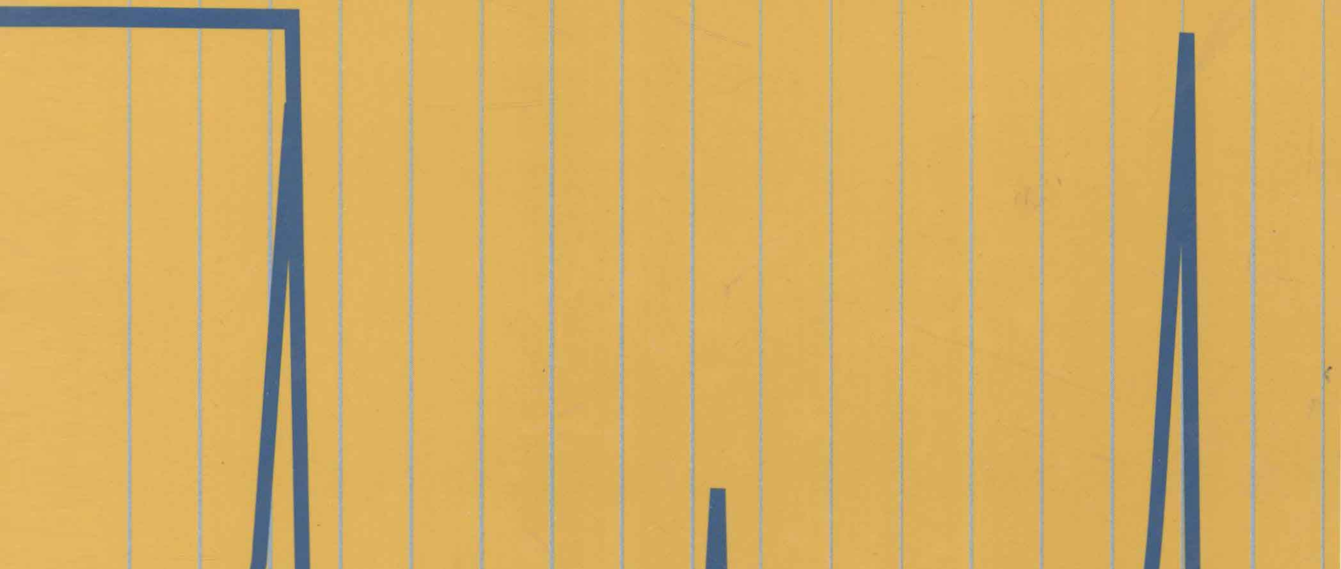
Indian Society for Non-Destructive Testing – National Certification Board Series

Practical Ultrasonics



C.V. Subramanian

Alpha Science

Indian Society for Non-Destructive Testing – National Certification Board Series

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Published for

Indian Society for
ISNT
Non-Destructive Testing

Alpha Science International Ltd.
Oxford, U.K.

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www.alphasci.com

ISBN-13: 978-1-84265-238-1
ISBN-10: 1-84265-238-9

Printed in India

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Foreword

I am delighted and happy to learn that the book titled "Practical Ultrasonics" authored by Shri C.V. Subramanian is now ready for printing/publication.

When National Cerification Board (NCB) came into existence few years back, for effective execution of its various activities and for meeting some of its prime objectives such as Training & Certification of NDT/NDE personnel, it is felt essential to bring out appropriate books and reference material on various methods/techniques of NDT. While realizing some books on the subject dealing the basics are available in the market, NCB however felt very essential to bring out at the earliest practical guide books on various NDT techniques, projecting the developments, achievements in the field and at the same time information relevant to academic, research and industry keeping also in view the practical applications, complying with the requirements of National and International standards.

I am fully aware and conscious of the stupendous and himalayan efforts that are needed for bringing out such a broad range of data/information with authority, style and simplicity for the benefit of very many who are directly or indirectly connected with NDT/NDE methods & techniques.

