



NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
 (Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University,
 Kerala)



DEPARTMENT OF MECHANICAL ENGINEERING

COURSE MATERIALS



ME367 NDT

VISION OF THE INSTITUTION

To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION

NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values.

We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- ◆ Established in: 2002
- ◆ Course offered : B.Tech in Mechanical Engineering

- ◆ Approved by AICTE New Delhi and Accredited by NAAC
- ◆ Affiliated to the University of Dr. A P J Abdul Kalam Technological University.

DEPARTMENT VISION

Producing internationally competitive Mechanical Engineers with social responsibility & sustainable employability through viable strategies as well as competent exposure oriented quality education.

DEPARTMENT MISSION

1. Imparting high impact education by providing conducive teaching learning environment.
2. Fostering effective modes of continuous learning process with moral & ethical values.
3. Enhancing leadership qualities with social commitment, professional attitude, unity, team spirit & communication skill.
4. Introducing the present scenario in research & development through collaborative efforts blended with industry & institution.

PROGRAMME EDUCATIONAL OBJECTIVES

- PEO1:** Graduates shall have strong practical & technical exposures in the field of Mechanical Engineering & will contribute to the society through innovation & enterprise.
- PEO2:** Graduates will have the demonstrated ability to analyze, formulate & solve design engineering / thermal engineering / materials & manufacturing / design issues & real life problems.
- PEO3:** Graduates will be capable of pursuing Mechanical Engineering profession with good communication skills, leadership qualities, team spirit & communication skills.
- PEO4:** Graduates will sustain an appetite for continuous learning by pursuing higher education & research in the allied areas of technology.

PROGRAM OUTCOMES (POS)

Engineering Graduates will be able to:

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering

problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and teamwork:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSO)

PSO1: Students able to apply principles of engineering, basic sciences & analytics including multi variant calculus & higher order partial differential equations..

PSO2: Students able to perform modeling, analyzing, designing & simulating physical systems, components & processes.

PSO3: Students able to work professionally on mechanical systems, thermal systems & production systems

Course code	Course Name	L-T-P-Credits	Year of Introduction
ME367	Non-Destructive Testing	3-0-0-3	2016
Prerequisite : Nil			
Course Objectives - To introduce the basic principles, techniques, equipment, applications and limitations of NDT methods such as Visual, Penetrant Testing, Magnetic Particle Testing, Ultrasonic Testing, Radiography, Eddy Current. - To enable selection of appropriate NDT methods. - To identify advantages and limitations of nondestructive testing methods - To make aware the developments and future trends in NDT.			
Syllabus Introduction to NDT- Visual Inspection- Liquid Penetrant Inspection- Magnetic Particle Inspection- Ultrasonic Testing- Radiography Testing- Eddy Current Testing.			
Expected outcome The students will be able to differentiate various defect types and select the appropriate NDT methods for the specimen.			
Text book Baldev Raj, Practical Non – Destructive Testing, Narosa Publishing House ,1997			
Reference books - Hull B. and V.John, Non-Destructive Testing, Macmillan,1988 - Krautkramer, Josef and Hebert Krautkramer, Ultrasonic Testing of Materials, Springer-Verlag, 1990			
Course Plan			
Module	Contents	Hours	End Sem. Exam Marks
I	Introduction to NDT, Comparison between destructive and NDT, Importance of NDT, Scope of NDT, difficulties of NDT, future progress in NDT, economics aspects of NDT.	1	15%
		1	
	Visual Inspection - tools, applications and limitations - Fundamentals of visual testing: vision, lighting, material attributes, environmental factors.	1	
		1	
II	visual perception, direct and indirect methods mirrors, magnifiers, boroscopes, fibrosopes, closed circuit television, light sources	1	15%
		1	
	special lighting, a systems, computer enhanced system	1	
	Liquid Penetrant Inspection: principles, properties required for a good penetrants and developers - Types of penetrants and developers	1	
II	and advantages and limitations of various methods of LPI - LPI technique/ test procedure	1	15%
		1	
	interpretation and evaluation of penetrant test indications, false indication	1	
		1	

	and safety precaution required in LPI, applications, advantages and limitations	1	
FIRST INTERNAL EXAMINATION			
III	Magnetic Particle Inspection (MPI)- Principles of MPI, basic physics of magnetism, permeability, flux density, cohesive force, magnetizing force, retentivity, residual magnetism Methods of magnetization, magnetization techniques such as head shot technique, cold shot technique, central conductor testing, magnetization using products using yokes direct and indirect method of magnetization, continuous testing of MPI, residual technique of MPI, system sensitivity, checking devices in MPI Interpretation of MPI, indications, advantage and limitation of MPI.	1	15%
		1	
		1	
		1	
		1	
		1	
IV	Ultrasonic Testing (UT): principle, types of waves, frequency, velocity, wavelength, reflection, divergence, attenuation, mode conversion in ultrasonic UT testing methods contact testing and immersion testing, normal beam and straight beam testing, angle beam testing, dual crystal probe, ultrasonic testing techniques	1	15%
		1	
		1	
		1	
	resonance testing, through transmission technique, pulse echo testing technique, instruments used UT, accessories such as transducers, types, frequencies, and sizes commonly used Reference blocks with artificially created defects, calibration of equipment, Applications, advantages, limitations, A, B and C scan - Time of Flight Diffraction (TOFD).	1	
		1	
		1	
SECOND INTERNAL EXAMINATION			
V	Radiography Testing (RT): Principle, electromagnetic radiation sources: X-ray source, production of X-rays, high energy X-ray source, gamma ray source - Properties of X-rays and gamma rays Inspection techniques like SWSI, DWSI, DWDI, panoramic exposure, real time radiography, films used in industrial radiography, types of film, speed of films, qualities of film screens used in radiography, quality of a good radiograph, film processing, interpretation, evaluation of test results, safety aspects required in radiography applications, advantages and limitations of RT	1	20%
		1	
		1	
		1	
		1	
		1	
VI	Eddy Current Testing (ECT) - Principle, physics aspects of ECT like conductivity, permeability, resistivity, inductance, inductive reactance, impedance Field factor and lift of effect, edge effect, end effect, impedance plane diagram in brief, depth of penetration of ECT, relation between frequency and depth of penetration in ECT equipments and accessories, various application of ECT such as	1	20%
		1	
		1	
		1	
		1	

	conductivity measurement, hardness measurement, defect detection	1	
	coating thickness measurement, advantages and limitations of eddy current testing	1	
END SEMESTER UNIVERSITY EXAMINATION			

Question Paper Pattern

Maximum marks: 100

Time: 3 hrs

The question paper should consist of three parts

Part A

There should be 2 questions each from module I and II

Each question carries 10 marks

Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part B

There should be 2 questions each from module III and IV

Each question carries 10 marks

Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part C

There should be 3 questions each from module V and VI

Each question carries 10 marks

Students will have to answer any four questions out of 6 (4X10 marks =40 marks)

Note: Each question can have a maximum of four sub questions, if needed.

COURSE OUTCOME

CO No.	Course Outcome
C367.1	Comparison between destructive and NDT techniques, methods and applications of visual inspection.
C367.2	Demonstrate the principle, advantages, limitations and applications of Liquid Penetrant Inspection.
C367.3	Examine the magnetizing methods, principle, advantages, limitations and applications of Magnetic Particle Inspection.
C367.4	Demonstrate the principle, methods, advantages, limitations and applications of Ultrasonic testing.
C367.5	Examine the principle, techniques, advantages, limitations and applications of Radiographic testing.
C367.6	Demonstrate the principle, advantages, limitations and applications of Eddy current testing.

CO-PO-PSO MAPPING

CO Vs PO															
ME367															
COURSE COUTCOME	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
C367.1	1	-	-	2	-	-	-	-	-	-	-	2	2	-	3
C367.2	2	-	-	1	2	-	-	-	-	-	-	2	2	2	3
C367.3	2	-	-	1	2	-	-	-	-	-	-	2	2	2	2
C367.4	2	-	-	2	2	-	-	-	-	-	-	3	2	3	2
C367.5	2	-	-	2	2	-	-	-	-	-	-	3	2	3	2
C367.6	2	-	-	1	2	-	-	-	-	-	-	2	2	2	2

QUESTION BANK

MODULE 1			
SL NO	QUESTIONS	CO	KL
1	Define Non Destructive Testing.	CO1	K1
2	Explain the future scope of Non Destructive Testing Methods	CO1	K2
3	Describe the importance of Non Destructive Testing.	CO1	K3
4	List the optical aids used in visual inspection	CO1	K2
5	Write short notes on, (i)Boroscope (ii)Endoscope	CO1	K2
6	Draw the block diagram of computer enhanced visual system	CO1	K3
7	Write the advantages and disadvantages of computer enhanced visual system	CO1	K2
8	Differentiate destructive and non-destructive testing	CO1	K4
9	Explain computer enhanced visual system for visual inspection	CO1	K2
10	Describe any of the two optical aids used in visual inspection	CO1	K2

MODULE 2			
SL NO	QUESTIONS	CO	KL
1	List the materials for liquid penetrant test	CO2	K1
2	Explain any of the two penetrant testing methods	CO2	K2
3	With neat sketches explain the steps involved in conducting LPI.	CO2	K3
4	State the principle of Liquid Penetrant Inspection	CO2	K3
5	Analyse the properties required for good penetrant	CO2	K3
6	Based on the physical properties enumerate the features of different penetrants	CO2	K3
7	Analyse the various steps involved in Liquid penetrant inspection	CO2	K4
8	Write the limitations of LPI.	CO2	K2
9	Write properties of developer	CO2	K2
10	Name the excess penetrant removal methods	CO2	K2

MODULE 3			
SL NO	QUESTIONS	CO	KL
1	Define the term residual magnetism	CO3	K1
2	Explain the procedure used in magnetic particle inspection	CO3	K2
3	Describe the importance of Interpretation of MPI	CO3	K3

4	List the various methods of magnetization	CO3	K2
5	Describe the limitations of MPI	CO3	K1
6	With neat sketch explain any four magnetization techniques used in MPI	CO3	K2
7	Is it essential to demagnetise the specimen before and after the magnetic particle testing? Substantiate your answer	CO3	K3
8	Differentiate between direct and indirect method of magnetization	CO3	K4
9	Describe the limitations of MPI	CO3	K2
10	Write the advantages and disadvantages of MPI	CO3	K2

MODULE 4			
SL NO	QUESTIONS	CO	KL
1	List the type of waves used in UT	CO4	K1
2	Explain in detail normal beam and angle beam testing	CO4	K2
3	State the principle of Ultrasonic Testing	CO4	K3
4	With neat sketches explain the steps involved in conducting UT	CO4	K3
5	Write the advantages and disadvantages of UT	CO4	K2
6	Explain in detail A, B and C Scan in UT	CO4	K2
7	Explain in detail different modes of display in UT	CO4	K2
8	Analyze the procedure used in UT	CO4	K4
9	Write the limitations of UT	CO4	K2
10	Explain normal beam and angle beam testing used in UT	CO4	K2

MODULE 5			
SL NO	QUESTIONS	CO	KL
1	With neat sketch explain about the different inspection techniques in radiography testing (RT).	CO5	K3
2	Explain about real time radiography	CO5	K2
3	Explain about different types of screens used in RT, mention the advantages also	CO5	K2
4	Explain about various steps involved in film processing in RT	CO5	K2
5	Write short about various safety aspects required in RT	CO5	K2
6	Write short note on image quality indicators	CO5	K2
7	Compare the contrast between X-ray and Gamma ray	CO5	K4
8	Explain SWSI, DWSI AND DWDI inspection techniques in radiographic testing	CO5	K2

MODULE 6			
SL NO	QUESTIONS	CO	KL
1	Explain about eddy current testing techniques in details. List the advantages and disadvantages of the process. Include necessary figures	CO6	K2
2	Explain the following terms associated with ECT: Lift off effect, Edge effect and End effect	CO6	K2
3	Explain the various applications of ECT	CO6	K2
4	What are the major limitations of ECT?	CO6	K2
5	What are the applications and advantages of ECT?	CO6	K2
6	What are the different types of eddy current testing probes?	CO6	K2
7	Explain constant current drive and scanning probe ECT techniques	CO6	K2
8	What is the principle of Eddy current Testing?	CO6	K3

APPENDIX 1	
CONTENT BEYOND THE SYLLABUS	
SL No	WEB SOURCE REFERENCES
1	http://www.nptel.ac.in
2	https://www.asnt.org
3	https://www.ndt-global.com

MODULE – 1

OVERVIEW OF NDT

Introduction to NDT – Comparison between destructive and NDT – Importance of NDT – Scope of NDT – Difficulties of NDT – Future progress in NDT – Economics aspects of NDT – Visual Inspection – Tools applications and limitations – Fundamentals of visual testing – Vision – Lighting – Material attributes – Environmental factors – Visual perception – Direct and indirect methods mirrors – Magnifiers – Borescopes – Fibroscopes – Closed circuit television – Light sources, special lighting – Computer enhanced system – Overview of the Non Destructive Testing Methods for the detection of manufacturing defects as well as material characterisation. Various physical characteristics of materials and their applications in NDT.

1.1. INTRODUCTION OF NON – DESTRUCTIVE TESTING (NDT):

- ★ [Non – Destructive Testing (NDT) is the process of determining the characteristics of the materials, components or systems where we can detect and locate the discontinuities and harmful defects without reducing the usefulness of such materials, components or systems.]
- ★ [In other words, NDT is the means of testing the materials without causing any damage or destruction to the material.] In NDT, even after testing or inspecting, the sample will serve its purpose.

- ★ It is also known as Non - Destructive Evaluation (NDE) and Non-Destructive Inspection (NDI).
- ★ Non - Destructive Testing (NDT) plays an important role in quality control - not only of finished products, but also of semi-finished products as well as the initial raw materials.

1.1.1. Uses of NDT Methods:

- ★ **Automobiles** - To detect the flaws in brakes, steering and critical engine components.
- ✓ ★ **Aerospace** - To detect the corrosion, fatigue, operation and maintenance defects, fabrication defects using penetrant inspection method.
- ★ **Pipelines** - NDT is used to inspect oil and gas industry pipelines to detect any leakage in the pipes.
- ★ **Pressure vessels** - Tanks are inspected using radiography and ultrasonic testing to inspect where there is a leakage (or) release of enormous amount of energy.
- ✓ ★ **Powerplants** - To examine the structural integrity of primary circuit components such as boiler, condenser tubes, turbine components, etc.
- ✓ ★ **Quality control** in raw materials, semi-finished and finished components.
- ★ **To determine the remaining life of the component** by retaining its structural integrity.
- ★ **Dimensional measurement and material sorting.**

1.1.2. Objectives of NDT:

- ★ To aid in better product design.
- ★ To control manufacturing process.
- ★ To detect defect location and characterization.
- ★ To lower the manufacturing cost and maintain uniform quality level.

