecting it from the atom. If the photon possesses energy in excess of that required to remove the electron from the atom it imparts to the electron additional energy in the form of kinetic energy. This process obeys the Einstein photoelectric equation

$$h\nu = \phi + E_k \qquad \text{(II-5)}$$

Where:

h = Planck's constant = 6.62509×10^{-27} erg-sec

ν = frequency of the photon

$h\nu$ = total energy of the incident photon

ϕ = energy required to remove the electron from its atom

E_k = the kinetic energy of the ejected photon

2. Compton effect. In this effect, a photon interacts with an electron in the outer orbital of an atom of the absorber. Electrons in the outer orbital of an atom are loosely bound and are referred to as "free" electrons. If a photon is properly incident upon a free electron it may be scattered by the electron and suffer a loss in energy. The electron takes up the difference in energy between the incident and scattered photon and is ejected from the absorber atom with this recoil energy.

3. Pair production. This effect is more prevalent with high energy photons and accounts for the majority of the photon absorption especially in absorbers of high atomic number. This process requires a minimum energy of 1.02 Mev as a threshold. Above this energy level the probability for pair production increases almost linearly. Pair production involves the complete disappearance of the incident photon and the creation of a pair of electrons, one positive (a positron) and the other negative (a negatron or ordinary electron). In the process, a high-energy photon, passing close to the nucleus of an absorber atom, gives rise to the creation of an electron pair. The positron has exactly the same mass and magnitude of electric charge as the electron. In the process of pair production all of the photon's energy is given up to the electron pair. Energy in excess of the 1.02 Mev required for pair production is imparted to the electron pair equally as kinetic energy.

Cobalt 60 was used as the source of penetrating radiation in this work. The energies of the gamma photons emitted by

cobalt 60 are 1.17 and 1.33 Mev respectively. With steel as the absorber of photons of these energies the biggest contribution to absorption is by the Compton effect, with the photoelectric effect and pair production playing only minor roles (24, 25).

Radiographic Contrast and Density

The radiographic contrast is an important characteristic of a radiograph since it measures the difference in density between an image and its immediate surroundings. This difference in density enables us to identify discontinuities that are present in the interior of the object under inspection. The contrast is the result of the different intensities of penetrating radiation that strike the film after passing through the object. To provide a radiograph with suitable contrast, we must choose a film that is best at differentiating between the intensities of radiation involved.

The density of a film is determined by the amount of white light that is transmitted through the film. The transmittance T is defined as

$$T = \frac{I_t}{I_o} \qquad \text{(II-6)}$$

Where:

I_t = intensity of light transmitted through the film

I_o = intensity of light incident on the film

The film density D is defined as the logarithm of the reciprocal of the transmittance T of the film.

$$D = \log_{10} \frac{1}{T} = \log_{10} \frac{I_o}{I_t} \qquad \text{(II-7)}$$

If a film transmits 1/100 of the incident light, its density D is

$$D = \log_{10} 100 = 2.0 \qquad \text{(II-8)}$$

A radiographic density of two was used throughout this investigation.

Since the radiograph is formed by the shadows that result when radiation is differentially absorbed by material through which it passes, geometrical factors play a big part in the sharpness or detail of the image present on the radiograph. The sharpness or detail of the image is a very important factor since ultimate radiographic interpretation is done by the human eye and the eye can detect an image of low contrast much easier if its outline is sharply defined. The sharpness of the image is primarily dependent upon geometrical factors such as the size of the focal spot, distance from the radiation source to the defect, and the distance from the defect to the film. In addition, scattered radiation will reduce the sharpness of the radiographic image and steps should be taken to reduce scattering as much as possible while the radiograph is being taken.

In Figure 1 let S be the source of radiation (imagine a point source), let D be the defect that will cause the darkened area of the radiograph, and let F be the film where the image will be recorded. Note that radiation from a point source is desirable since the image produced when using such a source

is extremely sharp in detail and easy to see.

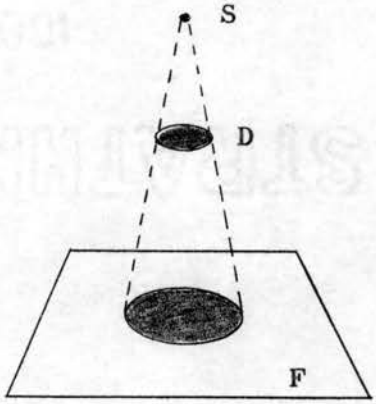

FIGURE 1: Radiographic Exposure Using a Point Source

However, it is impossible to have exactly a point source, so an attempt should be made to use the smallest possible source when taking radiographs. Note in Figure 2 that as the size of the source increases, the image becomes less sharp due to the penumbra around the image. In many applications a collimated beam of radiation is more desirable than a small source. If the beam is collimated thinly enough, scattering is greatly reduced, and the penumbra is small enough that a sharp image of any defect is recorded on the radiograph.

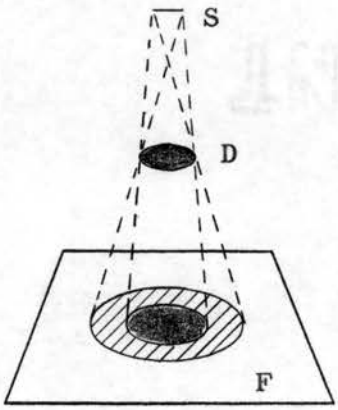

FIGURE 2: Radiographic Exposures Using Larger Sources

Other geometrical factors are the distance from the source S to the defect D and the distance from the film F to the defect D. X- and gamma radiation follows the inverse square law and exposure time must be adjusted any time the source to film distance is adjusted.

Flash-Welds

This investigation was conducted in an attempt to develop a rapid, reliable, and easily repeatable method for the radiographic inspection of flash welds. The weld under examination was a flash weld located in the inner cylinder of the nose gear of the KC-135 tanker. This flash-weld is a circumferential weld located approximately five inches above the trunion.

A flash weld is a resistance weld in which two metal surfaces are butted together, heated to a plastic state, and joined by the application of pressure. In practice, two pieces of metal to be joined are butted together lightly and an electric potential is applied to the circuit. The current applied to the circuit is sufficient to produce a flashing action between the two pieces of metal, thereby heating them to the fusion point at the interface. As the metal at the interface flashes, some of it is expelled from the fusing area and it is necessary to advance the metal slightly to insure continuous contact. When the plastic state has been reached, the current is turned off and the weld is completed by a rapid advancement or upset of the parts being joined.

Two sets of variables are involved in the flash welding

process. These are flashing variables and upsetting variables. Flashing variables are strength of the electric current, rate of advancement of the parts being joined, and the length of time for current application. Controlling variables during the upset phase are time of current shut-off and upsetting pressure. Failure to properly control these variables can result in weakness in the weld area. Weld weakness may be caused by cast metal, oxides, or other inclusions at the interface; longitudinal cracks in the weld; a cold weld; and other factors resulting from improper control of the operating variables.

Magnetic Particle Inspection

When a magnetic field is applied to a ferromagnetic material, magnetic lines of force are established within the material. The orientation of these lines of force in the material depends on the manner in which the field was applied. If a crack, inclusion, or other flaw is present in the material, a distortion will be produced in the magnetic field. Magnetic particle inspection is one means by which this distortion, or leakage flux, is detected (12).

Magnetic particle inspection can be used to detect all surface flaws present in ferromagnetic materials, and if the material can be strongly magnetized, many sub-surface flaws may be detected.

The surface of the part to be inspected should be cleaned before beginning the testing procedure. Dirt, grease, oil, rust, and scale must be removed to prevent inaccurate indica-

tions from occurring during the inspection.

Magnetic particle inspection is done by an easy and fairly simple technique. It consists of three basic operations;

1. Magnetization of the part.
2. Application of magnetic particles to the surface of the part.
3. Interpretation of surface indications.

Magnetization of the Part

Magnetic fields may be established in a ferromagnetic part in a number of ways. The method of magnetization used will depend on such things as the size and shape of the part, the material of which the part is made, the type of defect likely to be found in the part, and whether the inspection can be conducted in a shop or must be conducted in the field.

