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MASTER

THICKNESS MEASUREMENTS BY NONDESTRUCTIVE
TESTING METHODS (U)

R. E. Cofield

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the **ATOMIC ENERGY COMMISSION** *under* **U. S. GOVERNMENT** **Contract W-7405 eng 26**

OAK RIDGE Y-12 PLANT
P. O. Box Y
OAK RIDGE, TENNESSEE 37831

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ABSTRACT

Dimensional parameters such as thickness can frequently be measured by nondestructive testing methods which are normally used for the evaluation of internal quality. These methods generally respond to the nature of the test object material rather than merely to the relative location of its surfaces. Thus, many of the techniques can measure thickness when only one surface is accessible or when the thicknesses of several layers of materials are involved. Tangential-projection radiography, narrow-beam radiation absorption gaging, radiation backscatter, electromagnetic induction, microwave interaction, and ultrasonic wave propagation are practical thickness-measurement techniques that are discussed in this report.

CONTENTS

INTRODUCTION	5
SUMMARY	6
MEASURING THICKNESS BY NONDESTRUCTIVE TESTING	7
Principles of Nondestructive Testing	7
Types of Nondestructive Tests	8
Penetrating Radiation	8
Area Radiation Imaging	8
Narrow-Beam Radiation Absorption Gaging	8
Radiation Backscatter Gaging	10
Electromagnetic Induction	11
Microwave Testing	12
Ultrasonic Testing	14
CONCLUSIONS	16

INTRODUCTION

Nondestructive testing methods, normally used to evaluate the internal quality of materials, are frequently applicable to the measurement of such dimensional parameters as thickness. Generally, the most straightforward and desirable method of determining the thickness dimension of a test object is to align two reference points (such as the anvil faces of a caliper micrometer or the rulings on a length scale) with the opposite faces or surfaces of the test object and then determine the linear distance between the two points by the use of some length reference system. A graduated micrometer barrel or the scale markings on the ruler are two examples of rather simple length reference systems.

All such thickness measurement methods, ranging from the simple 12-inch ruler having 1/16-inch graduations to the most complex multico-ordinate, tape, or computer-controlled continuous-path gaging machine using opposable LVDT's or laser interferometers, may be classed together under the general term "dimensional thickness gaging" instruments. They are characterized by the fact that they measure thickness by sensing "the presence and relative location in space of the surfaces of the test object". By definition, this familiar and vast field of measurement is not involved in determining the qualities or properties of the material between the surfaces.

If this simple and direct dimensional thickness measurement method cannot be used to determine the relative locations of the surfaces defining the thickness of a test object, it may be possible to deduce the thickness of the test object from its response to a nondestructive testing method.

SUMMARY

Various nondestructive testing methods have been adapted to the problem of measuring the thickness of materials. In fact, when one surface is inaccessible to the usual direct methods, nondestructive testing usually provides the only method of measurement. Penetrating radiation, radiation backscatter, electromagnetic induction, microwave interaction, and ultrasonic wave propagation are some of the nondestructive testing methods that have been adapted to the problem of measuring material thicknesses.

MEASURING THICKNESS BY NONDESTRUCTIVE TESTING

PRINCIPLES OF NONDESTRUCTIVE TESTING

A distinguishing feature of determining thickness measurements by nondestructive testing methods is the fact that nondestructive tests generally evaluate not only the relative location of the surfaces of the test object, but also the basic nature of the material of the test object. In contrast, a caliper micrometer can be used to measure the thickness of a metal plate or a rigid plastic sheet, essentially without regard for the material composition and certainly without individual calibrations. However, if it were impossible to use the simple dimensional-measurement technique, typified by the micrometer, and a nondestructive testing method had to be used, different instruments would probably be required for the two different materials with separate calibrations. For these reasons, the use of nondestructive testing for thickness measurements requires knowledge of the existence and characteristics of many methods and careful consideration of the nature and behavioral response of the test object to the nondestructive tests.

Since nondestructive tests sense the nature of the test-object material rather than the location of the object's surfaces, it may not be essential that both surfaces or even either surface defining a thickness be accessible. For this reason, nondestructive tests are particularly applicable for measuring the thickness of a material that is plated or coated onto another material and for layered thicknesses of different materials.

Nondestructive testing involves the collection and evaluation of information provided by some sensor or probing medium which is modulated by or interacts with the test-object properties. This sensor may be a form of energy which probes the test object and is influenced by the test object characteristics, or it may be some built-in characteristic of the material which may be detected externally. For example, penetrating X rays, gamma rays, neutrons, or beta rays may be passed into the test object. The number and energy of the rays which pass through is determined by the radiation interaction characteristics of the test object, including its thickness. The radiation passing through the test object may be sensed on a film in radiography, or in a radiation detector in narrow-beam radiation absorption gaging. The quantity, energy, and direction of the radiation that is reflected or scattered by the test object may be sensed in a backscatter gage. The production of prompt or delayed secondary radiation in the test object may be sensed in X-ray emission spectrometry and activation autoradiography. Similarly, the probing medium may be high-frequency mechanical vibration (ultrasonic energy), visible or infrared radiation, heat pulses, microwaves, magnetic fields, or electromagnetic fields and currents. In radioactivity measurements and autoradiography, the quantities and energy of the radioactivity of the test object may be sensed and the effects of thickness or coatings studied.