1.2. MATERIALS TESTING:

(Materials testing is the measurement of characteristics such as physical and mechanical properties of substances such as metals, ceramics (or) plastics under various conditions.)

Materials testing breaks down into five major categories:

- ★ Mechanical testing.
- ★ Testing for thermal properties.
- ★ Testing for electrical properties.
- ★ Testing for resistance to corrosion, radiation.
- ★ Non-destructive testing.

1.2.1. Important engineering characteristics of materials:

Mechanical properties

- ★ Density. ✓
- ★ Strength. ✓
- ★ Hardness. ✓
- ★ Ductility. ✓
- ★ Toughness. ✓
- ★ Fatigue resistance. ✓
- ★ Creep. ✓

Chemical properties

- ★ Reactivity. ✓
- ★ Combustibility. ✓

Thermal properties

- ★ Thermal conductivity. ✓
- ★ Coefficient of expansion.
- ★ Melting point. ✓

Electrical properties

- ★ Conductivity.

Optical properties

- ★ Transmissivity.
- ★ Colour. ✓

Physical properties

- ★ Surface finish. ✓
- ★ Size and shape. ✓
- ★ Colour. ✓
- ★ Porosity and structure. ✓

1.3. CLASSIFICATION OF MATERIALS TESTS:

The materials tests can be classified into

- ✓ 1. Destructive tests.
- ✓ 2. Non – Destructive Tests.

1.3.1. Destructive Testing:

- ★ Destructive testing is the method where the specimen is broken down to determine the physical and mechanical properties such as strength, toughness and ductility.

The commonly used destructive tests include:

- (i) Tensile test.
- (ii) Compression test.
- (iii) Shear test.
- (iv) Hardness test. ✓
- (v) Fatigue test.
- (vi) Impact test. ✓
- (vii) Creep test.
- (viii) Torsion and bending test.

1.3.1.1. Tensile Test:

- ★ Tensile testing is also known as "Tension testing" where the specimen is subjected to controlled tension until the failure (or) fracture occurs.
- ★ It is performed on ductile materials to determine the ultimate tensile strength, maximum elongation and reduction in area, Young's modulus, poisson's ratio, yield strength and strain-hardening characteristics.
- ★ Tensile test is carried out using the Universal Testing Machine (UTM).

1.3.1.2. Compression Test:

- ★ Compression Test is performed in same manner as tensile test but the load here is compressive in nature. It is suitable for brittle material.

1.3.1.3. Impact Test:

- ★ A notch is cut at the standard specimen which is blown using the impact testing machine. Using the scale on the testing machine, energy absorbed in breaking the specimen is measured.

Types of Impact Test:

- ✓ (i) **Izod test** – Specimen is placed as a cantilever beam.
- ✓ (ii) **Charpy test** – Specimen is placed as a simply supported beam.

1.3.1.4. Hardness Tests:

- ★ The resistance to indentation and to scratching or abrasion is known as hardness. The two most common hardness tests are the Brinell test and the Rockwell test.
- ✓ ★ In **Brinell hardness test**, a known load is applied for a given period of time to a specimen surface using a hardened steel or tungsten-carbide ball, causing a permanent indentation. Standard ball diameter is 10 millimeters, or approximately four-tenths of an inch. The diameter of the resulting permanent indentation is then measured and converted to a Brinell hardness number.
- ★ The **Rockwell hardness test** involves the use of an indenter for penetrating the surface of a material first by applying a minor, or initial load, and then applying a major, or final load under specific conditions. The difference between the minor and major penetration depths is then noted as a hardness value directly from a dial or digital readout. The harder the material the higher the number.

1.4. OVERVIEW OF NON - DESTRUCTIVE TESTING METHODS:

1.4.1. Visual Inspection:

★ Visual Inspection is one of the simplest, fastest and most commonly used non-destructive testing method.

★ As the name implies, Visual Inspection involves the visual observation of test specimen to detect the presence of surface discontinuities.

★ It may be done by direct viewing (or) with the help of optical instruments such as, magnifying glasses, mirrors, borescope (or) microscope to inspect closely the subject area.

★ Corrosion, misalignment of parts, physical damage and cracks are some of the discontinuities which can be detected by visual inspection.

1.4.1.1. Principle:

★ The basic procedure involved in the visual inspection is the illumination of the test specimen with the light, usually in the visible region.

★ It also requires the proper eye-sight of the tester.

★ The surface of the test specimen is adequately cleaned before inspection, where the test specimen is illuminated and inspected using the naked eye (or) with the help of optical aids such as mirrors, magnifying glasses, microscopes (or) video-cameras.

1.4.1.2. Visual Testing Requirements:

The requirements for visual testing typically depend on three areas:

★ The inspector's vision.

★ To check whether the area being inspected is obstructed for the inspector.

★ To check the amount of light falling on the specimen using the light meter.

1.4.2. Liquid Penetrant Testing:

- ★ Liquid Penetrant Testing is also known as Dye Penetrant Inspection (DPI) or Penetrant Testing (PT).
- ★ As the name implies, liquid called penetrant is used for detecting cracks, fractures, porosity, laps and other flaws which are open to the surface of the test specimen.
- ★ It can be used to detect flaws on ferrous and non-ferrous metals. Liquid penetrant testing can be used effectively on non-porous and non-metallic materials like glass, plastics and ceramics.

1.4.2.1. Principle:

- ★ Liquid Penetrant Testing depends on the wettability of the liquid on the specimen's surface uniformly and penetrating effect of the liquid on the open flaws. This effect depends upon the surface tension and capillary action of the liquid.
- ★ Surface tension depends upon the cohesive force between the molecules, whereas the capillary action is the phenomenon of rise or fall of the penetrant liquid in the flaws.
- ★ Penetrant may be applied to the specimen using spraying, dipping (or) brushing. After sufficient dwell time, the excess penetrant is removed and developer is applied which draws the penetrant out of the flaw. When the UV light is made to fall on the surface, drawn penetrant molecules absorb the UV light and excite to higher energy level.
While returning to its original (or) lower energy level, they emit light which appears bright in the dim background indicating the flaw clearly.

1.4.2.2. Procedure for Penetrant Testing:

- ✓ 1. Pre-cleaning.
- ✓ 2. Application of penetrant.
- ✓ 3. Removal of Excess penetrant.
- ✓ 4. Application of Developer.
- ✓ 5. Inspection.
- ✓ 6. Post-cleaning.

1.4.2.3. Penetrant Testing Materials:

1. Penetrants. ✓
2. Developers. ✓
3. Cleaners. ✓
4. Emulsifiers. ✓

1.4.3. Magnetic Particle Testing:

- ★ Magnetic Particle Testing (MPT) is used for detecting surface and near surface discontinuities in ferromagnetic materials such as iron, nickel, cobalt and their alloys. These materials can be easily magnetised using direct (or) indirect magnetization method.

1.4.3.1. Principle:

- ★ Magnetic Particle Testing is based on the principle that when a material is magnetised, magnetic lines of force will flow across the specimen. When there is flaw, there will be an interruption in the flow of magnetic lines of force. This interruption will create opposite magnetic poles.
- ★ At the same time, magnetic particles are applied in the form of dry powder (or) wet particle as “magnetic ink”. These magnetic particles are attracted by these opposite magnetic poles which indicates the clear indication of the flaws.

1.4.3.2. Procedure for MPT:

- ✓ 1. Surface preparation.
- ✓ 2. Demagnetization.
- ✓ 3. Magnetization of the component.
- ✓ 4. Addition of magnetic particle.
- ✓ 5. Viewing.
- ✓ 6. Marking of defects.
- ✓ 7. Demagnetization.
- ✓ 8. Removal of ink from the component.

1.4.4. Eddy Current Testing:

- ★ Eddy Current Testing (ECT) is one of the electromagnetic testing method used in NDT. It is used to detect surface and sub-surface flaws in electrically conductive materials.
- ★ It is used to detect surface defects, measure the thickness of non-conductive material coating on a conductive material, corrosion on the walls, tube thickness, etc.
- ★ It is also known as Inductive testing.

1.4.4.1. Principle:

- ★ Eddy Current Testing is based on the principle of electromagnetic induction.
- ★ In ECT, when an alternating current is made to pass through the coil, it produces an alternating magnetic field. This in turn induces an eddy current in the test specimen when it is brought close to the coil.
- ★ The presence of any defects affects the eddy current flow. These interrupted eddy current will produce an alternating magnetic field in opposite direction which changes the corresponding phase and amplitude which is being measured.

1.4.5. Thermography Testing:

- ★ Thermography testing is the non-destructive testing of parts, materials through the imaging of the thermal patterns at the object's surface.
- ★ It is also known as "infrared inspection" (or) "thermal imaging" where the test instrument detects the infrared energy emitted from the object and convert into either a temperature value or a thermal image. The image for the thermal distribution is known as infrared thermograph.

1.4.5.1. Principle:

- ★ Every object whose surface temperature is above absolute zero (-273°C) radiates energy at a wavelength corresponding to its surface temperature. Using high sensitive infrared cameras, it is possible to convert this radiated energy into a thermal image which is being surveyed to detect the cracks.

1.4.5.2. Elements of Infrared detection system:

1. Infrared source.
2. Transmission system.
3. Infrared detectors.
4. Optical components.
5. Signal processing.

1.4.6. Ultrasonic Testing:

- ★ Ultrasonic Testing (UT) is a type of non-destructive testing which is based on the propagation of ultrasonic waves through the material to be inspected.
- ★ Ultrasonic pulse – waves ranges from 0.1 to 15 MHz are transmitted into the materials to detect the internal flaws.

1.4.6.1. Principle:

- ★ (When the ultrasonic probe sends the ultrasonic waves through the component which reflects back from the surface and received by the receiver.) When there is an internal defect, results in the interruption of the ultrasonic wave which is reflected back. The amplitude of the energy reflected and the time required for returning indicates the presence and location of any flaws in the specimen.

1.4.6.2. Equipment used for Ultrasonic Testing:

- ★ Pulser/receiver.
- ★ Ultrasonic transducer.
- ★ Couplant.
- ★ Display.
- ★ Receiver/amplifier.

1.4.7. Acoustic Emission Testing:

- ✓ ★ Acoustic Emission (AE) testing is a non-destructive testing technique where minute AE signals generated by the change in load, pressure (or) temperature are analysed.

1.4.7.1. Kaiser Effect:

- ★ (An important feature of AE, is its irreversibility.) Kaiser effect states that "when a material is loaded to a certain stress value and unloaded, there will not be an emission of AE signals when it is reloaded until the stress value for the old load has been exceeded by the new load".

1.4.7.2. Principle:

- ★ AE is based on the principle that when a piece of an equipment is subjected to an external stimulus such as change in load, temperature, the release of energy in the form of stress waves are triggered.

- ★ These AE signals will propagate through the surface which is recorded by the sensor. By analysing the recorded signal, we can detect the location of the defect.

1.4.8. Radiography Testing:

- ★ Radiography Testing is a non-destructive testing of components which is based on the penetrating ability of shorter wavelength electromagnetic radiations, such as X-rays or gamma rays. In general, rays with shorter wavelength has the greatest penetrating power.
- ★ It is used to verify the internal structure and integrity of the specimen.

1.4.8.1. Principle:

- ★ Radiography uses X-ray (or) Gamma rays as a source of radiation which passes through the test object and captured on a film called radiograph.
- ★ The radiation that enters the material are being absorbed by the material itself. Absorption level depends on the thickness and density of the material.
- ★ When there is a cavity (or) discontinuity, radiation will have less material to travel and there will be a reduction in the absorption level by the material. The variation is recorded on the film which produces an image to indicate the presence of the defect.

1.4.8.2. Elements of Radiography Testing:

- ★ Source of radiation.
- ★ Object to be radiographed.
- ★ Detector (or) recording film.

1.5. COMPARISON BETWEEN DESTRUCTIVE AND NON-DESTRUCTIVE TESTING:

Destructive Test	Non-destructive Test
① ✓ Destructive testing is the <u>method where the specimen is broken to determine the physical and mechanical properties.</u>	✓ Non-destructive testing is the <u>process of determining the characteristics of materials to locate the defect without destroying the material.</u>
② ✓ Mainly used to detect the <u>properties of the material.</u>	✓ Mainly used to find out the <u>defects of the material.</u>
③ ✓ <u>Measurements are direct, and reliable.</u>	✓ <u>As the measurements are indirect, reliability is to be verified.</u>
④ ✓ Load is applied on the material.	✓ Load is not applied on the material.
⑤ ✓ Mainly involves quantitative measurement • Special equipments are required. • Correlation between the test measurements and material properties are direct.	✓ Mainly involves qualitative measurement. • Special devices and instruments are needed. • Skilled labours are required to interpret the result.
⑥ ✓ A destructive test can not be repeated on the same specimen as it is being destroyed.	✓ A non-destructive test can be repeated on the same specimen.
⑦ ✓ Testing is not made on the <u>actual</u> object directly.	✓ Testing is made 100% on the <u>actual</u> component.
⑧ ✓ Test equipment are not portable.	✓ Test equipment is often portable.

Overview of NDT

1.15

Destructive Test	Non-destructive Test
- Using a single specimen, only a one (or) few properties of the material can be measured. - Tests are not made on the objects actually used in service. - Measurement of properties over a cumulative period of time cannot be measured in a single unit. - It is very costly for the preparation of test specimen. - The time and man – hour requirements of many destructive tests are very high. (e.g) Tensile test, compression test, hardness test, impact test, torsion test, etc.	- Many properties of the specimen can be measured as many NDT methods can be applied on the same specimen. - Tests are made directly upon the objects to be used in service. - Non-destructive tests permit repeated checks of a given unit over a period of time. - Little or no specimen preparation is required. - Most NDT methods are rapid and require fewer man – hours. (eg) Visual inspection, liquid penetrant test, eddy current test, radiographic testing, etc.

1.6. IMPORTANCE OF NDT:

- ★ NDT increases the safety and reliability of the product during operation.
- ★ It decreases the cost of the product by reducing scrap and conserving materials, labour and energy.
- ★ Applied directly to the product.
- ★ Tested parts are not damaged.
- ★ Various tests can be performed on the same product.