To obtain maximum sensitivity, the part should be magnetized with the direction of the magnetic field perpendicular to the defect. If the inspector possesses no initial knowledge as to possible defect orientation, he may wish to employ a "rotating vector field" for magnetization of the part. The advantage of this method of magnetization is that the fields cross nearly all defects at angles favorable for detection.

In general, current values used for magnetization are not critical. If the established field is too strong, dense accumulations of magnetic particles may result which partially obscure or completely hide the pattern produced by the flaw. On the other hand, if the field is too weak the particles may

not form a pattern at all. If current requirements are not determined by specifications or standards, they are normally obtained from experience or by experimentation.

Magnetization may be applied by either the "continuous technique" or the "residual technique." In the continuous technique the magnetization is continued throughout the application of the magnetic particles. This technique is the most sensitive of the two. However, when the magnetizing current is flowing, leakage fields other than those caused by defects are present. Indications will be caused by these fields as well as by defect leakage fields. In the residual technique the magnetizing current is applied to the part, then turned off. The magnetization remaining in the part is then used to attract, orient, and hold the magnetic particles. This residual magnetic field is relatively weak compared to the field established by the continuous technique and therefore has a lower sensitivity. However, the possibility of receiving false indications is eliminated with the residual field.

Application of Magnetic Particles to the Surface of the Part

Magnetic particles may be applied to the surface of the part being inspected as a powder or in a liquid carrier. In the dry method carefully selected magnetic particles borne by an air stream are applied to the surface of the part, generally from above. As the particles contact the surface of the part, they align themselves in patterns that indicate

the location of the leakage fields. Dry particles are most sensitive on very rough surfaces, and on parts containing sub-surface flaws.

Wet particles are normally used for detecting fine surface flaws such as fatigue cracks. In the wet method, finely divided magnetic particles are suspended in an oil or in water. This suspension may be applied to the surface of the part either by spraying or by immersing the part in a bath.

In both the wet and dry methods visibility of the indications may be increased by using particles whose color contrasts with that of the part being inspected. Fluorescent powders are sometimes used to realize increased sensitivity in cases where sub-surface flaws are suspected. In this case the inspection area must provide facilities for observing the part under ultraviolet light.

Interpretation of the Surface Indications

Experienced inspectors are required for accurate interpretation of the magnetic particle indications (7). In some cases ASTM and other standards are available as guides for acceptance or rejection of a part. Magnetic particle inspection standards have been discussed by Caine. In general, flaws located in areas where the strength of the part is not of great importance will not constitute a basis for rejection.

Demagnetization

If the part being inspected will have inservice applications where magnetization is not desirable it should be demagnetized after inspection. One case where magnetized parts are undesirable is in aircraft, where the part may cause compass error or affect the sensitivity of other electrical components. Demagnetization is usually accomplished by subjecting the part to the action of a magnetic field which is continually reversing in direction and at the same time gradually decreasing in strength. Alternating 60-cycle currents may be used for this purpose.

Advantages and Disadvantages

The advantages of magnetic particle inspection are:

1. This method of inspection may be used on any part made of magnetic material.
2. The method enables positive detection of surface or barely sub-surface flaws.
3. The method may be easily adapted to portable equipment.
4. The method is financially attractive since the cost per part is low compared with other non-destructive tests.

The main disadvantage of magnetic particle inspection is that it may be used only on ferromagnetic materials.

Eddy Current Methods

When a coil carrying alternating current is brought near an electrically conducting part, eddy currents are induced in the

part by electromagnetic induction. The magnitude of these eddy currents depends on such things as the magnitude and frequency of the alternating current flowing through the coil; the electrical conductivity, magnetic permeability, and geometry of the part; the relative position of the coil and the part; and the presence of flaws in the part.

When eddy currents are induced in a part, they set up a magnetic field which opposes that established by the coil. The impedance of this exciting coil or any pickup coil located close to the part is affected by the presence of eddy currents. Eddy currents within the part being inspected are distorted by the presence of nonhomogeneous material. Distortion of the eddy currents causes the magnetic field of the eddy currents to be distorted. The distortion of the magnetic fields causes an apparent change of impedance of the coil. The change in impedance can be measured and used to indicate the presence of defects or changes in the structure of the part.

Applications of eddy current testing include measurement of plate or tubing thickness, metal sorting, detection of cracks, voids and inclusions in parts, determination of coating thickness, and measurement of thickness of nonconducting films on electrically conducting base material (1).

The detection problem is complicated because variation in the impedance of the coil may be due to any or all of a number of factors. Some of these factors are coil-to-part spacing, electrical conductivity of the part, shape of the part, and cracks, voids or inclusions present in the part.

The composite effect of these factors may produce an impedance variation indicating that the part is unacceptable, while in reality it may be well within the limits of acceptability.

The influence of the physical properties of the part being inspected upon the impedance characteristics of the probe coil can be calculated for various test frequencies in certain cases. Often it is possible to determine from the impedance change not only the conductivity, dimensions, and magnetic permeability of the part, but also the magnitude and direction of cracks (15).

The basic principles applicable to eddy current test methods were developed in two ways. First, problems suitable for mathematical analysis were calculated quantitatively on the basis of reasonable assumptions as to shape and material properties of the part. In the second group mathematical solutions were impossible because of the boundary conditions involved. This group was treated using quantitative information taken from measurements on models. Data from these models is then applied to parts whose dimensions, electrical conductivity, and relative permeability are given. Comparisons between the data from the model and from the part whose properties are known yield the necessary solution to the problem.

Coils

Coils used in eddy current testing may take any one of several forms depending on the application of the test equipment (22). Three general types of test coils in common usage are the concentric coil, the point probe, and the inside coil.

The concentric coil completely surrounds the part being inspected. The probe consists of a small coil that can be placed near the surface of the part. The probe investigates an area essentially equal to the cross sectional area of the probe. The inside coil is made to be moved through the part (tubing or pipe) being examined.

The size and type of test coil are governed by the material of the part being tested and the kind and size of defect to be detected. The initial design of test coils or probes may be done through theoretical considerations alone. Then the design must be checked experimentally, making necessary design changes as indicated by test results. Experimentation is necessary in determining final coil design since analytical treatment of coil design deals with ideal coil configurations, while in the actual case the configuration of the final coil design is far from ideal. In the case of some small test coils, there may be more inductance in the leads to the coil than in the coil itself.

Ultrasonic Inspection

Ultrasonic inspection is a relatively new tool in the field of nondestructive testing. Until recently it was more a curiosity than a usable test method. Early attempts to use ultrasonics were largely unsuccessful due to inadequate instrumentation. The ultrasonic type of instrumentation was developed rapidly during World War II as radar and sonar came into wide use. Ultrasonics today is essentially an offspring of the

union between acoustics and electricity. Transistorized commercial equipment now available can be used by non-technically trained personnel of ordinary skill.

Ultrasonics is the study of the principles, equipment and applications of ultrasound (4, 8, 9, 13, 17, 32). Use of the term ultrasound is usually restricted to sound waves with frequencies beyond the range of human hearing. This upper limit is normally accepted as being about twenty kilocycles. Ultrasonic frequencies used in nondestructive testing usually lie in the range from one to twenty megacycles.

Ultrasonics find application in flaw detection, thickness measurement, determination of the elastic moduli of materials, the study of metallurgical structure and many other investigations (2, 18, 30, 39).

There are three basic reasons why ultrasonics rather than audible sound waves are used in most applications.

1. Many applications require high acoustic power. Ultrasonics prevent the noise level from becoming intolerable. Some ultrasonic applications use power levels of the order of one watt per square centimeter. The magnitude of this power requirement is evident when it is recognized that a small radio has a power level of 10^{-9} watts per square centimeter.

2. Nondestructive tests utilize high frequencies and small wave lengths. Small wave lengths are used to advantage in the detection of very small flaws. The wave length should have an order of magnitude at least

as small as the smallest flaw to be detected. When the wave length is small compared to the size of the flaw, the sound wave follows the laws of geometric optics. Attenuation becomes important as the wave length approaches the grain size of the material being inspected.