I am very much pleased to see that Shri C.V. Subramanian has readily agreed to author this book. I am one of those passionate admirers of the author for his outstanding professional abilities, rich practical knowledge/experience particularly in ultrasonics field, authority on the subject and for the style of presentation. It is worth noting that the book has been very thoughtfully planned & structured with over 60 useful and selfexplanatory illustrations. Interestingly almost every page there-in contain crisply the essential points what one has to remember and at the end of each chapter a set of good and useful objective type of questions on the topic covered. Good also to note that one chapter is devoted to special techniques in UT, to appraise the reader about the new developments that are taking place. He has also given in Appendix, a very useful and relevant data on the subject.

On behalf of every one in NCB including myself, I would like to place on record our sincere thanks and congratulate the author Shri C.V. Subramanian, for doing a very excellent job in bringing out a very useful & informative book on "Practical Ultrasonics".

I have no doubts in my mind that this book will be very useful not only to the students but also to all professionals at different levels in the NDT community and occupy a prominent place in all professional libraries.

K. BALARAMA MOORTHY
Chairman, NCB

Preface

Nondestructive material testing with ultrasonics is more than 50 years old. From the very first examination using ultrasonic oscillations for detection of flaws in different materials, ultrasonics has emerged as a valuable diagnostic tool both in the field of medicine and industry. While in medical field, it is applied extensively for the detection of abnormalities in human body, in the industrial sector, it ensures the safety and reliability of the welds, components and plants.

The reliability of any NDT technique depends on the judicious understanding and proper application of the technique. Training and certification is thus an essential part of any NDT program. This is particularly true for ultrasonics where even though tremendous advances in instrumentation have resulted in imaging systems, it is still the operator who gives the final decision. The first and foremost requirement of any training program is the availability of appropriate books and reference materials. The amount of knowledge gained by the NDT professional depends on the contents of the course notes and its style of presentation. Course notes are also essential for the harmonisation of training program nationally and internationally. Thus the course notes should reflect authenticity of the facts and also present the latest developments during that period.

Keeping in mind all the above mentioned facts, this book titled "Practical Ultrasonics" has been written. It is intended as a practical guide for the novice in the field be it—engineering or science students, technicians or any other NDT professional involved in ultrasonics. Every effort has been made to present the matter in a lucid and simple format with more than **50** detailed illustrations and explanations wherever needed. A novel feature is the summary of the important points in each page. Sample questions have been provided at the end of each section. The contents of this book comply with the syllabus prescribed by various international and national bodies under their training and certification schemes such as IS 13805, ISO 9712 and ASNT SNT-TC-1A. We are sure that this book would provide a valuable insight into the fundamental and practical aspects of ultrasonic for the reader. For those desirous of enhancing their knowledge further, a detailed reference list has been provided.

A REQUEST

Finally, a request for assistance from you the valued reader. Our primary objective has been to find ways of presenting the central ideas of ultrasonic technique in clear, interesting and professionally useful fashion. Please do let us have your suggestions on additions, or deletions or corrections or simply put any aspect which would make the book more useful. Thus, when the second edition appears, you could be an important part of it.

Baldev Raj

Acknowledgements

This is the second handbook published by the National Certification Board (NCB). The compilation and edits has been solely done by the author, the editors and the Secretariat of NCB with the intent of reducing costs and controlling deadlines. In less than two years, the nine Chapters have been made. The results are a source of pride for the NCB. While it is the duty of NCB to publish such books, the complete preparation is a herculean task. The real credit for this goes to the motivators namely Shri K. Balaramamoorthy, Chairman, NCB and Shri V.A. Chandramouli, Controller of Exams, NCB. The author wish to place on record the unstinting help and support received from *S/Shri S. Bagavathiappan, V. Chandrasekhar, N. Raghu, and L. Pandian* of the Division for PIE & NDT Development, IGCAR, Kalpakkam and *Miss Jayalakshmi* (NCB-Secretariat) Kalpakkam. We also thank all the members of NCB and the Chapters of ISNT for their valuable suggestions and support.