1.16

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- ✓★ Specimen preparation is not required.
- ★ Can be performed on parts that are in service.
- ★ Low time consumption.
- ✓★ Low labour cost.

1.7. SCOPE OF NDT: (area)

There are four main ways in which non-destructive testing can be incorporated into manufacturing practice:

- ✓1. (To provide control of quality at product manufacture) or during plant fabrication.
 - ✓2. To ensure that an item conforms to specification.
 3. To examine plant, equipment or components during service, in order to meet the requirements or as an insurance against premature breakdown or failure.
 - ✓4. As a diagnostic tool in research and development.
- ★ (Non-destructive testing is not confined to the factory and foundry. On-site testing of pressure vessels, pipelines and bridges, and in-service maintenance of airframes, aero-engines and refinery installations all present special problems to both instrument designer and operator.)
 - ★ (Then again, automated inspection, computer-aided manufacturing and in-line process control raise quite different problems) **Figure 1.1** shows a range of surface and internal variables that may need to be controlled and hence monitored now destructively, again emphasizing that flaw location and sizing represents only one of the many facts that may need to be considered when assessing overall quality.

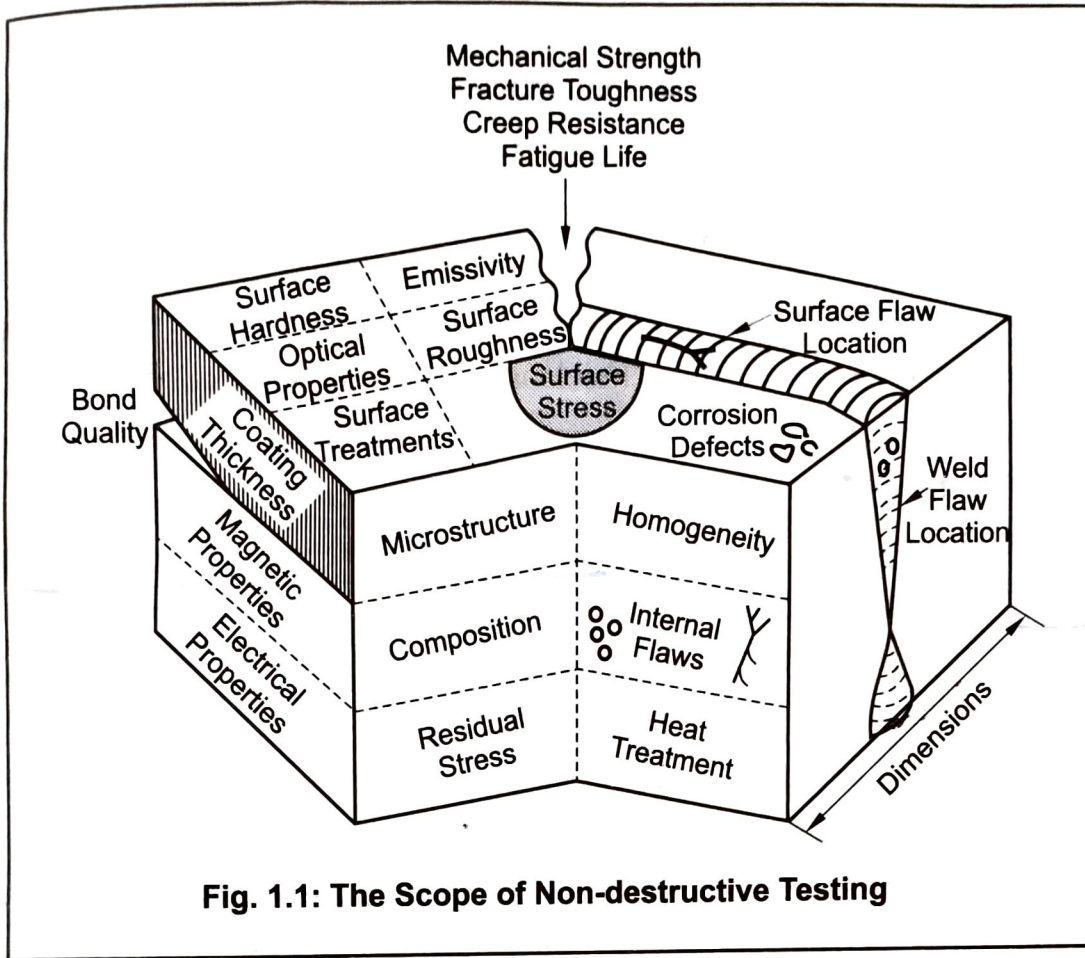


Fig. 1.1: The Scope of Non-destructive Testing

Non-destructive testing during production and fabrication is closely allied with 'condition' monitoring of plant during service and regular 'health' monitoring of installed machinery. Many of the techniques can also be adapted for manufacturing control, enabling flaws to be eliminated as early as possible during the manufacturing process. NDT is also now an important element in the 'fitness-for-purpose' philosophy of manufacture in which design, materials selection, manufacturing and quality control are integrated and properly coordinated.

1.8. FUTURE PROGRESS IN NDT:

There are two general trends within the NDT community that are influencing development. First one is the instrumentation which is being developed to reduce the operator's involvement as much as possible through automating functions and computerizing results. On the other side there are significant efforts to quantify or standardize the human element through

training and qualification. These trends will continue. External factors are several. Perhaps most implant is the introduction of computers to document results to simplify instrumentation and even to analyse and interpret test data. Second is an increasing demand from users for more precision, more reliability and more speed. As users become more dependent on NDT results, to support extended component life and lower factors of safety, this pressure will increase. Finally the need for specialist technicians as well as applications specialists will grow to cope with the many opportunities being presented. There is a new factor coming into NDT, which seems likely to bring major modifications to most NDT methods. This is the use of computer techniques, using small computers. Apart from this it is now possible to collect, store and process vast quantities of digital data at very high speeds. For example, in ultrasonic testing, in the signals produced by a transducer from a flaw there is a mass of data which is not used in conventional ultrasonic flaw detection. This can all be taken into a data store, and computer programmes devised to extract information such as spectral composition, rise-time, pulse length, and maximum amplitude. In addition, the computer can be used to choose the technique parameters for a given application, to adjust the equipment accordingly, and to provide warning if there are deviations, or a change in monitoring signals.

1.9. DIFFICULTIES OF NDT:

- ★ Lack of skilled operators.
- ★ There may be an interference of background noises with the actual signal which is reflected back from the original material.
- ★ Difficulties like wrong positioning, orientation and the wrong determination of the defect type will be there. (Peter J. NDT)
- ★ Lack of protective equipments may cause damage to the operating person as in case of radiography testing by radiations.
- ★ Surface preparation is necessary. Presence of oil, grease, paint, dirt may cause error in the output.

VISUAL INSPECTION:

1.10. INTRODUCTION:

The brief introduction of visual inspection and its principle and requirements are explained in the **section 1.4.1.**

1.10.1. Vision:

The eye

- ★ Human eye is the most valuable NDT tool. ✓
- ★ Sensitivity of the human eye varies according to the light source. ✓
- ★ Human eye has an excellent visual perception. ✓
- ★ Yellow green light of wavelength $5560\text{\AA}$ is the most suitable light for human eye at normal condition. ✓
- ★ For maximum efficiency, human inspector is not allowed to work for more than 2 hours continuously. ✓
- ★ An adequate lighting of about 800 – 1000 lux should be provided. ✓

1.11. TYPES OF VISUAL INSPECTION:

1. Unaided Visual Inspection. ✓
2. Aided Visual Inspection. ✓

1.11.1. Unaided Visual Inspection:

- ★ It is also known as **direct visual inspection**. ✓
- ★ It can be accomplished with the help of naked eye. ✓
- ★ Inspection can be done without using any optical aids. ✓

1.11.1.1. Defects Detected:

- ★ Presence or absence of cracks, corrosion layer, position of the cracks.
- ★ Unfilled craters and contour of the welded parts.
- ★ Surface porosity and general condition of the component.
- ★ Misalignment of mated parts.

1.11.2. Aided Visual Inspection:

- ★ It is also known as indirect visual inspection.
- ★ A visual inspection which is performed using any optical aids (such as magnifying mirrors, borescopes, telescopes, etc..)
- ★ It is used to magnify the defects which cannot be detected by human eye.
- ★ It permits visibility to areas which are not accessible to human eye.

1.12. LIGHTING:

An important factor affecting visual tests is lighting. If appropriate lighting is not achieved, any amount of magnification is not going to improve the image. The amount of light required for a visual test is dependent on the type of test, the importance of speed and accuracy, glare and an inspector's vision capability. Inspector variables such as physiological processes, psychological state, working experience, health and fatigue while not affecting the system of light travel and image projection all contribute to the accuracy of a visual inspector.

For an appropriate visual inspection, suitable lighting of about 800 - 1000 lux is to be provided.

1.12.1. Lighting Sources:

✓ ★ Incandescent lamps.



✓ ★ Fluorescent lamps.



✓ ★ High intensity discharge lamps.

✓ Halogen bulbs

1.13. MATERIAL ATTRIBUTES/FACTORS THAT AFFECT VISUAL TESTING:

1. Surface Conditions:

★ Cleanliness. ✓

★ Colour. ✓

★ Texture. ✓

2. Physical Conditions:

★ Specimen Conditions. ✓

✓ ★ Shape. ✓

✓ ★ Size. ✓

✓ ★ Temperature. ✓

3. Environmental Factors:

★ Atmosphere. ✓

★ Cleanliness. ✓

★ Humidity and Temperature. ✓

★ Safety. ✓

4. Physiological Factors:

- ★ Physical Comfort.
- ★ Health.
- ★ Mental Attitude.
- ★ Fatigue.
- ★ Test Item Position.

1.14. VISUAL PERCEPTION:

★ It is the interpretation of impressions transmitted from retina of the eye to the brain in terms of information about the specimen which is viewed in the visual inspection.

- ★ Visual Perception depends on the ~~vision acuity~~ *clarity of vision*

★ Human eye has an excellent visual perception.

It involves the following steps:

- ★ Recognising the presence of defect in the specimen.
- ★ Identifying it.
- ★ Locating the defect in the specimen.
- ★ ~~Noting its relation to the surface.~~
- ★ Identifying its features like size, shape, colour, etc.

1.15. OPTICAL AIDS USED IN VISUAL INSPECTION:

1. ★ Mirrors. ✓
2. ★ Magnifying glasses. ✓
3. ★ Microscopes. ✓
4. ★ Borescope. ✓
6. ★ Endoscope. ✓
8. ★ Flexible Fibre – Optic Borescope. → Fibroscope ✓
7. ★ Telescope. ✓
10. ★ Holography. ✓
- ★ Optical comparators. ✓
9. ★ Closed – Circuit Television (CCTV) system. ✓
11. ★ Computer enhanced systems. ✓

1.15.1. Magnifying Mirrors:

- ★ It is also known as concave spherical mirrors. 
- ★ It is used to magnify the areas which are not accessible to human eye.
- ★ Magnifying Mirrors work on the principle that angle of incidence of a light beam is equal to the angle of reflection of the same beam of light.

1.15.2. Magnifying Glass:

- ★ It is also known as hand lens. 
- ★ It is a convex lens which is used to produce a magnified image.

- ★ (It works on a principle that if an object is placed on one side of a convex lens closer to it than the focal point, then the image will be formed on the same side as the object and the resultant would be a magnified one.)
- ★ (Magnification of a magnifying glass depends on the position where it is being placed between the human eye and the object.)
- ★ (For lower power magnification, simple lens is used and on the other hand for high power magnification, double or multiple lenses are used.)

1.15.3. Microscope:

- ★ (Microscope is an optical instrument having a magnifying lens or a combination of lenses which is used to magnify the image of a small object.)
- ★ The simplest form of a microscope is a single converging lens which is also known as **simple magnifier**.
- ★ (The object is placed between the lens and the focal length of lens and the distance from lens to object is adjusted until a clear image is obtained.)
- ★ Magnification power of the lens is given by the equation, $M = 10/f$, where f is the focal length of the lens and 10 represents the average minimum distance where the image is seen clearly by the **unaided eye**.
- ★ Depth of field defines the distance the lens can be moved towards or away from the object so that the object remains in good focus.
- ★ For low-power magnifier, depth of field is high and it decreases as the power of lens increases.

1.15.4. Borescope:

- ★ Borescope is an optical instrument which is used to inspect the inside of a narrow tube, bore or chamber.
- ★ It consists of a rigid or flexible tube with an eyepiece at one end and an objective lens on the other end.
- ★ It consists of a complex arrangement of prisms and plain lenses through which the light is passed to obtain a clear image.
- ★ It is available in diameter which ranges from 2.5 to 19 mm and of smaller length, as the length of borescope increases, brightness of the image decreases due to loss of light.

There are three types of borescopes:

1. Rigid borescopes.
2. Flexible borescopes.
3. Video borescopes.

1.15.5. Endoscope:

- ★ It is same as the borescope but it has a superior optical system and a high-intensity light source.
- ★ It is also used to examine the interior of an object.
- ★ Objects are in focus from 4 mm to infinity, where a magnification factor of '10X' is obtained when it is at 4 mm distance.
- ★ 'No focusing' feature is the one which makes it preferable than borescope.
- ★ Endoscope are available in smaller diameter upto 1.7 mm which makes it comfortable for viewing smaller objects and ranges to a length of about 100 to 150 mm.

1.15.6. Fibroscopes:

ME367 NDT

- ★ It is also known as flexible fibre-optic borescope (or) flexiscopes.
- ★ It is used to provide clear and sharp images of parts and interior surfaces which are not easily accessible.
- ★ Fibre optics is used to carry the information and it permits several dimensional changes depending on the object.
- ★ Tip can be adjusted using rotating control mechanism depending on the object size and it also has a wide-angle objective lens with a 100° field of view.
- ★ It ranges to a diameter of about 3 to 12.5 mm with a length which varies from 60 to 365 cm.

1.15.7. Telescope:

- ★ Telescope is a device which makes the faraway objects to appear much closer.
- ★ It consists of two lenses called objective and eyepiece.
- ★ Glass lenses are provided at the refractor telescopes and mirror replaces the glass lenses in case of reflector telescopes.
- ★ The objective lens (in refractors) (or) primary mirror (in reflectors) collects light from the object and focuses as it to a point.
- ★ An eyepiece lens takes the light from the focus and magnifies it.

1.15.8. Closed Circuit Television (CCTV):

- ★ Closed Circuit Television is a system where the circuit in which the video transmitted will be a closed one.
- ★ Elements like camera, display monitors, recording devices are connected to each other.
- ★ It has a high-resolution display and has the ability to zoom in (or) track the defects from the features.