The relation between frequency and wave length is:

$$\lambda \nu = c \qquad \text{(II-9)}$$

Where:

c = the speed of sound in the media (a constant)

λ = the wave length

ν = the frequency

Note that as the frequency is increased, the wave length is decreased.

3. Ultrasonic waves may be generated directionally. If the size of the sound source is considerably less than one wave length of the emitted sound, the sound wave is radiated in a circular (non-directional) pattern. If the source is several wave lengths in size, the sound waves will be radiated in a beam. Note that the utilization of higher frequencies will cause the sound to be radiated in beams.

Ultrasonic inspection is usually performed by one of two test methods. A beam of ultrasonic energy is directed into the part being examined and (1) the energy transmitted through it is indicated or (2) the energy reflected from areas within it is indicated. If the material through which the beam travels is completely homogeneous, the beam will

experience very little loss of energy from transmission to ultimate reception. If a defect is present in the part, a decrease of energy will be noted at the receiver. This is the basis of ultrasonic testing.

Types of Ultrasonic Waves

There are three main types of ultrasonic waves; namely, longitudinal, transverse, and surface.

The longitudinal or compressional wave is the ultrasonic wave in widest use. It was the first to be used in the field of nondestructive testing. It is the simplest wave to generate and possesses the property that it may be sustained in a liquid.

Transverse or shear waves vibrate at right angles to the direction of propagation. Transverse waves are characterized by lower velocities than longitudinal waves and are therefore able to detect smaller flaws. At the present time transverse waves are not used as extensively as longitudinal waves, but considerable work is being done to extend their application. Note that since most gases and liquids are inelastic to shear they will not support transverse waves.

Surface waves can be divided into three classes: Rayleigh waves, Lamb waves, and Love waves. Waves which are propagated over the surface of a solid whose thickness perpendicular to the surface is large compared to the wave length of the wave are known as Rayleigh waves. These waves are roughly analogous to water waves, and the motion of the particles is both

transverse and longitudinal. Surface waves which are propagated over the surface of a solid whose thickness is comparable to the wave length of the wave are known as Lamb waves. A thin plate is capable of transmitting an infinite number of Lamb waves (42). The velocity of their propagation is determined by the product of the thickness of the plate and the frequency. Love waves propagate on the surface without any vertical component. Such waves require that a thin layer of some material of different density be present on the bulk material below. Love waves propagate with velocities which are dependent upon frequency, the velocity decreasing with increasing frequency. Waves analogous to Rayleigh and Love waves can be propagated along the interface of two materials differing in elastic properties and density.

Generation of Ultrasonic Waves

Numerous methods are available for the generation of ultrasonic waves, but the only one of much interest in non-destructive testing is the piezoelectric effect (4, 8). This effect was discovered by Curie in 1880. Piezoelectric transducers make use of the expansion and contraction of certain crystalline and ceramic materials under the influence of varying electrical fields. This phenomenon is reversible, since a mechanical strain input will create an electrical output signal. The efficiency of conversion differs between transmission and reception.

When selecting a piezoelectric crystal, the first

consideration should be the type of waves that are desired. Certain crystals will produce transverse waves while others will produce longitudinal waves. The most common crystal in use that will produce either type of wave is quartz. When quartz is cut on the x-axis, the crystal will produce longitudinal waves and when it is cut on the y-axis, the crystal will produce transverse waves. The frequency emitted by a crystal is determined by its thickness; the thinner the crystal, the higher the resonant frequency. Several materials other than quartz have been found satisfactory for use as piezoelectric transducers. Among the most common are barium titanate and lithium sulfate.

In order to generate the frequency required for the inspection of a given material, an electronic oscillator is usually employed. The output from this oscillator is normally weak. To correct this an amplifier circuit is employed between the oscillator and the transducer. When attempting to receive signals from a transducer it is necessary to amplify the signal from the crystal.

To send and receive signals through an object, good contact is required between the transducer and the material under examination. Since ultrasonic waves are rapidly attenuated in air, precautions must be taken to insure that no air is present between the transducer and the material. This is accomplished by placing a fluid couplant between the material and the transducer. The Nondestructive Testing Handbook gives the following as criteria for a good couplant.

1. It must wet both the transducer and the material
2. It must be easily applied
3. It must not run off the surface too fast
4. It must be homogeneous and free from bubbles and solid particles
5. It must not be corrosive or toxic
6. It should have an impedance near that of the test material

The most common coupling materials are water or oil with wetting agents added, or water-glycerin solutions.

Reflection of Ultrasonic Waves

When explaining the reflection of sonic waves it is necessary to define a quantity known as specific acoustic impedance, which is the product of the density of the material and the speed of sound in the material. The specific acoustic impedance.

$$L = \rho c \qquad \text{(II-10)}$$

Where:

L = the specific acoustic impedance of the material

c = the speed of sound in the material

ρ = the density of the material

The fraction of a sound wave that is reflected by a non-homogeneous portion of the material is

$$X = \frac{L_1 - L_2}{L_1 + L_2} \qquad \text{(II-11)}$$

Where:

X = the fraction of the wave that is reflected.

From this equation and the acoustic impedance of steel (3.9×10^6 gram/sec. cm^3) and air (4.8 gram/sec. cm^3) it can be seen that an air bubble in the steel would cause almost 100 per cent reflection, provided the wave lengths are not long enough to bend around the air bubble. When it is desirable to transfer sound waves from one media to another, the impedances of the two media should be matched as closely as possible.

Immersion Testing

When the part to be inspected is irregular in shape or when it is necessary to make a more complete inspection, it may be desirable to use the immersion bath for the test (30). This bath should consist of water, oil, or some other couplant. The immersion method is considerably faster than the direct contact method unless a great deal of time is required to prepare the part for inspection. In applications utilizing the immersion technique the transducer mounting must be thoroughly waterproofed. In immersion testing the transducer is normally mounted on the end of a scanning tube which in turn is attached to a manipulator or fixture that permits controlled movement of the tube in any direction.

Types of Input Signals

Three types of input signals used in ultrasonic testing are continuous, frequency modulated or FM, and pulsed. The continuous beam is used only with systems containing two

transducers. The beam leaves a transmitting transducer and is received at a receiving crystal after having traversed the part being examined. Any flaws present in the part will cause an appreciable energy loss in the transmitted beam. One transducer is used when the input signal is frequency modulated. The radio frequency signal applied to the transducer is rapidly changing in frequency. An echo which arrives after the signal leaves the transducer will have an instantaneous frequency differing from that being transmitted. The greater the depth of the flaw, the greater the difference in frequency. This difference in frequency can be measured, giving a measurement of the depth of the flaw.

The pulsed technique, or pulse-echo technique also involves the use of a single transducer. A pulsed input is sent through the transducer and the part. At the opposite face the beam is reflected and the echo picked up by the same transducer that sent the signal. A discontinuity or flaw within the part will also send back an echo. The time intervals that elapse between the initial pulse and the echos are used to detect any defects present in the part.

Data Presentation Devices

In theory any type of device that will show variations in an electric field will serve as a data presentation device (3). When dealing with relatively simple inspections, such as that of sheet metal on a production line, a light or a bell may be used to indicate the presence of a defect. As the parts being

inspected become more complex and the technique less standardized, other devices must be utilized. Meters may be used to indicate flaws where quantitative data only is required. However, the most common device used in ultrasonic testing is the cathode ray tube. The cathode ray tube may be used to measure defects by A, B, or C scans. The A scan is most frequently used. The A scan presentation is a horizontal line on the cathode ray tube with echoes appearing as vertical pips on the horizontal base line. The B scan utilizes the sweep of the electron beam of the cathode ray tube and is synchronized with either the movement of the transducer or the movement of the part. By using a long persistence phosphor, the presentation gives the appearance of the cross-sectional view of the part. The C scan presents a plan view of the part. In addition to the cathode ray tube, recording devices that provide a lasting record of inspection are coming into wide use, especially by aircraft manufacturers.