The author is extremely grateful and credits the following organizations for the technical content, figures etc. included in this book.

1. M/s. SONASPECTION INTERNATIONAL, Lancaster, England for types of weld defects and Fig. 1.8.
2. M/s. Krautkramer, GMBH, Cologne, Germany for Ultrasonic testing of Austenitic Welded joints and Fig. 6.12.
3. Editor, Materials Evaluation, The American Society for NDT, Columbus, Ohio, USA for TOFD technique and Fig. 9.1.

Contents

Chapter 1

General Knowledge

1.1 Introduction of NDT Methods

Non-destructive testing is the technology of assessing the soundness and acceptability of an actual component without affecting the functional properties of the component. Non-destructive testing technique is the technology in general, whereas Non-destructive inspection is the use of technology for inspecting materials to a known standard. Non destructive evaluation is the art of developing NDT techniques and arriving at acceptance standard for components for which, nothing will be available to start with. NDT is basically a branch of material science coming under the category of physical testing.

> NDT
> *Testing a component without affecting its functional properties.*
>
> *NDT is a branch of material science*

Material Testing	
Destructive	Non-destructive
Tensile testing	Radiography
Compression testing	Ultrasonic Testing
Impact Testing	Magnetic Particle Testing
Fatigue Testing	Liquid Penetrant Testing
Creep Testing	Eddy Current Testing
Bend Testing	Acoustic Emission
Micro/Macro Testing	Neutron Radiography
Chemical Testing. etc	Holography
	Thermography

Measure accurate or specific characteristics of materials by destroying the specimen	Monitoring and maintaining material quality, components reliability & systems safety without destroying component.

1. Ultimate Tensile Strength.
2. Proof stress
3. % Elongation.
4. Reduction of area
5. Young's Modulus
6. Fatigue Strength
7. Creep Strength
8. Fatigue properties etc.,

1. Surface/Internal defects
2. Coating/plating thickness
3. Sorting
4. Velocity/Thickness Monitor
5. Structural/Assembly Evaluation

1.2 Most Commonly Used NDT Methods

Most commonly used conventional NDT methods are Visual, Dye Penetrant, Magnetic particle, Eddy Current, Radiography and Ultrasonics. Principle of each technique is discussed in brief in the following section.

> Six common NDT methods.
>
> Visual,DPT, MPT, ECT, RT, UT.
>
> DPT:
>
> *Principle-Capillary action*
>
> *Only surface defects can be detected.*

1.2.1 Visual Testing

The most widely used of all NDT techniques is Visual Testing (VT) and it is the oldest of them. Although it is not possible to quantify the observations made, it is very important that all inspections include a preliminary visual check during which abnormal conditions such as high wear, corrosion, erosion, impact damage, distortion, discoloration, missing parts, etc. can be noted. Based on these findings, the course of further inspection is generally decided.

1.2.2 Dye Penetrant Testing

This is an aided visual technique. In this method a bright coloured liquid which penetrates into cracks and fissures open to surface is used. First the surface is thoroughly cleaned and wiped clean. A penetrant is sprayed onto the surface. The bright coloured penetrant seeps into all surface flaws. The surface is now carefully wiped clean to remove all the excess dye on the surface. A developer is applied to the surface. White coloured developer has a blotting action on the dye and draws it up to the surface. A bright coloured indication of the flaw is presented to the inspector. Dye penetrant Testing principle is shown in Fig. 1.1