1.16. APPLICATION OF VISUAL INSPECTION:

- ★ It is used to inspect whether there is a misalignment of parts in the equipment.
- ★ It checks for corrosion, erosion, cracks and deformities of machine components.
- ★ It inspects the plant components for any leakage (or) abnormal operation.
- ★ It is used in pumps, compressors, turbo generator to check for minute discontinuities.
- ★ It is used to identify the defects in weldments.

1.17. LIMITATIONS OF VISUAL INSPECTION:

- ★ (Using unaided inspection, only large discontinuities are identified.)
- ★ Limited to detection of only surface discontinuities.
- ★ Skilled labour is required.
- ★ Results depend on the eye resolution of the inspector.
- ★ It may cause eye fatigue to the inspector.

1.18. LIGHT SOURCES:

For various reasons, visual inspection cannot be carried out using day light.

1.18.1. Classification of light sources:

1.18.1.1. Continuous:

(a) Flash Lamp:

- ★ It is a tungsten filament bulb, with a battery supply upto 12 V.
- ★ It is portable and easy to use.

(b) Incandescent Lamps:

- ★ Incandescent lamps are the oldest electric lighting technologies available.
- ★ They are used as microscopic lights.
- ★ Light is produced by passing a current through tungsten filament, causing it to become hot and glow.
- ★ Lifetime of this light source is short as the tungsten evaporates slowly causing the filament to break.

(c) Discharge Lamps:

- ★ They are gas discharge lamps.
- ★ They are rarely used as they emit only selective wavelength of light.
- ★ Mercury and sodium vapour lamps come under this type.

(d) Fluorescent Lamps:

- ★ It consists of glass tube which is filled with argon or argon-krypton gas.
- ★ Glass tubes are coated with phosphorus and electrodes are placed at both ends.
- ★ It provides soft uniform light over a large area.

Fluorescent lamps provide light by the following process:

- ★ An electric discharge (current) is maintained between the electrodes through the mercury vapour and inert gas.
- ★ This current excites the mercury atoms, causing them to emit non-visible ultraviolet (UV) radiation.

- ★ This UV radiation is converted into **visible light** by the phosphorus coated over the tube.

1.18.1.2. Non-continuous – Electronic Flash (Stroboscopic):

- ★ It uses a synchronised pulse of light to inspect the moving components.
- ★ It makes rotary/moving components appear still, so that the component can be inspected accurately.

1.19. SPECIAL LIGHTING:

1. Front lighting:

The light source and image sensor are on the same side of the component. It is the most convenient mode for machine vision systems.

2. Back lighting:

The light source and image sensor are placed on opposite sides of the component.

3. Structured lighting:

It is a combination of light source and optical element to form a line of light. The line of light can be formed in two ways,

(a) By placing a semi cylindrical lens in front of light source.

(b) By using a scanning mirror to deflect a laser beam.

4. Strobe lighting:

Strobe lighting is used to image moving objects or still objects with potential movement. In this technique, a pulse of light illuminates the object momentarily.

5. Ultraviolet lighting:

Ultraviolet light causes fluorescent material to glow and is used in liquid penetrant and magnetic particle testing for detecting discontinuities.

6. Optical filtering:

Image sensors used in machine vision systems detect the intensity of the electromagnetic waves in the visible range. If only a portion of visible spectrum is of interest, a filter in front of sensor is used to produce a high quality image.

Band pass filters transmit a band of electromagnetic waves and reject the remaining. Short pass filters transmit the waves below a cut off wavelength. Long pass filter transmits the waves above a cut off wavelength. Neutral density filters attenuate the light level incident on the image sensor.

7. Image sensors:

The two main types of image sensors are image tube and solid state imaging devices.

- (i) **Image tubes.** These are used to generate a train of electrical pulses that represent light intensities present in an optical image focused on the tube.
- (ii) **Solid state imaging devices.** The principle is based on the photoelectric effect and the fact that free electrons are generated in a region of silicon illuminated by photons. The number of free electrons is linearly proportional to the incident photons. If the pattern of incident intensity is an optical image of an object, then the charge packets generated form an electric image of the object.

1.20. COMPUTER ENHANCED VISUAL SYSTEM:

1.20.1. Introduction:

The computer enhanced visual system makes use of a video camera for data collection and a computer (software) for data analysis. The following block diagram explains the computer enhanced visual system.

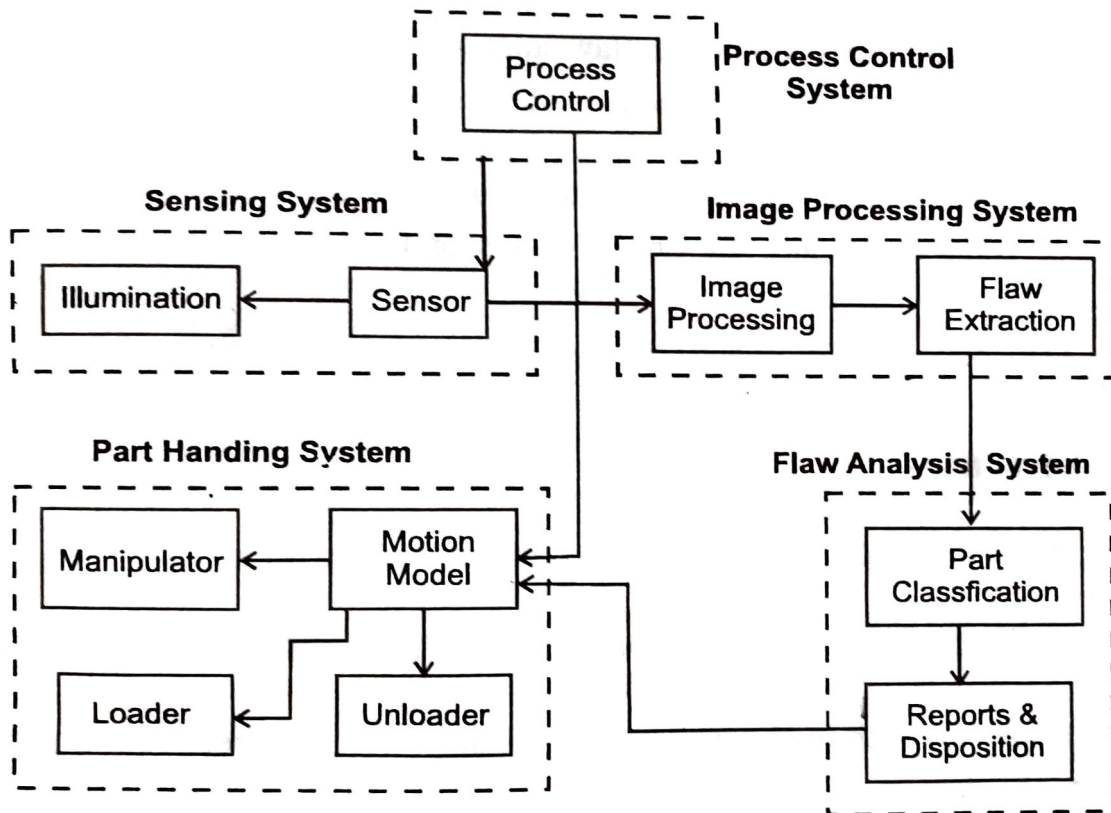


Fig. 1.2: Block diagram for computer enhanced system.

- ★ Process control system controls the overall inspection process.
- ★ It provides the commands and provides the timing signals to control the system wide database.
- ★ Sensing system provides the illumination source for the part.
- ★ Special purpose sensor system, such as scanning triangulation sensors, may require sophisticated optical systems such as scanning mirrors, elliptical mirrors and holographic gratings.

- ★ Image Processing system gets the input image data from the sensing system.
- ★ Flaw Analysis System examines the areas identified by image processing system and determines the part classification based on flaw decision rule.
- ★ Frame grabber card in the flaw analysis system examines the image which is captured by camera in the image processing system.
- ★ The software in the computer then analyses the image and makes a decision as whether the object passes or fails in the inspection.
- ★ Depending on the level of automation, task of the inspector is reduced.

1.20.2. Advantages:

- ★ It can be re-programmed offline on another machine.
- ★ It can be used to inspect wide range of products.
- ★ It can work throughout the day and does not get tired.
- ★ Inspection can be done at a higher speed than human being.
- ★ Maintains consistency of inspection.

1.20.3. Disadvantages:

- ★ Software must be carefully selected and implemented.
- ★ Lighting conditions must be well designed.
- ★ It follows only the rules and does not take real-time decisions.

MODULE - 2

LIQUID PENETRANT INSPECTION

Principles – Properties required for a good penetrants and developers - Types of penetrants and developers – Advantages and limitations of various methods of LPI – LPI technique/test procedure – Interpretation and evaluation of penetrant test indications False indication – Safety precautions required in LPI – Applications, advantages and limitations.

2.1. INTRODUCTION:

Liquid penetrant inspection is one of the oldest and most widely used non-destructive testing methods. It is also called as dye-penetrant inspection.

Liquid penetrant method is an effective method of detecting surface discontinuities in metals and other non-porous material surfaces.

It is suitable to detect flaws like pits, cracks, pores, unfills that are exposed to the surface. Materials that are commonly inspected using LPI include.

- (i) Ferrous metals.
- (ii) Non-ferrous metals.
- (iii) Non-porous, non-metallic materials (such as glass, rubber, plastics, ceramics).
- (iv) Non-magnetic materials.

LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity, leakage and fatigue cracks on in-service components.

2.2. PRINCIPLE:

In liquid penetrant testing a liquid with high surface wetting characteristics is applied to the cleaned surface of the test specimen.

The liquid penetrates into surface, breaking discontinuities via capillary action and surface tension. The cohesive force between the molecules of a liquid causes surface tension.

Excess penetrant is removed from the surface and a developer is applied to pull trapped penetrant back to the surface.

Then the surface is inspected for defects, either visually (or) with fluorescent lighting.

With good inspection technique, visual indications of any discontinuities present become apparent.

After inspection, the developer and residual penetrant are removed by post cleaning method.

Schematic of liquid penetrant inspection is given in the Fig. 2.1

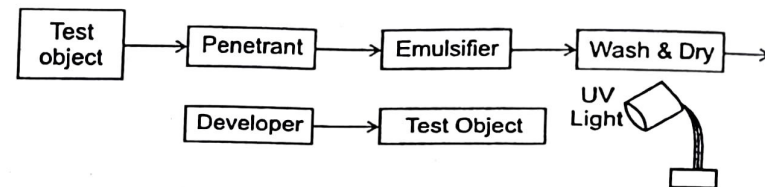


Fig. 2.1

What can be inspected by LPI?

Almost any material that has a relatively smooth, non-porous surface on which discontinuities or defects are suspected.

What cannot be inspected by LPI?

- ★ Components with rough surfaces, such as sand castings, that trap and hold penetrant.
- ★ Porous ceramics
- ★ Wood and other fibrous materials.
- ★ Plastic parts that absorb (or) react with the penetrant materials.
- ★ Components with coatings that prevent penetrants from entering defects.

2.3. PENETRANTS:

The penetrants are mixtures of organic solvents, which are characterized by their ability to wet materials, spread rapidly and penetrate into minute defects and dissolve dyes, so that the indications produce a definite colour as contrasted to the white background of the developer.

2.4

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Penetrant materials consist of

- (i) Indicating dye.
- (ii) Carrier fluid

The indicating dye is used to provide a colour contrast with respect to the surroundings.

2.3.1. Types of Penetrants:

Basically the penetrants are classified

- 1. Based on physical properties.
- 2. Based on removal techniques.
- 3. Based on strength of indication.

1. Based on Physical Properties:

According to the physical properties, penetrants are classified into

- (i) Fluorescent penetrants.
- (ii) Visible penetrants.

(i) Fluorescent Penetrants:

Fluorescent penetrants are generally green in colour and they contain a dye or several dyes that glow brightly when exposed to UV lights.

It is highly sensitive than visible penetrants and it requires a darkened area for inspection.

(ii) Visible Penetrants:

Visible penetrants are usually red in colour that provide high contrast against the white developer background.

It is less sensitive than fluorescent penetrants and it does not require a darkened area and UV light for inspection.

Liquid Penetrant Inspection

2.5

Note:

The fluorescent penetrants are most generally used for the detection of the cracks but these are not recommended for use on rough surfaces because of the difficulty in removing the excess penetrant.

2. Based on removal technique:

Based on method of removing excess penetrant from the surface, penetrants are classified as

- (i) Solvent removable.
- (ii) Water washable.
- (iii) Post emulsifiable.

(i) Solvent removable:

- ★ In this method, penetrants are removed by wiping with a cloth dampened with solvent.
- ★ They are available in aerosol cans for easy portability.
- ★ It is significantly used for spot checks.

(ii) Water washable:

- ★ In this method, penetrants are removed from the part / material by rinsing with water alone.
- ★ Water washable penetrants are sometimes referred to as self-emulsifying system.
- ★ Cost efficient and easy to apply.

(iii) Post emulsifiable:

Here the penetrants are not directly water washable and they require the use of an emulsifier (oil (or) water base).

Based on the type of emulsifier employed the post – emulsifiable method can be classified into two types.

(a) Post – emulsifiable lipophilic method

This method uses oil based emulsifier to remove the excess penetrant from the test surface.

(b) Post – emulsifiable hydrophilic method.

This method uses water – soluble detergent based emulsifier to remove the excess penetrant from the test surface.

3. Based on strength of indication:

Depending on the strength of indication, penetrants are classified into

(i) level $\frac{1}{2}$ – Ultra low sensitivity

(ii) level 1 – Low sensitivity.

(iii) level 2 – Medium sensitivity.

(iv) level 3 – High sensitivity.

(v) level 4 – Ultra – high sensitivity.

2.3.2. Characteristics of good penetrants:

1. It should spread easily over the surface being inspected.
2. It should be easily drawn into discontinuities by capillary action.
3. It should not be harmful to the inspector (or) to the material being tested.

4. It should remain well inside the defects but it should be easier to remove from the surface being tested.
5. It should possess high indicating capability.
6. It should remain in fluid state, so that it can be drawn back to the surface of the component through drying and developing steps.
7. It should be non-flammable & non-toxic.
8. It should possess less dwell time.
9. It should not affect the physical & chemical properties of the testing material.
10. It should be cohesive, adhesive and relatively low in cost.

2.3.3. Properties of good penetrant:**1. Capillarity:**

Capillarity is the ability of a liquid to flow in narrow spaces without the assistance of external forces.