CHAPTER III

EXPERIMENTAL APPARATUS

Equipment for the Comparison of Fluorescent Penetrant Brightness

The equipment used in the laboratory investigation of the brightness and contrast of fluorescent penetrants is specified by Military Specification MIL-1-25135B (ASG) and consists of the following:

1. Coleman 12-B photoelectric photofluorometer
2. Coleman B-1 primary filter
3. Corning CS 3-123 secondary filter
4. Holder rotation stop or equivalent.
5. Reflectance sample holder

Items 1 through 4 are pictured in Plate 1.

Plate 2 shows the reflectance sample holder. It is constructed of plastic and was made to fit the cavity of the photofluorometer. Each specimen of fluorescent penetrant impregnated filter paper is first placed in the reflectance sample holder, then placed in the cavity of the photofluorometer. The reflectance sample holder is rotated in the cavity until the maximum reading for the given specimen is noted on the instrument meter.

Figure 3 is a schematic diagram showing how the brightness and contrast of a fluorescent penetrant is determined (44). The mercury vapor lamp MV emits light over a wide range of wave lengths. Light from this mercury vapor lamp is then passed through the

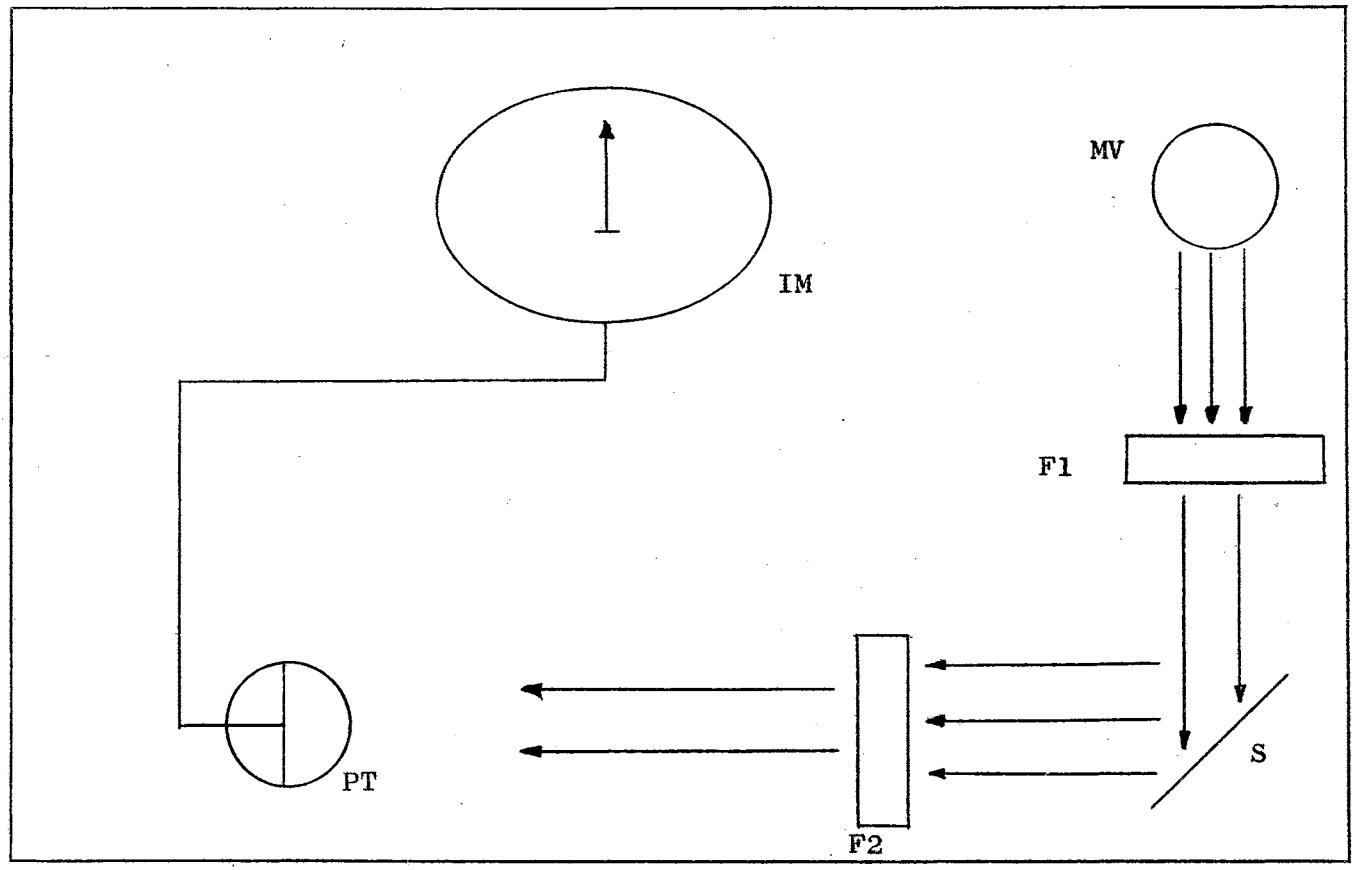

FIGURE 3: Schematic of a Photofluorometer System

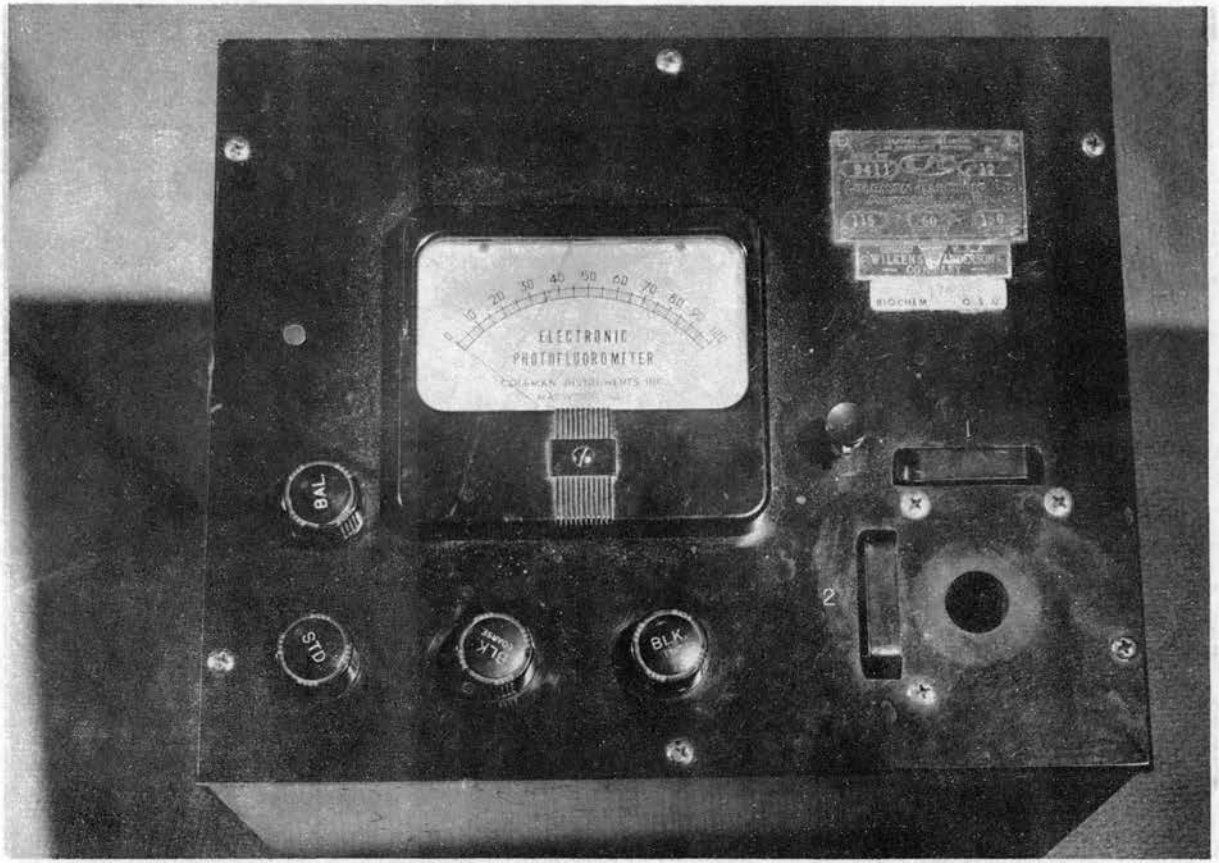

PLATE 1

Coleman 12-B Photoelectric Photofluorometer

PLATE 2

Reflectance Sample Holder

primary filter F 1. This filter passes light ranging in wave length from 3200 to 4100 angstroms. This range of wave lengths includes ultraviolet light, which is utilized to excite the fluorescent material on the sample S. The sample S is a strip of filter paper impregnated with the fluorescent penetrant being tested. The light emitted by the fluorescent material present in the sample is reflected through the secondary filter F 2. This filter passes those wave lengths of light which are visible to the human eye. After passing through the secondary filter, the light is directed to a phototube which converts the light energy into electrical energy. The intensity of this visible light emitted by the fluorescent material in the sample is indicated by the value of the electrical impulse from the phototube. The value of this impulse may be read from the instrument meter IM. By noting the readings taken from several samples and comparing these readings with those taken while using samples of the standard penetrant, an accurate comparison of penetrant brightness can be made.

Equipment for the Gamma Radiography of Flash Welds

The only radioactive source available that was suitable was a cobalt 60 source located at the Oklahoma State University Radiation Laboratory. Its activity was approximately 300 millicuries. The source is encapsulated in a small metal cylinder which is attached to the point of a lead cone. Attached to the base of the lead cone is an aluminum handle six feet long. This handle allows the source to be carried at a safer distance from