In all of the measurement techniques to be discussed, there are responses to other test-object properties as well as to thickness, and the possible effect that the changes in these properties may have on the apparent thickness must be considered.

TYPES OF NONDESTRUCTIVE TESTS

Penetrating Radiation

Area Radiation Imaging - The difference in transmission of penetrating radiation through a material (particularly X rays or gamma rays) is a function of the thickness, density, and atomic composition of the material. If density and composition are known, thickness can be measured. In measuring thickness by this method, test objects are radiographed so that the radiation is recorded on film after passing through one thickness of the material or test object. Radiographic film density is measured and related to thickness of the test object. Generally, however, the requirements to maintain absolute calibration of the radiation energy and intensity, of radiographic geometry control, and of film response and development make narrow-beam radiation absorption gaging a better choice for simple thickness measurement. A more useful radiographic technique, particularly for wall-thickness measurements on hollow, closed test objects and for layer-thickness measurements is tangential projection radiography. In this method, the parallel beam of radiation is directed tangential to the wall of the test object, and the projected image of the wall at the tangency point is recorded on film.

Subsequently, the actual linear dimensions of the wall images are measured on the film and corrected for the radiographic projection to provide actual wall-thickness data. The thicknesses of individual adjacent layers of materials can be measured by this technique if the radiation opacities of the various materials are sufficiently different.

The applicability of the tangential radiographic technique is dependent upon: (1) the wall thickness, diameter, and radiation absorption coefficients of curved test objects; (2) the dimension along the radiation path for straight-sided objects; and, (3) the radiographic unsharpness. This last factor includes the size of the radiation source, the relative distances between radiation source and tangency point on the test object and between the tangency point and the film, and film-resolution capabilities.

This method has been used to determine wall and layer thicknesses for test objects varying from hollow spheres a few microns in diameter to 24-inch-diameter spheres and cylinders having 1/2-inch wall thicknesses.

Narrow-Beam Radiation Absorption Gaging - In contrast to the rather large areas imaged in radiography, narrow-beam radiation absorption gaging probes a thin

column of the test object. Figure 1 shows the arrangement of a collimated radiation source and detector to permit a pencil-like beam of penetrating radiation to pass through the test material. Various radioisotopes for X-ray tubes are used as sources for gages that measure the thickness of plates and the wall thickness of vessels. Since the same tests are used to evaluate the density and composition uniformity of alloys, it is obvious that these factors must be known or controlled to permit an accurate measurement of thickness. On this subject it should be noted that actually areal mass or mass per unit area (the product of thickness and density) is the property measured by the radiation absorption gage, and dimensional thickness is obtained only when density and radiation absorption coefficients are known and constant.

Figure 1. NARROW-BEAM RADIATION ABSORPTION GAGING.

Radiation beams as small as 1/8 inch in diameter are frequently used, and variations in thickness or density of $\pm 1/2\%$ are easily measured. Of course, access to both sides of the thickness to be measured is necessary.

Radiation absorption gages are frequently incorporated into scanning equipment to permit continuous measurements on test objects. Careful mechanical arrangements are needed to keep the radiation beam normal to the thickness being measured and to keep the source and detector collimators aligned.

In a technique analogous to tangential radiography, a closed test object may be moved through a thin radiation beam so that the beam becomes tangential to the two

surfaces (inside and outside) at the desired location for a thickness measurement. The changes in radiation intensity as each surface passes tangentially through the beam may be related to the distance moved by the test object and, hence, to the wall thickness.

Radiation Backscatter Gaging

The intensity of radiation that is reflected, rather than transmitted, can be a useful sensor of thickness, particularly of coatings. Figure 2 presents a diagram of a beta backscatter gage as used for measuring the thickness of one material coated onto another material. The beta radiation is shielded by its holder to prevent direct irradiation of the detector. However, beta rays, which strike the test object through the collimator aperture, may be reflected into the detector. The reflection coefficient is a function of the atomic number and the thickness of the reflector, so backscatter from a thin layer of one material on a different atomic number substrate can be related to the coating thickness. Various forms of this gage have been developed to permit measurements inside small objects (on surface areas as small as 20 mils in diameter) and on coatings ranging from a few microinches of plating on printed circuit boards to 15 mils of plating thickness. A simpler measurement is a gaging of thin foils and sheets by their backscatter characteristics.

Figure 2. BETA BACKSCATTER GAGE.