This property helps the penetrant to fill a void.

The formation of penetrant indication during development period is based on reverse capillary action.

2. Contact angle:

Angle formed by the solid – liquid interface and liquid-vapour interface measured from the side of the liquid is called contact angle.

A penetrant is effective when the contact angle is as small as possible.

Mostly the liquid penetrant has contact angle close to 0°

The wetting agent improves the wettability and also reduces the contact angle drastically.

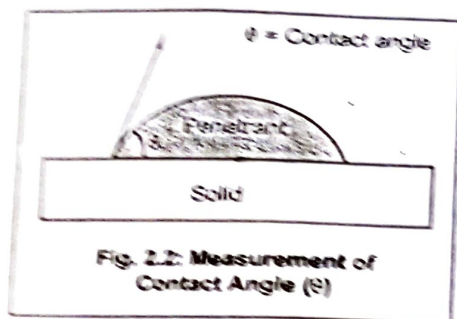


Fig. 2.2: Measurement of Contact Angle (θ)

3. Viscosity:

Viscosity is the internal resistance of a liquid to flow.

It is an important factor in determining the speed with which a penetrant will enter the defect.

The penetrants with less viscosity fill the cracks in time.

Also the less viscous penetrant can be more easily washed out of defects during cleaning.

4. Surface Tension:

Surface tension is nothing but wetting capability of a liquid.

Penetrant should have good wetting capability to spread over the surface.

This wettability of penetrant can be improved by adding wetting agent.

5. Cohesiveness and Adhesiveness:

The attractive force between like molecules and unlike molecules are called Cohesive and Adhesive forces respectively.

The penetrant should be both cohesive and adhesive, during contact with developer and cracks of the component.

6. Specific Gravity:

Specific gravity is the ratio of the density of a liquid to the density of the standard liquid.

Actually specific gravity has no direct effect on the performance of a penetrant.

A penetrant should have specific gravity less than one.

7. Non-flammable:

Flash point is the temperature at which the liquid can form explosive mixture.

It does not affect the penetrant performance.

But the penetrant should have high flash point to avoid fire hazards.

8. Volatility:

The tendency of a substance to evaporate at normal temperature is called volatility.

Volatility depends on boiling point.

Penetrants should have high boiling point to be less volatile.

On other hand, high boiling point penetrant will have high viscosity.

Anyway it is necessary for a penetrant to be less volatile.

9. Removability:

The penetrant should be easily removable from the surface but should provide resistance to being removed from discontinuities.

For achieving this, the penetrant should be more adhesive than cohesive, so that the attractive force between developer and penetrant is weaker than the force between penetrant and solid discontinuities.

10. Indicating Capability:

A penetrant must provide good indication which can be identified with less effort.

The colour of the penetrant is an important factor in indication.

The dye used in the penetrant should be very bright so that the indication can be easily identified through naked eye.

2.4. DEVELOPER:

Developer is a good absorbent material capable of drawing traces of trapped penetrants from the discontinuities back into the surface.

It also provides a light background to increase contrast when visible penetrant is used.

For fluorescent penetrant, the developer background should appear black when illuminated by the UV light.

For visible penetrant, the developer creates a white background that contrasts the normal red appearance of the dye pulled out of the crack (or) pore.

2.4.1. Properties of good developer:

1. It should have good absorption characteristics to maximize blotting of the penetrant.
2. It should have good contrast background.
3. It should be able to uniformly cover the surface with the thin smooth coating.
4. It should be chemically inert with test materials.
5. It should provide a good contrast background for bright and clean indications.

6. It should be non-toxic.
7. It should be easily applied to the test materials.
8. It should be easy to remove after inspection.

2.4.2. Types of Developers:

1. Dry powder developers.
2. Water suspendable developers.
3. Water soluble developers.
4. Non-aqueous developers.

1. Dry-powder Developers:

It is a mix of light feathery powder that clumps together where penetrant bleeds back to the surface in order to produce very defined indications.

Dry powder developers can be applied to the test material.

- (i) by dipping parts in a developer container.
- (ii) by placing parts in a dust cabinet where the developer is blown.
- (iii) by using a buffer to dust parts with the developer.

2. Water – Suspendable Developer:

Water suspendable developers consist of insoluble developers particles suspended in water. Water suspendable developers require frequent stirring (or) agitation to keep the particles from settling out of suspension.

The solution is difficult to maintain as the powder settles out over time.

It is applied by dipping, pouring or brushing the solution onto the test specimen.

The solution is generally dried using warm air at 21°C.

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3. Water – Soluble developer:

Water – soluble developer is a crystalline powder that forms a clear solution when mixed with water.

The solution recrystallizes on the surface when the water is drained off.

It is applied as same as water suspendable developer.

This developer is not recommended for water washable penetrants.

4. Non-Aqueous:

Non-aqueous developers suspend the developer in a volatile solvent.

It is supplied by a spray gun or aerosol can and is the most sensitive developer for inspecting small areas.

This method is too costly and difficult to apply in the large areas.

Developer	Advantages	Disadvantages
Dry powder	(i) Easy to apply (ii) Inexpensive (iii) Can be easily cleaned.	(i) Difficult to cover the entire surface (ii) Does not form contrast background. (iii) Less sensitive to indications.
Water – Suspendable	(i) Easy to coat the entire part (ii) Indications are sharp & clear. (iii) Can produce good contrast	(i) Indications fade away by time. (ii) Requires frequent stirring.
Water soluble	(i) Easy to coat the entire part (ii) Easily washable. (iii) Fast and effective method.	(i) Provides poor contrast (ii) Indications are very light.
Non-aqueous	(i) Highly sensitive. (ii) Easy to apply. (iii) Does not require forced drying.	(i) Difficult to cover the entire part evenly. (ii) Difficult for post cleaning.

Liquid Penetrant Inspection

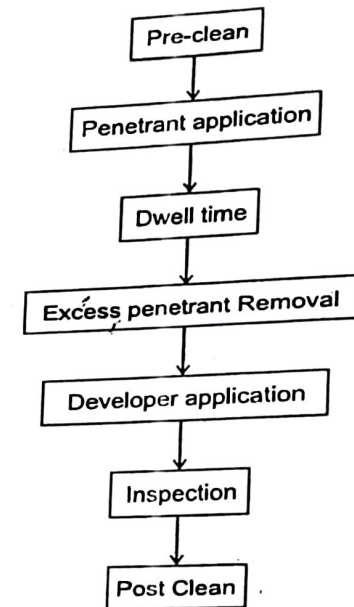
2.5. PROCEDURE FOR LIQUID PENETRANT INSPECTION (LPI):

Fig. 2.3

1. Pre-cleaning:

Pre-cleaning is the most important step in the liquid penetrant inspection procedure.

The test surface to be inspected is cleaned to remove oil, grease, flakes, scales, paint (or) other contaminations.

Cleaning methods may include vapour degreasing, solvent wiping, solvent spraying, ultrasonic immersion using solvents etc.

2. Penetrant application:

At this stage, the penetrant is applied on the surface to be inspected.

The liquid penetrant is applied by dipping, brushing (or) spraying on the cleaned test surface.

Many methods of application are possible such as

1. Brushing method.
2. Spraying method.
3. Dipping / immersing method
4. Flowing method.

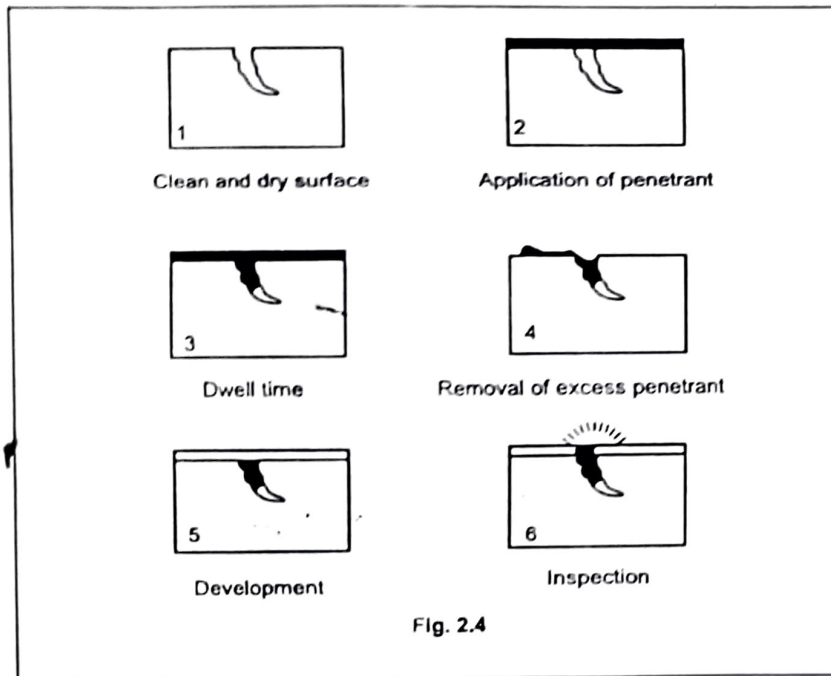


Fig. 2.4

3. Dwell Time:

Dwell time is the period of time from when the penetrant is applied to the surface until it is removed.

The penetrant solution must be allowed to “dwell” on the surface of the part to fill any defects.

The dwell time vary according to penetrant type, temperature, material type and surface finish.

A minimum dwell time of 20 to 30 min may be allowed.

4. Excess Penetrant Removal:

Here, the excess penetrant is removed from the test surface so that the retention of penetrant from discontinuities can be ensured.

The removal technique depends upon the type of penetrant used.

In case of excess cleaning, the developer will not reach the penetrant which indicates no defect.

In case of insufficient cleaning, a less contrast background is created where the defect is difficult to identify.

So care must be taken so that neither excess cleaning nor insufficient cleaning is done.

The methods used to remove excess penetrant includes.

- (i) Water – Washable method.
- (ii) Post – Emulsifiable method.
- (iii) Solvent removable method.

The above mentioned 3 methods are briefly explained in section 2.8.

5. Developer application:

Developer is applied to pull back the trapped penetrant so that the indication of discontinuity / defects will be very clear.

Types of developers:

The four types of developers used in liquid penetrant inspection are

- (i) Dry powder developers.
- (ii) Water – suspendable developers
- (iii) Water – Solvable developers.
- (iv) Non-aqueous wet developers.

The above developers were already explained briefly in section 2.4.2.

Developing time:

Developing time is the time it takes the application of the developer until the actual evaluation commences.

6. Inspection, Interpretation and evaluation:

After completion of the developing time, the indications from discontinuities that are formed on the test surface should be inspected, interpreted and evaluated.

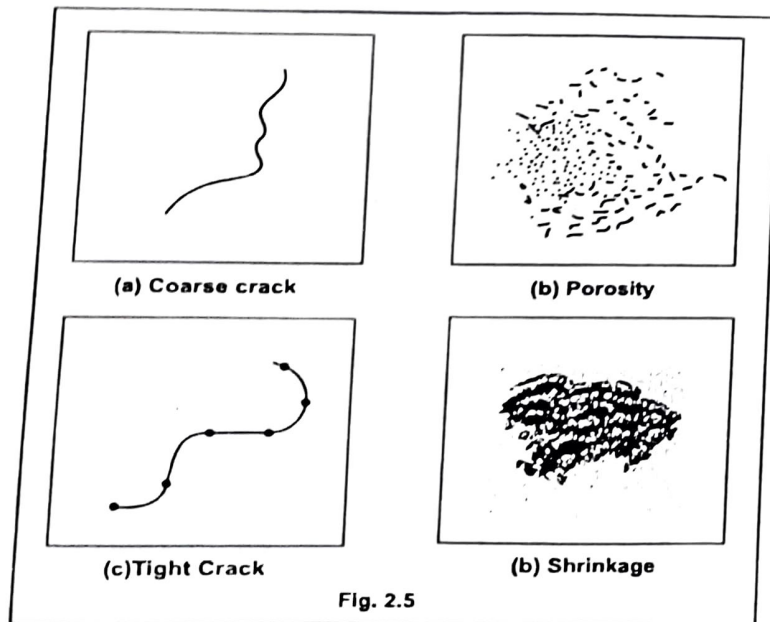
The inspection may be carried under visible light conditions (or) with UV (or) Laser incident light. The defect recognition may be made with the human eye (or) with automated optical scanners.

7. Post – Cleaning:

The final step in the penetrant inspection process is to thoroughly clean the part that has been tested to remove all penetrant processing materials.

The residual materials may affect the performance of the part (or) its visual appearance.

Typical penetrant indications are shown in Fig. 2.5.



Liquid Penetrant Inspection

Table 2.1

S.No.	Nature of Defect	Visible Penetrant	Fluorescent Penetrant
1.	Cracks	Thin red lines-depth indicated by the degree of spread	Thin, greenish-yellow lines.
2.	Porosity	Series of red spots spread over the surface	Series of greenish yellow spots.
3.	Very tight crack	Series of very small red dots in continuous formation	Series of very small, greenish-yellow dots.
4.	Shrinkage	Pale red blotches	Pale greenish-yellow blotches.

Some of the defects that can be detected with liquid penetrant testing and their indications are given in Table 2.2.

Table 2.2

S.No.	Defect	Description
1.	Casting porosity	Spherical surface indications.
2.	Porosity (glass)	Spherical surface indications.
3.	Casting cold shut	Dotted or smooth continuous lines.
4.	Cracks	Straight or jagged continuous surface lines.
5.	Hot tears	Ragged line of variable width, numerous branches.
6.	Sand casting shrinkage	Crack indications where part thickness changes.
7.	Forging lap (Al)	Sharp crescent-shaped indications on aluminum.

S.No.	Defect	Description
8.	Forging lap (partial)	An intermittent line indication.
9.	Rolling lap	Continuous line on rolled bar stock.
10.	Crater crack (Al)	Dish-shaped indication with spoke propagation.
11.	Crater crack (deep)	Rounded indication.
12.	Lamination (rolling)	Seams on rolled plate.
13.	Inclusion (rolling)	Broad elongated indications in rolled plate.
14.	Heat-treat cracks	Multiple irregular lines in fired ceramics.
15.	Thermal cracks (glass)	Jagged interconnecting lines fired ceramics.
16.	Lack of fusion (welds)	Broken line of varying width near centerline.
17.	Fatigue cracks	Continuous line in parts that have been in service.

2.6. INTERPRETATION OF RESULTS:

The indication play a major role in reliability of penetrant testing. On interpreting the indications & results there are several key features are noted.