the radiographer during its use. When the source is not in use, it is placed in a lead "pig" containing a hollow cavity that will hold the source and the lead cone. Figure 4 shows the source in its mounting.

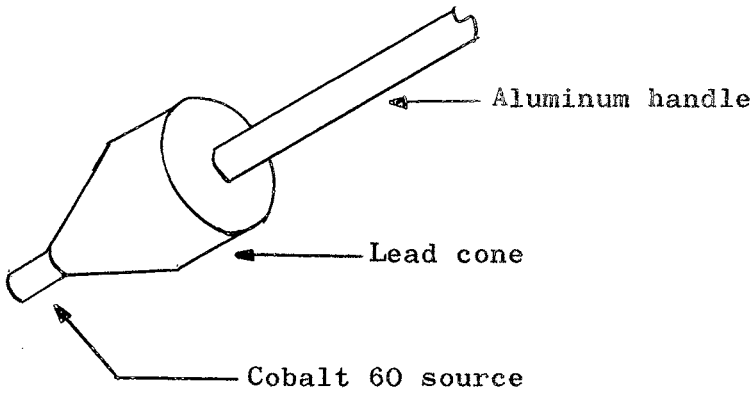

FIGURE 4: Cobalt 60 Source in its Mounting

The subject of the radiographic inspection was a flash-weld located around the circumference of a steel cylinder. By placing the cobalt 60 source on the interior of the cylinder at a point just opposite the weld, and wrapping film around the exterior of the cylinder at the weld, a radiograph of the entire flash-weld could be obtained in one "shot."

A lead cylinder containing a cavity suitable for holding the lead cone and the cobalt 60 source was cast. The outside diameter of the lead cylinder was made small enough to allow the lead cylinder to be placed inside the smallest of the flash-welded steel cylinders. The lead cylinder was cut in two at a point half way along that section of the cavity designed to house the source. A side view of the sectioned cylinder is

shown in Figure 5.

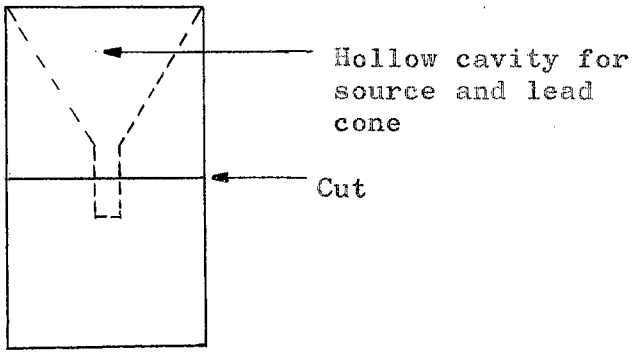

FIGURE 5: Sectioned Lead Cylinder

Five cylinders of polyethylene were cut to be used as spacers for separating the two sections of the lead cylinder. These spacers were 1/8, 1/4, 3/8, 1/2 and 5/8 inch in thickness. The purpose of these spacers was to provide slits of varying widths in the lead cylinder so that radiation from the cobalt 60 source could be collimated in the direction of the weld. A side view of the lead cylinder with a spacer installed is seen in Figure 6.

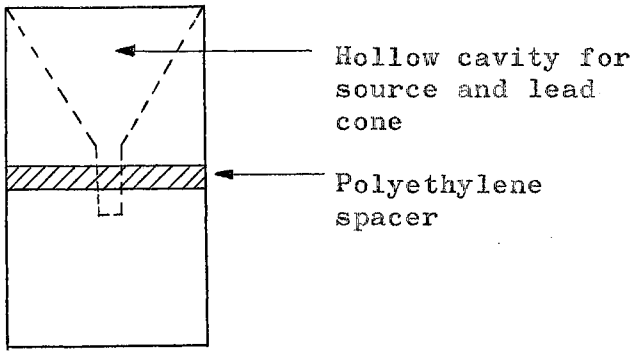

FIGURE 6: Sectioned Lead Cylinder with Spacer Installed

Five of the flash-welds to be radiographed were located in short sections of oil well tubing supplied by American Iron Works of Oklahoma City. In order that radiographs of these specimens could be easily produced, a wooden box was constructed, and in its top a large hole was drilled. The diameter of this hole was large enough to allow the lead cylinder to travel freely through it. Inside the box was placed a scissors jack to serve as a raising and lowering mechanism for the lead cylinder. A diagram showing the box, jack, and cylinder is seen in Figure 7.

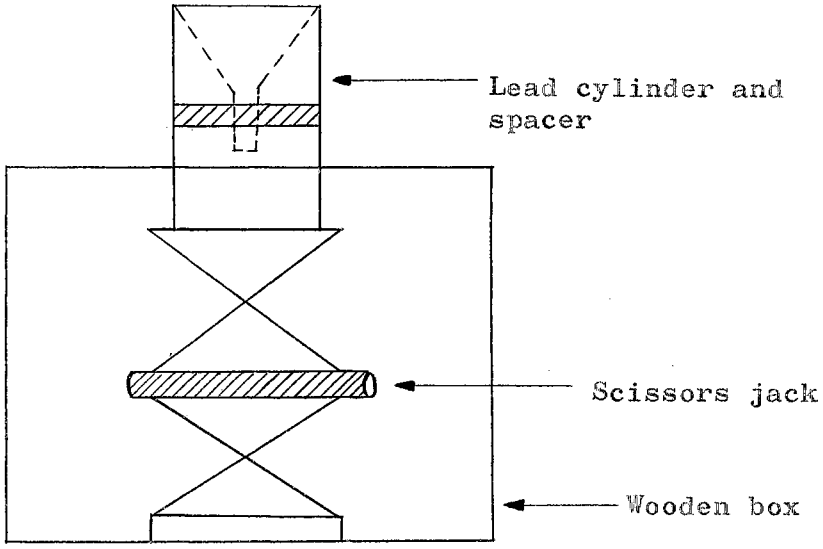

FIGURE 7: Assembled Equipment for the Radiography of Steel Cylinders

The flash-welded oil well tubing was placed over the outside of the lead cylinder. Using the scissors jack, the lead cylinder was raised or lowered to position the polyethylene spacer at a point opposite the weld line on the tubing. X-ray film was wrapped around the circumference of the tubing at the weld line. The cobalt 60 was removed from the "pig" and inserted into the

cavity of the lead cylinder. After leaving the source in the lead cylinder for a previously determined exposure time, the source was removed from the cylinder and replaced in the lead "pig". The exposed X-ray film was then removed from the tubing and the process repeated using another tubing specimen.