Electromagnetic Induction

In electromagnetic induction testing, the electrical and magnetic properties of the test materials are exploited, usually by electrical or electronic instruments which sense changes in these properties. Figure 3 shows such an instrument, an eddy-current tester, which uses a small probe, made up of a coil of wire carrying a high-frequency electrical signal, to induce circulating or eddy currents in electrically conductive material. The intensity, distribution, and any disturbances of these eddy currents are sensed by a pickup coil and related to the test-object properties. The equipment, shown in Figure 3, is used to measure the thickness of one metal plated on a material of a different electrical conductivity.

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Figure 3. EDDY-CURRENT TESTER.

The same principle can be used for measuring thin sheets or foil thicknesses and for measuring the thickness of a nonconductive layer over a conductive substrate. Gages of this type can be used for wall and plating thickness measurements up to about 200 mils.

A related gage, the magnetic-induction gage, measures the thickness of a nonmagnetic coating over a magnetic substrate. For instance, plastic layers, silver plating, and other coatings can be measured on steel substrates.

A typical instrument (Figure 4) used by this technique employs a small horseshoe-shaped probe with a primary winding on one leg and a secondary winding on the other. When the probe is brought near a magnetic material so that the gap at the bottom of the probe is closed, the efficiency of the resulting transformer is determined by the effective magnetic permeability of the layer to be gaged.

Figure 4. RECORDING MAGNETIC-INDUCTION THICKNESS GAGE.

Originally, this instrument was designed for measuring nonmagnetic layers over magnetic substrates; eg, cadmium on steel and glass-fiber windings or plastic on steel or iron. The technique is quite useful for this application because the low frequency (60 cycles as compared to 2.5 kc with the eddy-current technique) eliminates the effect of electrical conductivity (Figure 5). Consequently, it is not necessary to make standard samples for every type of coating. Plastic shims can be used to maintain a known spacing between the probe and the substrate material for calibration. However, the basic magnetic response of the substrate must be the same as that of the test block on which the calibration curve is made.

Figure 5, which shows the response of such an instrument to the thickness of various materials, indicates that the material type and electrical properties of the coating are not important as long as the coating is nonmagnetic.

If a closely conforming magnetic backing plate (such as machining mandrel) is provided on one side of the nonmagnetic material, this gage can be used to measure wall thicknesses of test objects.

Microwave Testing

One of the newest areas of testing physics involves the interaction of a microwave or radar radiation with nonconductive materials. Figure 6 shows a block diagram of a microwave material tester which permits the microwaves reflected from the test

Figure 5. RESPONSE CURVE FOR MATERIALS OF VARIED ELECTRICAL CONDUCTIVITY.

object or those which penetrate through it to be studied. The microwave signal resulting from the interaction may be evaluated for both phase (relative to the input signal) and amplitude. These two sources of information provide a more selective evaluation of the material. The great penetration that is possible in non-metallic layers is illustrated in Figure 7. This thickness-response graph for fiber glass-plastic plates indicates that thicknesses as great as 1 1/2 inches could certainly be measured.

Ultrasonic Testing

In ultrasonic testing, high frequency sound waves are introduced into metallic and nonmetallic material and the thickness is deduced from the velocity of sound in the test material. Two approaches are frequently used:

Figure 6. MICROWAVE APPARATUS FOR MATERIALS TESTING.

Figure 7. MICROWAVE THICKNESS MEASUREMENTS OF FIBER GLASS PLATES. (Amplitude-phase Response at 10^{10} CP5)

1. In pulse-transient time measurements, a piezoelectric transducer is excited with a short pulse of high-frequency electrical signals, producing a pulse of acoustical waves or mechanical vibrations. This ultrasonic signal is introduced into the test material and the time required for the pulse to traverse the thickness and either be detected by a transducer on the opposite face or be reflected back to the sending transducer is measured. From knowledge of the velocity of sound into material, this transient time is related to thickness.
2. In the resonance method of measurement, the frequency of the vibrations introduced is repeatedly varied over a preset frequency range. When frequencies are reached for which the wave length of sound into samples is equal to or a sub-multiple of the soundpath (twice the thickness), a resonance condition is established that can be recognized electronically by circuitry attached to the transducer. The frequencies of these resonances can be related to thickness.

The ultrasonic methods are suitable for thicknesses from a few mils to several inches. A constant or known sound velocity in the material is necessary for accurate thickness measurements.

CONCLUSIONS

Since new methods to nondestructively test materials are continuously being developed, it may be expected that adaptations of these methods will be made to measure thicknesses.

If "direct dimensional thickness gaging", as originally defined, can be applied to a measurement requirement, it should be used because it is straightforward and not subject to errors because of inherent materials properties. However, when direct dimensional thickness gaging cannot be used, judicious selection and application of nondestructive testing techniques can frequently provide valuable and necessary measurements of thickness.