1. Penetrant must enter the discontinuity / defect in order to form an indication. So, it is important to allow sufficient time so the penetrant can fill the defect. The defect must be clean and free of foreign materials so that the penetrant is free to enter.
2. Clean cracks are generally easy to detect. But some uncontaminated surface opening which are very fine is difficult to detect.
3. If all penetrant is washed out of a defect, an indication cannot be formed. During the washing (or) rinsing operation, prior to development it is possible that the penetrant will be removed from the defect as well as from the surface.

4. Smaller the defect, the longer the penetrating time. Fine cracks like apertures require a longer penetrating time than defects such as pores.
5. When the dwell time is more, we can get good indication. On the other hand if the dwell time is less, it reflects on indication with less clarity.
6. Visible penetrant type developer when applied on the test surface, bright red indications will appear where there are surface defects. If no red indications there are no surface defects.
7. Fluorescent penetrant type developers, when applied on the test surface, the defects will show up as a brilliant yellow-green colour and the surface area will appear deep blue colour.

The interpretation of the characteristic patterns indicating the type of defect is of great significance.

The size of indication can be usually be related to the amount of penetrant entrapped in the discontinuity.

2.7. FALSE INDICATIONS:

A false indication is an accumulation of penetrant caused by a drop of penetrant left on the workpiece inadvertently.

With the liquid penetrant inspection, there are no false indications in the sense that they occur in the MPI (Magnetic Particle Inspection).

However, there are two conditions which may create accumulations of penetrant that are sometimes confused with true cracks and discontinuities.

The first condition includes indications caused by **poor washing**.

If all the surface penetrant is not removed in the washing (or) rinsing operation following the penetrant dwell time, the unremoved penetrant will be visible.

When accumulations of unwashed penetrant are found on a part, the part should be completely reprocessed.

Degreasing is recommended for removal of all traces of the penetrant.

False indications may also be created where parts press fit to each other.

If a wheel press fit onto a shaft, penetrant will show an indication at the fit line.

This is perfectly normal since the two parts are not meant to be welded together.

Indication of this type are easy to identify since they are regular in form and shape.

2.8. PENETRANT TESTING METHODS:

The commonly used penetrant testing methods are

- (i) Water washable method.
- (ii) Post emulsifiable method.
- (iii) Solvent removable method.

Liquid Penetrant Inspection

2.8.1. Water washable method:

In this method as shown in the Fig. 2.6, the materials used are water soluble. After the initial cleaning and drying process, the penetrant applied shall be a water based fluid.

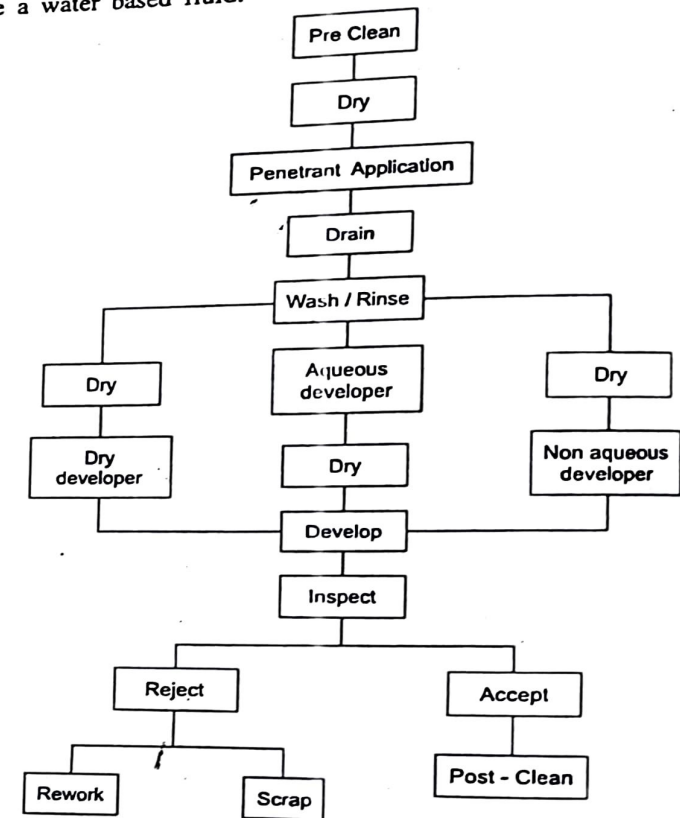


Fig. 2.6: Water washable penetrant method

After the dwell time, the rinse or penetrant removal step is different for various application methods.

Use of large volume of water would require facilities for adequate draining and disposal of the rinsed water.

The differences between the post – emulsifiable penetrant method and water – washable method are

1. Penetrant used.
2. Need for an emulsifier.

If the solvent based penetrant is used and followed by an emulsifier application, it allows the remaining process to follow the water washable path.

Advantage of this method is that solvent penetrants that may be required for some parts may be removed by water.

Advantages:

1. Highly sensitive to fine flaws.
2. Adaptable for high volume testing.
3. Not easily affected by acids.

Limitations:

1. Not portable.
2. Not effective for parts with intricate shape.
3. Emulsification time must be closely controlled.
4. Inexpensive.

2.8.3. Solvent – removable Method:

★ Fig. 2.8 represents the solvent removable method.

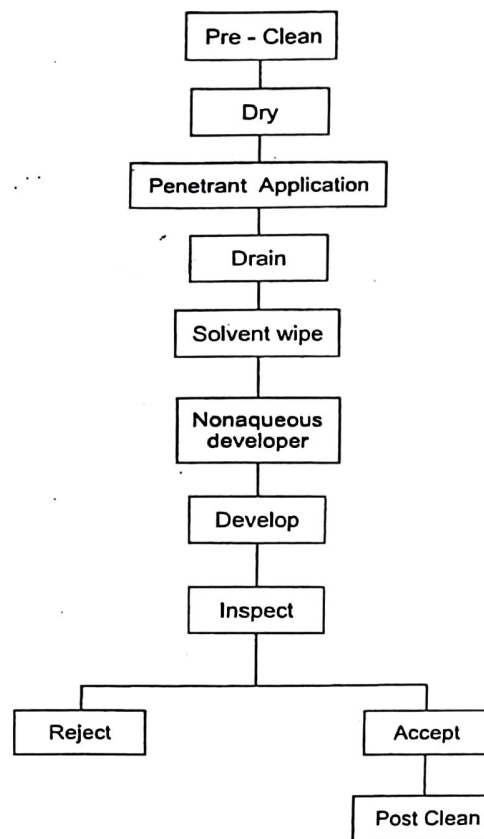


Fig. 2.8: Solvent Removable Penetrant Method

- ★ It is an oil-based inspection process.
- ★ After the preliminary processes like precleaning, drying, penetrant application, the penetrant is removed by wiping action using a solvent dipped cloth.

- ★ Here the non-aqueous developer is used for developer action.
- ★ This method is most suitable for small parts and onsite applications due to its portability.

Advantages:

1. Used for spot examinations on large parts.
2. Effective when water removal is not feasible.
3. Since using non-aqueous developer, no-need of drying time.

Limitations:

1. Limited to smaller surfaces.
2. Dark environment is required.
3. Background indications may be generated.
4. Sensitivity can be reduced if excessive remover is applied.

2.9. SAFETY PRECAUTION REQUIRED IN LPI:

When proper health and safety precautions are followed, liquid penetrant inspection operations can be completed without harm to inspection personnel. However, there is a number of health and safety related issues that need to be taken in consideration.

Some of the most common safety precautions are given below:

1. The certified inspector shall be responsible for compliance with applicable safety rules in the use of liquid penetrant materials..
2. Liquid penetrant should not be heated (or) exposed to open flames.

Liquid Penetrant Inspection

3. Some of the penetrant materials are flammable and therefore should be used and stored in small quantities.
4. Penetrant materials may be highly volatile, relatively toxic and the liquid may cause skin irritation. Adequate ventilation at all times should be used.
5. Eye protection should always be worn to prevent contact of the chemicals with the eyes.
6. Gloves and other protective clothing should be worn to limit contact with the chemicals.
7. Aerosol cans of penetrant materials should be kept out of direct sunlight or areas in excess of 130°F. Excessive heat may cause aerosol cans to explode.
8. Avoid looking directly into black light source, since the eyeball contains a fluid that fluoresces if black light shines directly into the eye.

2.10. ADVANTAGES AND LIMITATIONS OF LPI:

Advantages:

1. Simple and easy to use.
2. Highly portable.
3. Can be used on a wide range of material types i.e. metallic and non-metallic, magnetic and non-magnetic, conductive and non-conductive materials may be inspected.
4. Highly sensitive to small surface discontinuities.

5. Large surface areas and large volumes of parts / materials can be inspected quickly and at low cost.
6. Complex geometric shapes can be inspected.
7. Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
8. Penetrant materials and associated equipment are relatively inexpensive.
9. Requires no great skill and is easy to understand.

Limitations:

1. Can only detect defects open to the surface.
2. Surface preparation before testing is critical as contaminants may mask defects.
3. Preparation before testing can be time consuming and costly.
4. Interpretation of results is sometimes difficult.
5. Cannot be used on porous and very rough surfaces.
6. Requires a high degree of cleanliness for satisfactory inspection.
7. There may be a problem in disposing of contaminated cleaning and penetrant fluids.

2.11. APPLICATIONS:

LPI can be effectively used to detect surface discontinuities such as cracks, porosity, seams, laps, cold shuts, lamination or lack of bond on non-porous metallic materials both ferrous and non-ferrous and on non-porous non-metallic materials such as plastics and glass. Typical applications of liquid penetrant inspection include.

(i) Aerospace:

Liquid penetrant method is widely used in aerospace industries by both the producers for quality control of production and the users for regular maintenance and safety checks.

Typical components that are checked by this method include turbine, rotor discs and blades, aircraft wheels, castings, forged components and welded assemblies.

(ii) Automobile:

Many automotive parts particularly aluminium castings and forging including pistons and cylinder heads are subjected to this form of quality checks before assembly.

(iii) Railway:

Liquid penetrant inspection to detect fatigue cracking is also used for the regular in-service examination of the bogie frames of railway locomotives and the rolling stock.

(iv) Tools and dies:

Field drilling rays, drill pipe, castings and drilling equipments are inspected by this method.

(v) Inspection on reactors and tanks:

Tanks, vessels, reactors, piping, dryers and pumps in the chemical, petro-chemical, food, paper and processing industries use this liquid penetrant inspection.

MODULE – 3

MAGNETIC PARTICLE INSPECTION

Principles of MPI – basic physics of magnetism – permeability – flux density, coersive force – magnetizing force – magnetizing force – retentivity – residual magnetism – Methods of magnetization – magnetization techniques such as head shot technique – cold shot technique – central conductor testing – magnetization using products using yokes – direct and indirect method of magnetization – continuous testing of MPI – residual technique of MPI – system sensitivity – checking devices in MPI – Interpretation of MPI – indications – advantage and limitation of MPI.

3.1. INTRODUCTION:

Magnetic Particle Inspection (MPI) is a Non-Destructive Testing (NDT) method for detecting discontinuities (or defects) that are primarily linear and located at or near the surface of the ferromagnetic structures (or components). MPI is governed by the laws of magnetism and is therefore restricted to the inspection of materials that can support magnetic flux lines. Materials are generally classified as

- (i) Ferromagnetic.
- (ii) Paramagnetic.
- (iii) Diamagnetic.

Ferromagnetic Materials are those that are strongly attracted to a magnet and can become easily magnetized. eg: Fe, Ni, Co.

Paramagnetic Materials are those that are weakly attracted by magnetic forces of attraction and cannot be magnetized. eg: Austenitic stainless steel.

Diamagnetic Materials are slightly repelled by a magnet and cannot be magnetized eg: Bi, Au, Sb.

Out of which, only those materials classified as ferromagnetic, can be effectively inspected by MPI.

Further MPI is fast, cheap, robust, easy to perform, and can be handled by semi-skilled personnel without requiring much protection as needed for other NDT methods. The above characteristics, thus makes MPI as, one of the most widely used NDT method.

3.2. PRINCIPLES OF MPI:

The principle of Magnetic Particle Inspection is that the specimen is magnetised so as to produce the magnetic lines of force (magnetic flux) in the material. These lines of force gets interrupted, whenever there is a flaw or discontinuity (such as cracks) in the specimen. Due to this, some of the lines must exit and re-enter the specimen. These points of exit and re-entry

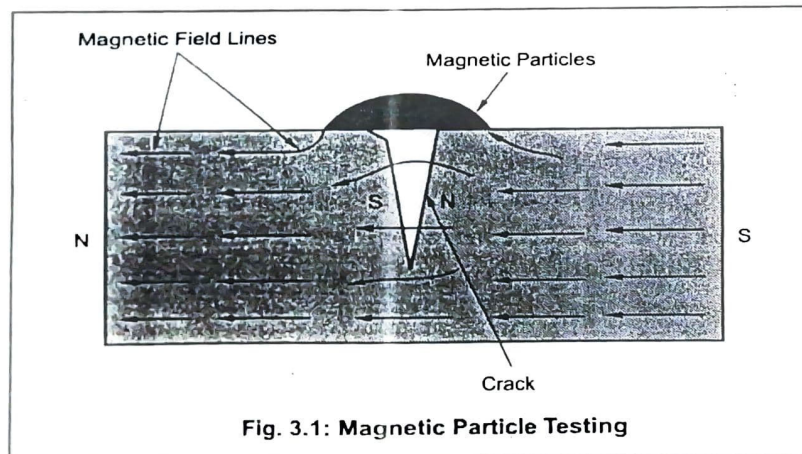


Fig. 3.1: Magnetic Particle Testing

form opposite magnetic poles. When minute magnetic particles are sprinkled onto the specimen, these particles are attracted by these magnetic poles to create a visual indication approximating the size and shape of the flaw.

The magnetic particles can be applied as powder or more commonly as liquid suspension, usually known as magnetic ink. Linear flaws such as cracks can be detected by favourably orienting the flaws in relation to the direction of the magnetic field. Also, for easy detection, the colour of the magnetic particles should be chosen in good contrast to the colour of the surface of the specimen.

3.3. BASIC PHYSICS OF MAGNETISM:

3.3.1. Polarity:

In magnetism, polarity refers to the orientation of north and south poles in space.

For example: If the rod is magnetised and suspended at its centre, it will eventually align itself with the earth's magnetic field so that one points to the geographic north and other end to the south. The end of the rod which is pointing north is called the "north seeking pole" usually abbreviated as north pole and the other end is called the south pole.