In addition to the equipment used for these interior shots, equipment was assembled for a series of panoramic shots of the specimens. Concentric circles of radius 6 inches to 24 inches were drawn at one inch intervals on a four foot square of masonite. By locating the cobalt 60 source at the center of the circles and placing the flash-welded specimens around the circumference of the circles, all of the specimens could be radiographed simultaneously.

CHAPTER IV

EXPERIMENTAL PROCEDURE

Brightness and Contrast of Fluorescent Penetrants

Laboratory Investigation

During this investigation, tests were performed in accordance with paragraphs 4.4 through 4.4.1.3 of Military Specification Mil-1-25135B (ASG), dated 2 July 1958.

Four penetrant samples were tested against two standard penetrants. Samples 1N, 2N, and 3N were each tested against an MA-3 standard. Sample 1H was tested against an MA-5 standard. Samples 1N, 2N, and 3N were Type I, Class 2, Grade B penetrants. This class of penetrant may be more clearly described as being of the postemulsifiable type with a normal amount of sensitivity. Sample 1H is a Type I, Class 2, Grade A penetrant. This is a postemulsifiable penetrant possessing a high degree of sensitivity. All penetrants and standards were supplied by the Oklahoma City Air Materiel Area, for whom this investigation was accomplished. Samples 1N and 2N were taken from bulk lots, while samples 3N and 1H were taken from small can lots.

The test apparatus used in the investigation was as listed in the specification and described in Chapter III. The apparatus is listed below:

a. Coleman 12-B photoelectric photofluorometer

b. Coleman B-1 primary filter

c. Corning CS 3-123 secondary filter

d. Reflectance sample holder

e. Holder rotation stop or equivalent

Preparation of Specimens

1. Immediately prior to testing, a small amount of each of the penetrants being tested was diluted with an organic solvent (monochlorobenzene) in the ratio of one part penetrant to nine parts solvent. Actual quantities used were 5 milliliters penetrant to 45 milliliters solvent. All penetrants tested were soluble in monochlorobenzene.

2. The solutions were agitated and poured into separate wide-mouth containers. Filter paper, cut to fit the sample holder of the photofluorometer, was dipped into each solution. After each specimen was saturated with solution, it was withdrawn from the solution and dried on a drying fixture. The specimens were dried in a horizontal position to insure uniformity of penetrant in the filter paper. Six specimens were prepared for each of the standards and five specimens were prepared for each of the penetrants being tested.

3. After the samples were dry, they were placed in a pre-heated oven (225 $\pm$ 5° F) for five minutes.

4. The samples were withdrawn from the oven and all specimens were examined under black light. The 3N sample appeared brighter than the MA-3 standard and the 1H sample appeared brighter than the MA-5 standard. In accordance with the specification, one of the six specimens of the MA-3 standard was used to

standardize the photofluorometer to a scale reading of 50. The standard specimen used for the standardization was then discarded. The remaining five specimens of the MA-3 standard and the five specimens each of the samples 1N, 2N, and 3N were in turn placed in the sample holder and tested in the photofluorometer against the scale setting established by the standard specimen. In each case the readings from the brightest side of each specimen were retained. After all the readings had been completed, the average of the readings from the standard specimens was taken to be 100, and the averages of the readings from each of the samples were compared with this value.

5. The above tests were duplicated using the 1H sample and the MA-5 standard.

Gamma Radiography of Flash Welds

Safety measures specified by the Atomic Energy Commission were followed throughout the experimental work. Use of the cobalt 60 source was supervised by the Coordinator of the Oklahoma State University Radiation Laboratory.

Kodak Type M Industrial X-ray Film was used in taking the radiographs. The film was the 35 mm size and was easy to use both during the exposure and during the development.

Before any radiographs were taken it was necessary to determine correct exposure times for a variety of source-to-film distances. Differences in total gamma ray absorption when shooting through one wall and both walls of the cylinders were also considered.

The activity of the cobalt 60 source had last been determined in March, 1960. At this time its activity was 300 millicuries. The activity of the source at the time of this work was calculated using the expression

$$N = N_o \exp(-\lambda t) = N_o \exp\left(-\frac{0.693\ t}{T}\right) \qquad \text{(IV-1)}$$

Where:

N = number of atoms of radioactive material remaining

N_o = number of atoms of radioactive material initially present

λ = decay constant = 0.693/T

t = time elapsed

T = half life of the radioisotope

The activity of the cobalt 60 source at the time of use was calculated to be 278 millicuries.

Test radiographs were made with the radioactive source located in the center of the flash-welded specimens and with the source located outside the specimens by the panoramic method. Exposures made by the panoramic method were made both through single wall and double wall thicknesses. From the test radiographs those with a radiographic density of two were selected as the most desirable for inspection purposes. The exposure times of these exposures were noted and used as a basis for the remainder of the radiographs.

With the cobalt 60 source located in the center of the specimen being radiographed an exposure time of seven minutes produced a radiograph whose density was two. An exposure time of 35 minutes at a source-to-film distance of six inches produced

a radiograph of density two with a single wall exposure. A double wall exposure with a six inch source-to-film distance required 50 minutes to produce a radiograph of density two.

The exposure time required for a given radiographic density is directly proportional to the square of the source-to-film distance. To calculate the exposure time for the same density at a new source-to-film distance the following relation is employed.

$$\frac{T_1}{T_2} = \frac{(S.F.D.)_1^2}{(S.F.D.)_2^2} \qquad \text{(IV-2)}$$

or, rearranging,

$$T_2 = \frac{T_1(S.F.D.)_2^2}{(S.F.D.)_1^2} \qquad \text{(IV-3)}$$

Where: T_2 and $(S.F.D.)_2$ denote the new exposure time and source-to-film distance, respectively.

Using the relationship (IV-3), exposure times for several source-to-film distances were calculated for both single wall and double wall exposures. These times appear in Table I.

TABLE I

RADIOGRAPHIC EXPOSURE TIMES

S.F.D. (Inches)	Exposure Times (Hours and Minutes)	
	Single Wall Thickness	Double Wall Thickness
6	0:35	0:50
7	0:48	1:08
8	1:03	1:29

TABLE I (Continued)

S.F.D. (Inches)	Exposure Times (Hours and Minutes)	
	Single Wall Thickness	Double Wall Thickness
9	1:19	1:52
10	1:38	2:18
11	1:57	2:47

Exposures were made of all specimens at source-to-film distances that permitted exposure times less than two hours. Ten radiographs were made of each specimen at each exposure time less than two hours. These radiographs were developed at times ranging from five to eight minutes in accordance with development procedures recommended by Eastman Kodak Company.

CHAPTER V

RESULTS AND DISCUSSION

Comparisons of Fluorescent Penetrant Brightness

The results of the comparison of the brightness of samples 1N, 2N, and 3N to the brightness of the MA-3 standard are given in Table II.

TABLE II

BRIGHTNESS COMPARISONS USING THE MA-3 STANDARD

Test Basis: Standard Set as 50 on the Photofluorometer Scale

Specimen Number	Photofluorometer Readings			
	MA-3 Standard	Sample 1N	Sample 2N	Sample 3N
1	52	27	59	75
2	50	26	57	77
3	50	28	55	75
4	51	27	59	80
5	51	28	58	79
Totals	254	136	288	386
Average	100	53.54	113.38	151.97

The military specification followed in conducting the laboratory investigation requires that, to be acceptable, a penetrant must have a brightness of at least 85 per cent of the standard being used in the test. The brightness comparisons conducted

using the photoelectric photofluorometer are the visibility determining criteria of the specification. There are those who feel that these should not be the sole determining criteria for visibility, but that another method should be employed as well (43).

At intervals during the laboratory investigation, specimens of the samples and the standards were arranged under ultraviolet light in an attempt to simulate conditions under which the penetrants would normally be seen. Several persons were asked to view the arrangement and list the specimens in the order of ascending brightness; that is, to list the brightest first, the next brightest second, and so on. It is interesting to note that when the results were analyzed, they agreed with the findings obtained using the photofluorometer. It would seem the criteria for brightness set forth in the specification is a valid one.