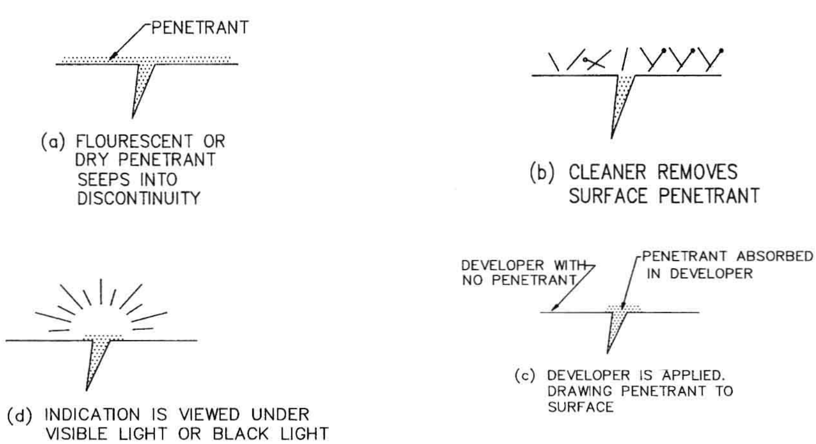

Fig. 1.1 Sequence of Liquid Penetrant testing

1.2.3 Magnetic Particle Testing

Magnetic Particle Testing is a very useful method for detection of surface and sub-surface cracks in ferrous material components. In this method, when the part being inspected is first magnetized, there is a flow of magnetic lines of force on the portion under test. At this stage, magnetic powder is sprayed on to the surface. If there is any discontinuity or flaw in the surface or just below it, the flow of magnetic lines is interrupted and intermediate poles are induced at either side of the discontinuity. These interpoles attract the sprinkled magnetic powder. This forms an exact image of the flaw (Fig. 1.2). The image is more sharp if the flaw is closer to the surface. One thing to be kept in mind during magnetic particle testing is the discontinuities parallel to the lines of magnetic force will not show any indication.

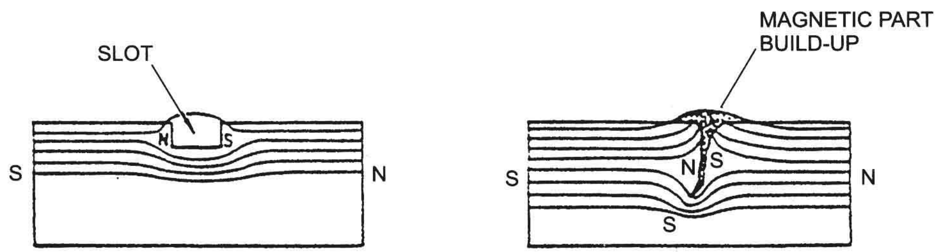

Fig. 1.2 Magnetic Particle Testing Principle

1.2.4 Eddy Current Testing

> MPT:
>
> *For surface and subsurface defects.*
>
> *Defect causes leakage –flux in the magnetic field.*
>
> *Magnetic powder forms an exact image of the flaw.*
>
> *Principle:*
> *Magnetic permeability.*

When a moving or changing magnetic field passes through a conducting material, it induces a current in it. A magnet pulled across a sheet of copper or aluminium will produce irregular current flow, inducing whirlpools very similar to those found in the wake of a ship. These turbulent and irregular electrical currents are called eddy currents. Though these currents are random in nature they produce their own magnetic fields which creates a dragging force between the plate and the magnet. This phenomenon is used for non-destructive inspection of non-magnetic but conductive material. In this technique an alternating current (frequency ranging from a few kHz to several MHz) is sent through a coil. This coil is moved along the test surface. The current flowing through the coil induces eddy currents in the test object. These eddy currents have their own magnetic fields which are picked up by a sensor probe moving along the exciter probe. As the probe transverses the surface, cracks, etc. result in the distortion of eddy current which are reflected and displayed on chart or cathode ray tube screen. (Fig. 1.3). This NDT technique is the only one where the depth of a crack can be read off a screen. This technique is applied not only in crack detection but also for material sorting, thickness determination of conductors, paint coating thickness check and surface roughness gauging.