3.3.2. Magnetic force:

Magnetic force is a force of attraction or repulsion that one body has upon another.

For example: When the north pole of a magnetized rod is placed closely to the south pole of another, they attract one another. Conversely, if two north poles or two south poles are kept close together, they will repel each other.

3.3.3. Magnetic field:

The magnetic field is the area around a magnet in which the magnetic forces are observable.

For example: The magnetic field can be observed by placing a sheet of plain white paper over a bar magnet and sprinkling ferromagnetic particles onto it.

3.4

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The particles will collect around the lines of force in the magnetic field, producing an image on the paper. This image is called the 'magnetograph' and the lines of force are referred to as the 'lines of magnetic flux'.

3.4. PERMEABILITY:

Permeability is the ease with which a material can be magnetised. It is expressed with the symbol ' μ '. It can be numerically represented as

$$\mu = \frac{B}{H}$$

where B = Flux density.

H = Magnetizing force.

Its S.I unit, it is henry per meter (H/M)

Material which gets magnetized under low magnetizing forces are said to have high permeability. Also, material with higher permeability has low reluctance and vice-versa.

3.5. FLUX DENSITY:

Flux density is defined as the number of lines of force per unit area. Flux density is measured in Gauss. It is represented with the symbol ' B '.

3.6. MAGNETIZING FORCE:

The total number of lines of force making up a magnetic field determines the strength of the force of attraction or repulsion that can be exerted by the magnet. This is known as the magnetizing force and can be represented by the symbol H .

It is the force which tends to set up magnetic flux in a material.

3.7. COERCIVE FORCE:

Coercive force is a measure of the ability of a ferromagnetic material to withstand an external magnetic field without becoming demagnetized.

Magnetic Particle Inspection

3.8. RETENTIVITY:

The ability of a coil to retain some of its magnetism within the core after the magnetisation process has stopped is known as retentivity.

3.9. HYSTERESIS LOOP:

By exposing an unmagnetized piece of material to magnetizing current, we can plot the flux density B of the field induced by the applied magnetizing force H and the resultant curve is called the hysteresis loop.

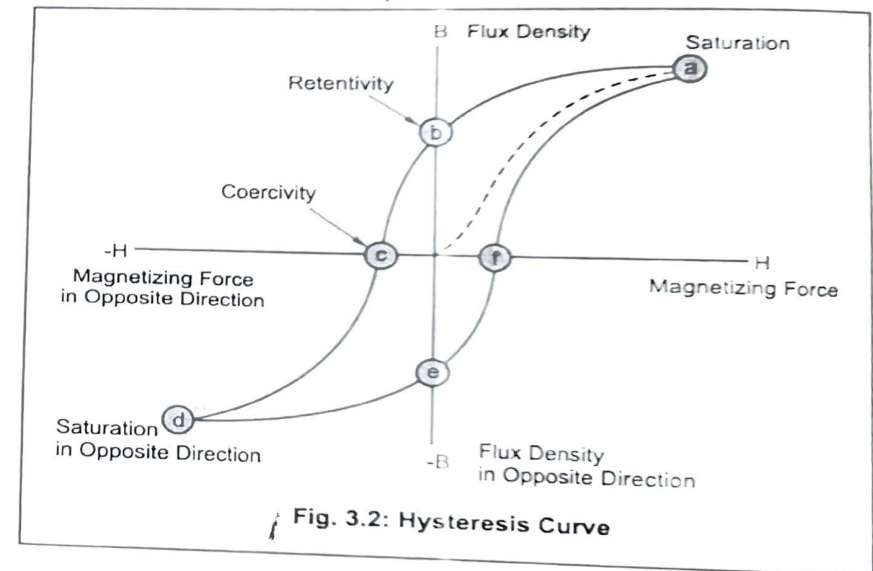


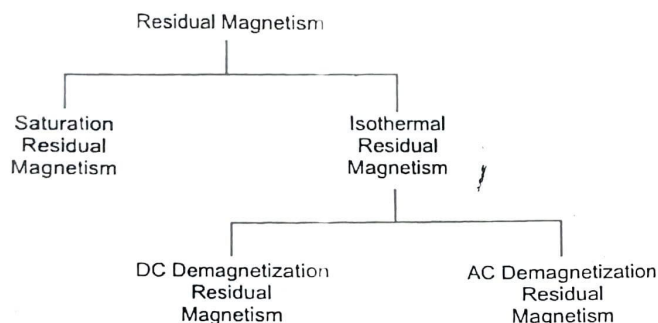
Fig. 3.2: Hysteresis Curve

3.10. RESIDUAL MAGNETISM:

Residual magnetism is defined as the amount of magnetism left behind after removing the external magnetic field from the circuit.

In other words, the value of the flux density retained by the magnetic material is called residual magnetism and the power of retaining this magnetism is called the retentivity of the material.

3.10.1. Types of Residual Magnetism:



Saturation residual magnetism:

It is the total magnetic moment per unit volume of the sample.

Isothermal residual magnetism:

In this method, first the magnetic material is magnetized in an alternating field and after that magnetizing field is applied and then removed. It is also called as initial residual magnetism.

DC demagnetization residual magnetism:

In this process, the magnet is magnetized in one direction by applying the electric current till it reaches the saturation point, and then applying the current in the opposite direction and removing the magnetic field.

AC demagnetisation residual magnetism:

In this process, the magnetic material is magnetized in an alternating current field and the saturation point is obtained.

3.10.2. Reduction of residual Magnetism:

Residual Magnetism can be reduced by the following methods.

- ★ It can be reduced by 45-50% by the use of hot rolled steel material.
- ★ The saturation level of the magnetic material can be decreased by providing higher exciting current.

- ★ The magnetization process should be started with constant force and gradually increasing till the saturation is achieved and then reducing it slowly to demagnetize it further.
- ★ In the process of magnetization and demagnetization of magnetic material the electric force, or the applied current should almost be similar.

3.11. METHODS OF MAGNETISATION:

The basic principle of magnetisation is to produce magnetic lines of force across the expected direction of cracks. If the likely crack direction is unknown, then test must be performed in two directions at right angles.

The basic magnetisation methods are.

1. **Magnetic flow:** To make the component of a magnetic circuit by effectively using it as the bridge of a permanent or electromagnet.
2. **Current flow:** To pass an electric current through the specimen, broadly along the direction and through the region in which cracks are to be expected.
3. **Induced current flow:** Used for ring specimens, by effectively making them the secondary of a main transformer. This method has no application to weld inspection.
4. **Electromagnetic Induction:** To pass an electric current through a conductor which is threaded through a hollow specimen or placed adjacent to or wrapped around it.

3.12. MAGNETIZATION TECHNIQUES:

3.12.1. Head Shot Technique:

This technique produces circular magnetization by passing electric current through the part itself. In this technique, a round bar is held between the heads in a wet horizontal unit. As the current flows from one end to the another end of the bar, the magnetic lines of force gets circulated around the bar. This circulation of magnetic flux around the bar is known as the circular magnetism and the technique is called as the head shot technique.

Note: Wet horizontal unit is a stationary unit in which longitudinal and circular fields can be produced. The unit has a fixed headstock and sliding tailstock. The part (round bar) can be placed between these, by adjusting the tailstock.

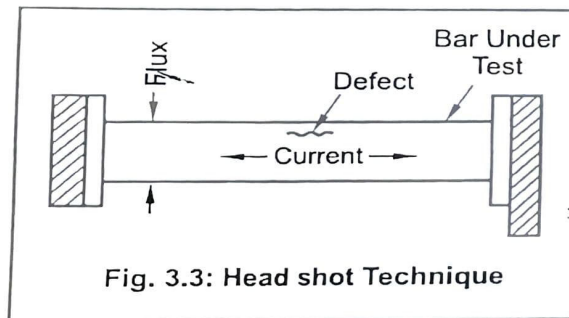


Fig. 3.3: Head shot Technique

One major disadvantage of head shot technique is that, it produces heating and arcing at the juncture. This is due to the passage of high current through small contact area. Therefore, to avoid over heating and arcing, the contact faces on the heads should be made flexible.

3.12.2. Coil Shot Technique:

This technique produces longitudinal magnetization, by placing the component longitudinally within a current carrying coil. As current flows through the coil, the flux will be generated in the component, creating magnetic poles at its ends. Due to polarity, the defects are revealed in the direction

perpendicular to the magnetic lines of force (i.e., in the transverse direction to the length of the part). This method of producing magnetism along the longitudinal direction of the component is known as longitudinal magnetism.

The major advantage of this technique is not causing thermal damage to the component, since the current does not flow through it.

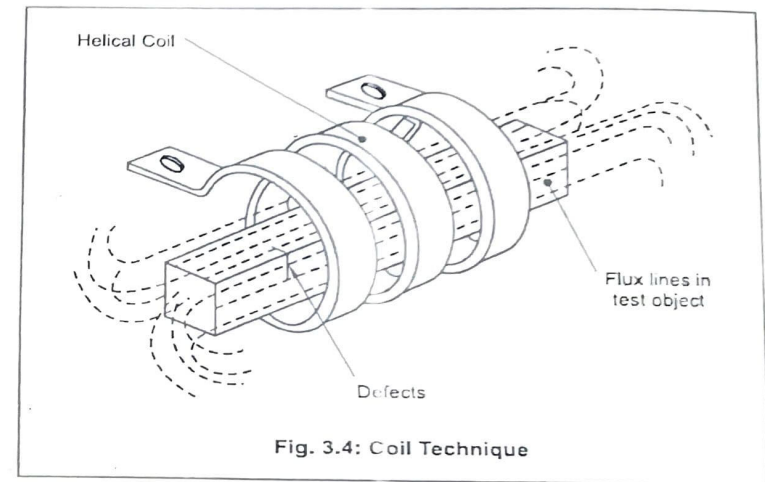


Fig. 3.4: Coil Technique

3.12.3. Central Conductor Technique:

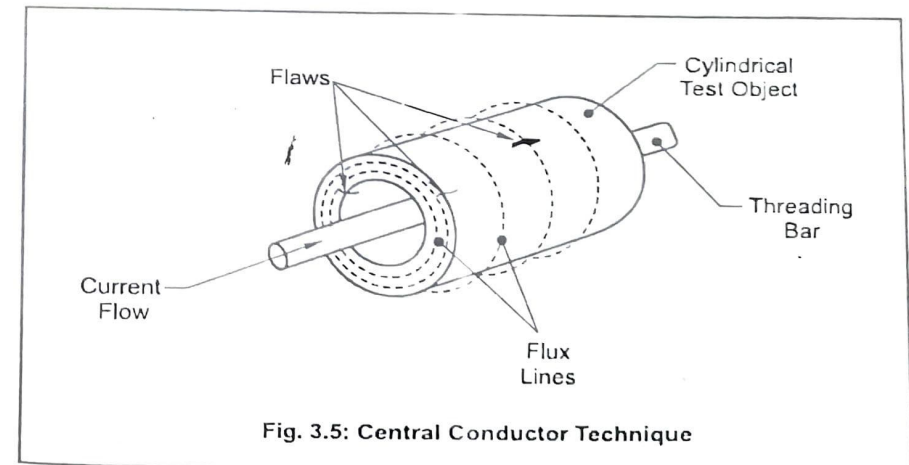


Fig. 3.5: Central Conductor Technique

Central conductor technique is also called as the threaded bar technique. This technique produces circular magnetization and can be used to inspect both the inside and outside of the component objects such as tubes, ducts can be inspected using this technique. The threading bar, which is placed inside the component, is made up of a good conductor such as copper and aluminium. As the current flows through the bar, the resultant flux field will be generated surrounding the test object. This flux field will be at right angles to the current flow but the defects are shown in the direction parallel to the current flow.

A big advantage is that the flux flows on both the inner as well as the outer surface of the tube, so that internal defects can be found. Also, there is a less risk of burning the component as the current flows through the threading bar.

3.12.4. Magnetization using Magnets:

The simplest way of magnetizing a component is possible only by means of a permanent magnets. In this technique, the test part (component) becomes a part of the magnetic circuit, thereby, bridging the path between the poles of a permanent magnet. The defects are revealed in the direction transverse to the test object. Further this method allows us to control the flux intensity. The flux intensity can be varied by using a strong or weak magnet or by introducing a gap in the flux path with a thin piece of aluminium or other non-magnetic material.

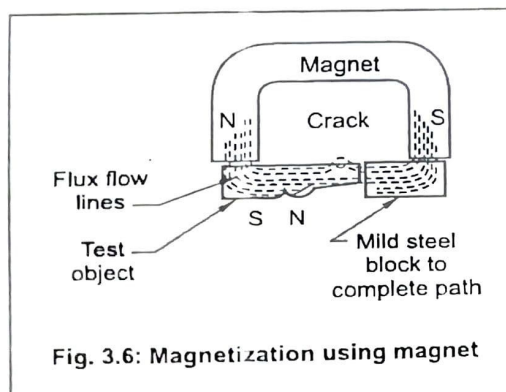


Fig. 3.6: Magnetization using magnet

3.12.5. Magnetization using Yoke:

A more refined magnetic flux can be produced through magnetising a component using AC yoke of electromagnet. In this method, components of varying cross section can be magnetised to produce same sensitivity, just by adjusting the variations in flux levels required to suit the components. Also the DC current is varied to provide a wide range of induced flux density. From the above information, we can say that, this method is highly suitable for components of simpler form and regular section.

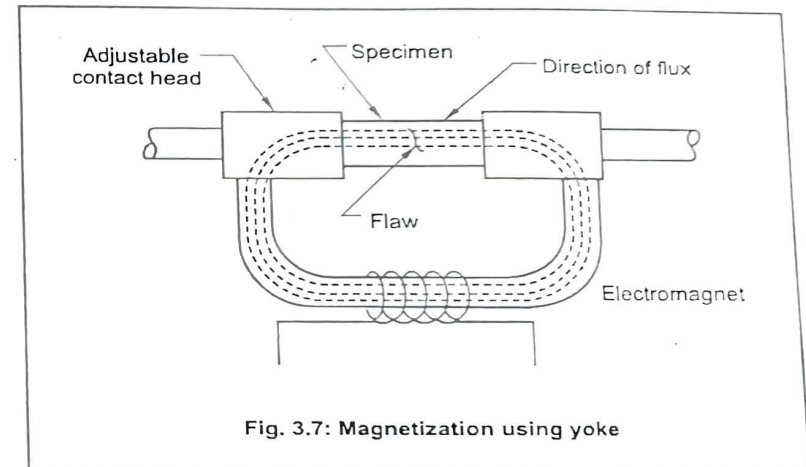


Fig. 3.7: Magnetization using yoke

3.13. DIRECT METHOD OF MAGNETIZATION:

The direct method of magnetization is also called as current flow method. In this method, the magnetising current flows through the part, thereby, completing the electric circuit. The magnetic field formed during this method is at right angles to the direction of current flow. Thus we can locate the defect at right angles to the applied magnetic field direction Eg: Head shot technique.