Table II shows that Sample 1N failed to meet the criteria of brightness set forth in the specification. This sample was picked last in every comparison made by the purely visual means described in the preceding paragraph.

The specimens were observed at intervals of approximately one hour for four hours and then at periods of eight hours until 24 hours had elapsed. The brightness of the specimens began to fade after the second hour and after 24 hours all the specimens had faded considerably from their initial brightness. Sample 1N was noted to have developed "splotches" or spots of light blue and light yellow indicating that oxidation and/or

decomposition was taking place. None of the other samples gave similar indications.

The results of the comparison of the brightness of Sample 1H to the brightness of the MA-5 standard is given in Table III.

TABLE III

BRIGHTNESS COMPARISONS USING THE MA-5 STANDARD

Test Basis: Standard Set as 50 on the Photofluorometer Scale

Specimen Number	Photofluorometer Readings	
	MA-5 Standard	Sample 1H
1	51	54
2	53	54
3	50	56
4	50	55
5	54	50
Totals	258	269
Average	100	104.26

Note from the results in Table III that the 1H sample was brighter than the MA-5 standard. Even though the difference in brightness is small the visual determination as outlined earlier substantiated this difference.

Gamma Radiography of Flash Welds

The results of this investigation were unfruitful insofar as the initial objective was concerned. The purpose of this part of the investigation was to attempt to develop a method for radiographing flash-welds using radioisotopes as sources of

penetrating radiation.

None of the radiographs taken following the previously outlined procedures revealed any defects in the weld area of the KC-135 nose gear inner cylinder or in the weld areas of any of the five specimens of oil well tubing. The findings in regard to the oil well tubing are not consistent with fact. During the preparation of these specimens efforts were made to intentionally make some of them defective. The five specimens were prepared in the following manner.

1. A "sticker"--Current was turned off one second before upset
2. Voltage was high
3. Had a hole drilled in the end of one section prior to welding
4. Had a hold drilled in the end of one section prior to welding
5. Standard weld

After welding, the five specimens were inspected ultrasonically using a Sperry Reflectoscope.

The only rejectable weld was No. 3. The ultrasonic indication of defects in this weld was severe. Radiographs of this weld failed to show any defects. Welds 1 and 2 gave slight indications of defects using ultrasonics, but were acceptable. Welds 4 and 5 gave no indications on the Reflectoscope. Although weld 4 had a hole drilled in the end of one of the joined surfaces prior to welding, no defect indications were noted ultrasonically. This was probably due to expulsion of the drilled portion of the cylinder in the form of molten metal during the welding process. This is a normal occurrence during flashing.

One factor that contributed to the failure to obtain usable radiographs was the radioactive source used. Cobalt 60 is normally used as a source of radiation when radiographing steel whose thickness is two to six inches. The wall thickness of the specimens used in this investigation ranged from 0.35 to 0.40 inches. The gamma photons from cobalt 60 are too energetic (1.17 and 1.33 Mev) for the radiography of steel of the thicknesses of the specimens used in this work. The effect of this excessive energy is to lessen the contrast between shadow pictures of the homogeneous and non-homogeneous sections of the weld area. This makes all but the largest and less dense discontinuities impossible to locate on the radiograph.

A radioisotope which emits gamma photons of lesser energies would have been more desirable than cobalt 60 in this investigation. Iridium 192 is such an isotope. Iridium 192 decays with the emission of more than 20 different gamma photons whose energies range from .136 to 1.157 Mev. The energies of the principal photons are .310, .470, and .600 Mev. This assortment of energies is equivalent to an X-ray tube operating at 800 to 900 Kilovolts. Iridium 192 is best for radiographing steel whose thickness is less than one inch. The main disadvantage of iridium 192 is its 74.4 day half life.

Thulium 170 is another radioisotope useful for radiography of these steel objects. It can be used to obtain better radiographs of steel specimens whose thickness is less than 1/2 inch than any other isotope now available. The half life of thulium 170 is 129 days.

Another factor making radiography of flash-welds difficult is the size and type of defects that are most prevalent in this type of weld. Blowholes, slag inclusions, and cracks large enough to be detected radiographically can also be detected by other means, such as ultrasonics. In fact, the results of the radiography done here were definitely not as revealing as ultrasonic indications from the same specimens.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Comparisons of Fluorescent Penetrant Brightness

As outlined in the introduction, one of the objectives of this thesis was to conduct a comparison of the brightness of some fluorescent penetrants in accordance with existing military specifications. This was accomplished and all but one of the samples tested met the criteria for acceptance established by the specification. The readings taken from a photoelectric photofluorometer indicated that this sample was definitely inferior in brightness when compared to the other samples being tested. The results obtained using the photofluorometer were substantiated by visual comparisons made by several persons. While the number of visual comparisons was not great enough to lend much in the way of valid statistical support, each of the comparisons was in complete agreement with the photofluorometer findings. This tends to support the present method of brightness comparison.

If the present methods of fluorescent penetrant brightness comparison cease to identify penetrants that fail to give the desired degree of reliability in industrial applications, a re-evaluation of the criteria for brightness would be in order. In the meantime, the present specification gives reliable results.

Gamma Radiography of Flash Welds

The radiographic inspection of flash welded steel cylinders remains a difficult operation. The use of cobalt 60 as the source of penetrating radiation should be avoided unless the specimen is steel or another high molecular weight material whose thickness is two inches or greater.

An area now in need of investigation is the evaluation of iridium 192 and thulium 170 as gamma photon sources for radiography of flash-welds. The specimens inspected should be steel or other high molecular weight material whose thickness is less than 1/2 inch. Some specimens could be deliberately made faulty by varying the flashing or upsetting variables during the welding process. Other specimens would be made according to previously established standards. Using iridium 192 and thulium 170, radiographs would be made of all welded specimens. The radiographs would be examined for discontinuities and nonhomogeneities present in the flash welds and the results of these examinations correlated with information obtained from some other nondestructive test, such as ultrasonics. After testing nondestructively, a destructive test would be performed on each specimen. Results of both types would be examined to see if a relationship between the two could be established.

If radiographic inspection of flash-welds using iridium 192 and thulium 170 does not give satisfactory results, consideration should be given to changing existing Air Force Technical Orders governing inspection of these welds to a type of nondestructive test that gives more reliable information.

A SELECTED BIBLIOGRAPHY

1. Allen, J. W. and R. B. Oliver, "Inspection of Small Diameter Tubing by Eddy Current Methods," Symposium on Nondestructive Tests in the Field of Nuclear Energy, American Society for Testing Materials, Philadelphia, Pa. (1957).

2. Barath, A. "Ultrasonic Testing of Aircraft Forgings," Symposium on Nondestructive Testing, American Society for Testing Materials, Philadelphia, Pa. (1956).

3. Beck, W. N. "An Ultrasonic Scanner and Recording System," Symposium on Nondestructive Tests in the Field of Nuclear Energy, American Society for Testing Materials, Philadelphia, Pa. (1958).

4. Bergmann, L. Ultrasonics and Their Scientific and Technical Applications, John Wiley and Sons, Inc., New York, (1938).

5. Betz, C. E. "Two New Testing Methods for Ceramic Products," Journal of the Society for Nondestructive Testing, Vol. 7, No. 2 (1948) pp. 22-26.

6. Bowen, E. J. and F. Wokes, Fluorescence of Solutions, New York, Longmans, Green and Co. (1953).

7. Caine, J. B. "Magnetic Particle Inspection Standards," Foundry, Vol. 83, No. 12, (1955).

8. Carlin, B., Ultrasonics, McGraw-Hill Book Co. Inc., New York, (1949).

9. Carlin, B.,"Material Testing and Gaging with Ultrasonics," Chemical Engineering Symposium Series, No. 1, Vol. 47 (1951).