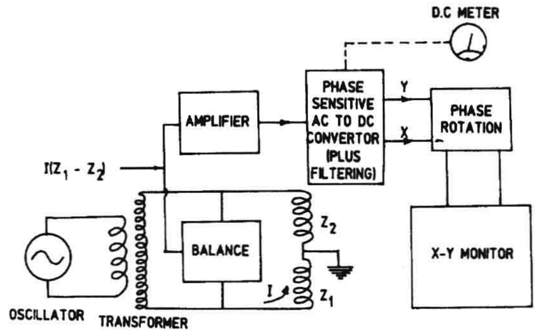

Fig. 1.3 Block diagram of ECT Instrument

1.2.5 Radiography

Radiography is a NDT method based on the principle of differential absorption of penetrating radiation by the object under test. Owing to the varying characteristics or composition of the structure of the test object, different portions absorb different amounts of penetrating radiation. The radiation passing through without being absorbed is recorded on a film and viewed on an illuminated screen. The picture thus seen is used to locate defects in the test object. Principle of radiography is shown in Figure 1.4.

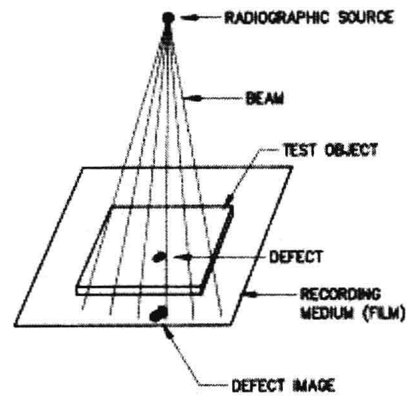

Fig. 1.4 Principle of Radiography inspection

1.2.6 Ultrasonics

In this inspection technique, high frequency sound waves are sent into the object under test. The sound wave travel through the material. During their path of travel they suffer loss of energy and are reflected at interfaces. A receiver probe picks up the reflected wave and an analysis of this signal is done to locate flaws in the object under inspection. Sound waves follow the laws of optics in their propagation. Further the velocity of propagation of sound in various metals has been very accurately determined. The time taken by a sound pulse to travel through a material is a direct measure of the length of path traveled by it. In ultrasonic inspection, both through transmission and pulse-echo techniques are used. Principle of pulse echo test technique, most widely used technique in ultrasonic testing is shown in Fig. 1.5. Ultrasonics can detect cracks, laminations, shrinkage, cavities, flakes, pores and other discontinuities, inclusions, etc. in plates, pipes, welds, castings and forgings. In service defects detection such as fatigue cracks,

ECT:

For electrically conducting materials.

To detect surface and sub-surface defects.

RT:

Principle:
Differential absorption of penetrating radiation.
A volumetric method.
Widely used in weld inspection.

creep cracks, hydrogen embrittlement, stress corrosion, etc., as well as thickness determination can be carried out using the ultrasonic pulse-echo technique.

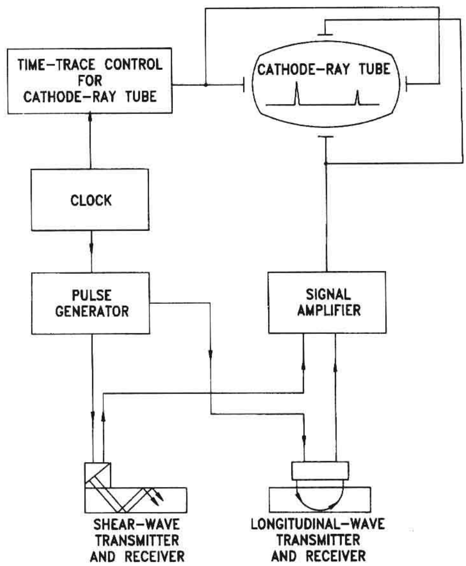

Fig. 1.5 Working Principle of Flaw detector

1.3 Defects in Materials

1.3.1 Definitions

Discontinuity: is any local variation in material continuity such as change in geometry, structure, composition or properties or presence of holes, cavities or cracks. Discontinuities are not always bad or hazardous and may even sometimes be needed in the design or may be helpful in some kinds of processing.