10. Carson, H. L., W. G. Cook and R. Schnurmann. "Symposium on Principles of Penetrant Methods"--Physics of Nondestructive Testing, British Journal of Applied Physics, Supplement 6, pp. 518-523 (1957).

11. Catlin, F. S. "Black Light Inspection of Castings," Foundry, Vol. 77, No. 8 (1949).

12. Catlin, F. S. "Testing Methods Valuable in Improving Casting Design," Foundry, Vol. 85, No. 3, (1957).

13. Crawford, Alan, Ultrasonic Engineering, Butterworths Scientific Publications, London, (1955).

14. Doane, F. G. and C. E. Bentz, Principles of Magnaflux, 3rd. ed., Photopress, Chicago, (1948).

15. Edwards, P. D., "An Approach to Versatility in Eddy Current Testing," Symposium on Nondestructive Tests in the Field of Nuclear Energy, American Society for Testing Materials, Philadelphia, Pa. (1957).

16. Gilbert, L. and Bunn. "Inspection Techniques for Quality Welding," Welding Journal, Vol. 32, No. 7, (1953).

17. Glickstein, Cyrus, Basic Ultrasonics, John F. Rider Publisher, Inc., New York (1960).

18. Hubbard, J. C., "Ultrasonics in the Study of Matter," Chemical Engineering Symposium Series, Vol. 47, No. 1 (1951).

19. Kelley, S. G., Jr. "New Magnetic Technique Speeds Inspection of Ferrous Parts," Materials and Methods, Vol. 33, No. 6, (1951).

20. Kunlin, S. A. "Fluorescent Inspection of Tungsten," Electronics Vol. 16, No. 7 (1948).

21. Lapp, R. E. and H. L. Andrews, Nuclear Radiation Physics, Prentice-Hall, Inc., Englewood Cliffs, N. J. (1954).

22. Libby, H. L., "Introduction to Eddy Current Methods and Techniques," Symposium on Nondestructive Tests in the Field of Nuclear Energy, American Society for Testing Materials, Philadelphia, Pa. (1957).

23. "Magnetic Particle Inspection," Welding Handbook, American Welding Society, New York.

24. McGonnagle, W. J. Nondestructive Testing, McGraw-Hill Book Co., New York, (1961).

25. McMaster, R. C. Nondestructive Testing Handbook, Vols. I and II, Roland Press Co., New York, (1959).

26. McParlin, J. L. "How Nondestructive Testing Aids Power Station Maintenance," Power Engineering, No. 3, pp. 57-60, (1957).

27. Metals Engineering Design, ASME Handbook, McGraw-Hill Book Co., Inc., New York, (1953).

28. Migel, Hamilton. "Activities of Subcommittee III on Magnetic Particle and Penetrant Testing," ASTM Special Technical Publication 213, p. 11. (1957).

29. Migel, Hamilton. "Megnetic Particle, Penetrant and Related Inspection Methods as Production Tools for Process Control," presented at SAE Summer Meeting, June, 1954.

30. Oliver, et al., "Production Inspection of Pipe and Tubing by the Immersed Ultrasonic Methods," Symposium on Nondestructive Tests in the Field of Nuclear Energy, ASTM, Philadelphia, Pa., (1958).

31. Radley, J. A. and J. Grant. Fluorescence Analysis in Ultra-Violet Light, Chapman and Hall, Ltd., London, (1954).

32. Richardson, E. G., Ultrasonic Physics, Elseuier Publishing Co., Houston, (1952).

33. Roda, D. E. "Magnetic Particle Inspection in Engineering," Iron Age, Vol. 162, No. 6, (1948).

34. Roll, K. H. "Latest Methods for Inspection of Lead Linings," Chemical Engineering, Vol. 63, No. 11, p. 250, (1956).

35. Schnurmann, R. "Penetrant Methods of Inspection," Research Applied in Industry, London, pp. 254-257, July, 1958.

36. Staats, H. N. "The Testing of Ceramics." Journal of the Society for Nondestructive Testing, Vol. 10, No. 3, pp. 23-26. (1952).

37. Stanford, E. G., et. al., Progress in Nondestructive Testing, Vol. I, the MacMill

38. Tenney, G. H. "Survey of Radiation Techniques," Symposium on Nondestructive Tests in the Field of Nuclear Energy, American Society for Testing Materials, Philadelphia, Pa., (1957).

39. Wenk, S. A., "Survey of Ultrasonic Methods and Techniques," Symposium on Nondestructive Tests in the Field of Nuclear Energy, ASTM, Philadelphia, Pa., (1958).

40. Wenk, S. A., K. D. Cooley, and R. M. Kimmel. "Photoelectric Scanning of Fluorescent Indications," Journal of the Society of Nondestructive Testing, Vol. 11, No. 1, pp. 28-31. (1952).

41. Wilson, T. C., "Nondestructive Testing of Refinery Equipment," Petroleum Engineer, Vol. 27, No. 7, (1955).

42. Worlton, D. C., "Applications of Lamb Waves in Ultrasonic Testing," Symposium on Nondestructive Tests in the Field of Nuclear Energy, ASTM, Philadelphia, Pa., (1958).

43. _____. "Brightness, Stability, and Sensitivity in Shannon-Glow Penetrant Systems." Los Angeles, The Alban H. Reid Foundation for Physical Research.

44. _____. "Directions for Model 12B Electronic Photofluorometer." Maywood, Illinois, Coleman Instrument Co.

45. _____. "Fluorescent Methods Detect Leaks in Pressure Vessels." Chemical and Metallurgical Engineering, Vol. 50, No. 8. (1943).

46. _____. "Fluorescent Penetrant Inspection." Welding Handbook, Vol. 1, 4th ed., New York, American Welding Society. (1957).

47. _____. "Met-L-Check Visible Penetrant Dye Methods Finds Defects in Jet Parts Faster at Less Cost." Western Metals, December (1954).

NOMENCLATURE

c = speed of sound in the media

= speed of sound in the material

D = film density

E_k = the kinetic energy of the ejected photon

h = Planck's constant = 6.62509×10^{-27} erg-sec

I = the intensity of the radiation after it has passed through a thickness x of the material

I_o = the intensity of the radiation at the surface of the material

= intensity of light incident on the film

I_t = intensity of light transmitted through the film

L = the specific acoustic impedance of the material

N = number of atoms of radioactive materials remaining

n = number of atoms per gram of absorber

N_o = number of atoms of radioactive material initially present

T = half life of the radioisotope

= transmittance

t = time elapsed

X = the fraction of the wave that is reflected

x = the thickness of the material through which the radiation passes

Greek Symbols

λ = decay constant = 0.693/T

μ = total absorption coefficient (linear, mass or atomic)

μ_a = atomic absorption coefficient

μ_c = absorption coefficient for Compton effect

μ_l = the linear absorption coefficient

μ_m = mass absorption coefficient

μ_p = absorption coefficient for pair production

μ_{ph} = absorption coefficient for photoelectric effect

ν = frequency of the photon

= the frequency of the sound wave

ρ = density of the material

= density of the absorber

ϕ = energy required to remove the electron from its atom

VITA

William Calvin Diehl, Jr.

Candidate for the Degree of

Master of Science

Thesis: AN INVESTIGATION OF SOME NONDESTRUCTIVE TEST METHODS

Major Field: Chemical Engineering

Biographical:

Personal Data: Born in Tulsa, Oklahoma, June 9, 1933, the son of William C. and Beulah S. Diehl, married to Claire E. Foster, Bristow, Oklahoma; father of three children.

Education: Attended grade school at the Berryhill School, Tulsa, Oklahoma; graduated from Bartlesville High School in 1951; received the Associate of Science Degree from Murray Junior College, Tishomingo, Oklahoma in May, 1953; received the Bachelor of Science Degree from Oklahoma State University, with a major in Chemical Engineering, in January, 1956; completed requirements for the Master of Science Degree in May, 1962.

Professional Experience: Entered the United States Air Force in 1956, and is now a Captain; served as an Instructor Pilot at Vance Air Force Base, Oklahoma from 1957 until September, 1960; entered the Graduate School of Oklahoma State University, Stillwater, Oklahoma in September, 1960.