Defect: When any discontinuity, single or multiple, is of such size, shape, type and location that it creates a substantial chance of material failure in service, it is commonly called a "DEFECT". Finding defects is one of the most frequent objectives of NDT. It must be understood, however, that a fault that is a defect under one set of conditions of service may be only a simple discontinuity that is not harmful in a different application.

The purpose of NDT is to locate various flaws in materials and products. To at least some degree, the flaws, defects or imperfections that may be located by inspection may be a result from the original material, caused by the processing used, created by some human error, or a result of some combination of these. In most cases, it is important

UT:
Principle:

Reflection of sound waves. Widely used for detection of defects in castings, forgings, Plates, pipesand welded components.

Discontinuity:

Local variation in material continuity.

Defect:
A discontinuity of such size and shape to create material failures.

Castings:
A basic method of producing shapes.

for the NDT inspector to be able to locate the source of the problem when it exists, or even when a fault is not located, know that the possibility of one exists. An understanding of the materials, the processes, and the possible interactions between them is a "MUST". Let us now go through in brief the most commonly adopted primary metallurgical processes and the nature and type of discontinuities which can be expected in the material at each stage. Since the causes for discontinuities in all metals are similar, we can consider the processing of steel.

1.3.2 Metallurgical Processes and Defects

Casting Defects: Casting is the process of causing liquid metal to fill a cavity or a mould and solidify into a useful shape. It is a basic method of producing shapes. With the exception of a very small volume of a few metals produced by electrolytic or pure chemical methods, all materials used in metal manufacturing are cast at some stage of processing. Castings of all kinds of metals, in sizes from a fraction of an ounce up to many tons, are used directly with or without further shape processing. Even those materials considered to be wrought , start out as cast ingots before deformation work in the solid state puts them in their final condition. The solidification from liquid at pouring temperature to the solid at room temperature, in the casting process, occurs in three stages: (1) contraction of liquid steel; (2) liquid to solid contraction; (3) contraction of the solid to room temperature. The flaws which may be formed during the above solidification process can be classified as follows:

(a) Non-metallic inclusions: The non-metallic inclusions within the molten metal, which are caused by the impurities in the starting material, are lighter than the molten metal and rise towards the surface. Most of the non-metallics manage to rise to the top of the ingot but some are trapped within because they did not have the time to reach the surface before the molten metal above them hardened. These inclusions are irregular in shape.

(b) Porosity: It is spherical or nearly spherical shaped and is caused by the entrapped gas in the molten material.

(c) Shrinkage flaws: Shrinkage flaws are cavities formed during liquid-to solid contraction. These flaws are not normally associated with gas formation but high gas content will increase their extent. The shrinkage flaws may occur in these different forms.

(i) Macro-shrinkage (piping): Liquid solidification and contraction in the mould will cause the formation of shrinkage cavities (piping). The molten material, after it is poured into the mould, starts to cool and solidify. The solidification process starts from the surface and travels towards the metal contracts. Since the center of the ingot is the last to cool and solidify, most of the shrinkage is absorbed in the center. This results in the cavity called the "pipe". By properly designing the mould and by adequate hot-topping, piping can be restricted to the top or to the feeder head. Piping may extend from the top towards the interior of an ingot along the axis.

(ii) Centre-line Shrinkage (filamentary shrinkage): Wherever solidification cannot be correctly controlled and is not directional, a coarse form of shrinkage may occur. These flaws may extensive, branching, dendritic and interconnected. Filamentary shrinkage should theoretically, occur on the centerline of the cast section but due to temperature gradients during solidification, the flaw may extend to the cast surface. Especially, in alloys with a broad freezing range (such as bronze). shrinkage is more dispersed than centerline.

> Non-metallic inclusions:
>
> *Lighter rhan molten metal.*
>
> *Irregular in shape*
>
> Porosity:
> *Caused by entrapped gases.*
>
> Shrinkage:
> *Cavities formed during solidification.*