Limitations:

In direct method, the head or prod can cause a burn in the part if the high current is passing through a small contact area. To avoid this, the contact faces on the heads should be flexible and the tips of the prods should have a low melting point in order to spread the thermal load.

3.14. INDIRECT METHOD OF MAGNETIZATION:

The indirect method of magnetization is also called as magnetic flow method. In this method the test part becomes a part of the magnetic circuit, thus bridging the part between the poles of a permanent magnet.

The main advantage of the indirect technique is that the risk of arc burning of critical components does not exist. Also, the use of permanent magnet or electromagnet can be very convenient for inspections in contained spaces or remote locations.

3.15. CONTINUOUS TESTING OF MPI:

Continuous testing of MPI can be broadly classified into two types. They are

1. Dry continuous.
2. Wet continuous.

1. Dry Continuous:

The term 'dry' means that the magnetic particles are applied in fine particle form. The term 'continuous' means that the magnetic particles are applied while the current is still flowing onto it.

In this technique, the dry particles are applied when the magnetizing force is on. The particle application must cease before the current flow ceases. The use of dry particle is useful for detecting slightly subsurface discontinuities, since the particles have higher permeability compared to the particle in a wet suspension. Further, applying the particles during the magnetization provides maximum sensitivity, since the flux density will always be at its maximum during the current flow.

One disadvantage of using dry particles is that their mobility which is relatively poor when used with DC current.

2. Wet continuous:

The term 'wet' means that the particles applied are suspended in a liquid carrier. The liquid carrier such as kerosene, other petroleum distillates or water containing specially formulated additives can be used during wet suspension.

In this technique, the particles suspended in a liquid carrier are applied simultaneously with the magnetizing current. Compared to the dry particles, the suspended particles are generally of a lower permeability which makes this technique less favourable for the detection of slightly subsurface discontinuities.

Some of the advantages of using wet continuous testing techniques are

- (i) The greatly improved mobility of the particles makes this technique very suitable for the detection of small surface discontinuities.
- (ii) The suspension will adhere to the complex shapes better than dry particles. These surface tension effects when combined with the high flux densities of the continuous technique, provide the maximum sensitivity for surface discontinuities.

3.15.1. Advantages and Limitations of Different Liquid Carriers:

1. Kerosene and Petroleum distillates:

Advantages:

- (i) They help to lubricate the parts.
- (ii) They do not constitute the corrosion source.

Limitations:

- (i) They are more expensive.
- (ii) They produce health and flammability problems.

2. Water:**Advantages:**

- (i) They are inexpensive.
- (ii) It produces no health or flammability hazards.

Limitation:

- (i) They constitute the corrosion source which can be reduced by using corrosion inhibiting additives, although it cannot be completely eliminated.

3.16. RESIDUAL TECHNIQUE OF MPI:

Similar to continuous testing process, the residual technique of MPI can also be classified into two types

1. Dry residual.
2. Wet residual.

1. Dry Residual:

The term 'residual' means that, the material has sufficient retentivity to allow applications of the magnetic particles after the current has ceased.

In dry residual technique, the dry particles are applied after the magnetizing force has ceased. The retentivity of the material produces a residual magnetic field, which results in leakage fields at discontinuities open to the surface. This technique is suitable only with materials having high retentivity. So retentivity of the material must be determined prior to selecting this technique.

Advantages of Dry Residual Technique:

- ★ Most suitable for materials with low sensitivity and high retentivity.
- ★ Multiple parts can be magnetized simultaneously and then examined individually after particle applications.

Disadvantages of Dry Residual Technique:

- ★ Small and subsurface discontinuities are difficult to detect due to the decrease in sensitivity and mobility.

2. Wet Residual:

This technique uses the suspended particles where the suspension is applied after the magnetizing force has been stopped.

Advantage:

- ★ Increase in inspection speed due to the inspection of multiple parts simultaneously.

Disadvantage:

- ★ Produces lower sensitivity than continuous testing method.

3.17. SYSTEM SENSITIVITY:

Sensitivity of MPI plays an important role in locating the small and sub surface cracks in ferro-magnetic components. Many fine cracks of size less than 0.02 mm deep can be located using the sensitivity of MPI.

Sensitivity not only involves crack detection, but also allows us to locate a wide range of defects like.

- ★ Detecting segregations, macro inclusions while inspecting steels.
- ★ Detecting marks generated during stamping operations.
- ★ Detecting laps in the threaded section of bolts.

Also, sensitivity depends on the type of current used, various tests has proved the following information.

- ★ AC magnetization is most effective for surface defects, but not effective for subsurface defects.
- ★ DC magnetization is effective for subsurface defects.

★ Half wave DC gives superior penetration as compared to straight DC.

★ Half wave DC dry method gives the greatest penetration.

3.18. CHECKING DEVICES IN MPI:

In order to maintain consistency and high level of control during MPI, it is highly recommended to use checking devices in MPI. Some of the commonly used checking devices are

- (i) Settling test.
- (ii) Ketos ring.
- (iii) Field indicator.
- (iv) Suspension contamination.
- (v) Ammeter accuracy.

(i) Settling test:

Settling test is also called as suspension concentration test. The purpose of settling test is to assure that the proper concentration of particles is being maintained in the liquid carrier.

(ii) Ketos ring:

The ketos ring is a device made of tool steel and is designed to show the effectiveness of the MPI and the relative penetration based on the number of holes that display indications. In ketos ring, both the wet suspension and dry particles can be used.

(iii) Field indicator:

Field indicator is used to check the presence of residual magnetism on the system.

3.19. INTERPRETATIONS OF MPI:

Interpretation of MPI involves testing the surface of inspection by a trained NDT engineer whose skill and experience is needed most to perform the test correctly. During Magnetic Particle Inspection, the magnetic particles adhere to the test object wherever leakage flux is present and the interpreter has to properly interpret the adherence of magnetic particles. Proper interpretation involves finding out whether.

- (i) Adherence is due to the presence of cracks, or
- (ii) Adherence is because of the change in cross section, or
- (iii) Particles are adhering to edges only.

Wrong interpretation may lead to rejection of the material, thus resulting in material wastage. Thus an NDT engineer who interprets the results, determine the success or failure of any NDT tests.

3.20. INDICATIONS:

Indications in MPI relies greatly on the qualification of the inspector (interpreter). So, after proper interpretation, the interpreter classify the indications as 'False', 'non relevant' or 'relevant' before final evaluation.

3.20.1. False Indications:

False indications can be produced due to improper handling, use of excessively high magnetizing currents, inadequate precleaning of the parts to remove oil, grease, corrosion products and other surface contaminates.

3.20.2. Non-relevant Indications:

Non-relevant indications are the result of flux leakage due to the geometrical or permeability changes of the test object.

Examples of geometrical changes include splines, thread roots, gear teeth, keyways etc.

Examples of permeability changes include localized heat treatment, variation in hardness, fusion zone of a weld etc.

3.20.3. Relevant Indications:

Relevant indications are produced by flux leakages due to discontinuities in the part.

Note: Discontinuities which cause the part to fail from its original purpose are classified as 'defects'.

3.21. ADVANTAGES OF MPI:

- (i) MPI does not require very stringent pre-cleaning operation.
- (ii) Most suitable method for the detection of fine, shallow surface cracks in ferromagnetic material.
- (iii) High sensitive and complex parts can be inspected rapidly.
- (iv) Fast and relatively simple NDT method.
- (v) Few limitations regarding the shape and size of the test specimen.
- (vi) Highly portable NDT method.

3.22. LIMITATIONS OF MPI:

- (i) Only ferromagnetic materials can be inspected.
- (ii) Only surface & near surface defects can be detected.
- (iii) Local heating and burning of finished parts is possible.
- (iv) Large currents are required to produce strong magnetic field.
- (v) This method cannot be used if a thick paint coating is present.
- (vi) Parts are often required to be demagnetised, which may be difficult.

MODULE – 4

ULTRASONIC TESTING AND ACOUSTIC EMISSION TESTING

Principle, types of waves, frequency, velocity, wavelength, reflection, divergence, attenuation, mode conversion in ultrasonic UT testing methods, Contact testing and immersion testing, normal beam and straight beam testing, angle beam testing, dual crystal probe, ultrasonic testing techniques, resonance testing, through transmission technique, pulse echo testing technique, instruments used in UT, accessories such as transducers, types, frequencies, and sizes commonly used, Reference blocks with artificially created defects, calibration of equipment, Applications, advantages, limitations, A, B and C scan – Time of Flight Diffraction (TOFD), Acoustic Emission Technique – Principle, AE parameters, Applications.

4.1. INTRODUCTION:

Ultrasonic testing is an effective NDT method which is applicable to most materials like metallic (or) non-metallic materials.

It is a method to detect surface and internal discontinuities such as laps, seams, voids, cracks, blow holes, inclusions and lack of bond.

Ultrasonic testing uses high frequency sound energy to detect surface and internal discontinuities.

Ultrasonic testing is completely a safe method of non-destructive testing and it is widely used because of its high-penetrating capacity, inspection of extremely thick sections etc.

In general, it is based on the capture & quantification of either the reflected waves (pulse - echo) or the transmitted waves (through transmission).

4.1.1. Ultrasonic Waves:

Sound waves having frequency above 20 kHz (20,000 Hz) are called ultrasonic waves.

The usual frequencies for Non-destructive testing of materials are in the range of 0.5 to 10 MHz. The selection of actual frequency depends on the roughness of the surface, grain size of the material and the dimensions of the flaw.

The detection of a small flaw requires the use of high frequency, but a practical limit is set up by the surface roughness and the grain size.

4.1.2. Principle:

A typical ultrasonic inspection system consists of several functional units, such as the pulser/receiver, transducer and display devices.

A pulser/receiver is an electronic device that can produce high voltage ultrasonic energy. Driven by the pulser, the transducer generates high frequency energy.

The sound energy is introduced and propagates through the materials in the form of waves.

When there is a discontinuity in the wave path, part of the energy will be reflected back from the surface.

The reflected wave signal is transformed into electrical signal by the transducer, and it is displayed on a screen.

In the Fig. 4.1, the reflected signal strength is displayed versus the time from signal generation when a echo is received.

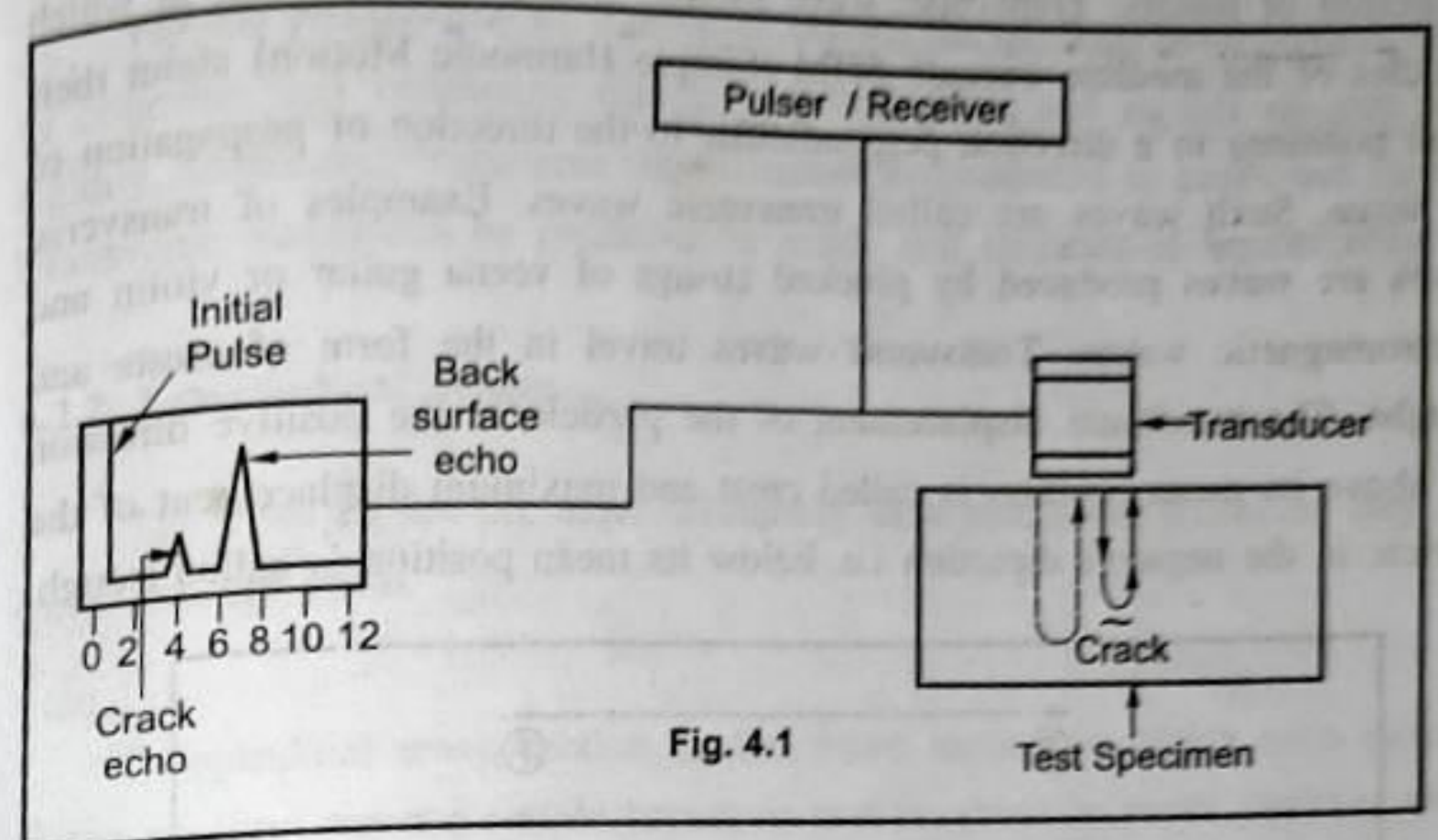


Fig. 4.1

Signal travel time can be directly related to the distance that the signal travelled.

From the signal, information about the reflector flaw location, size, and orientation and other features can be obtained.

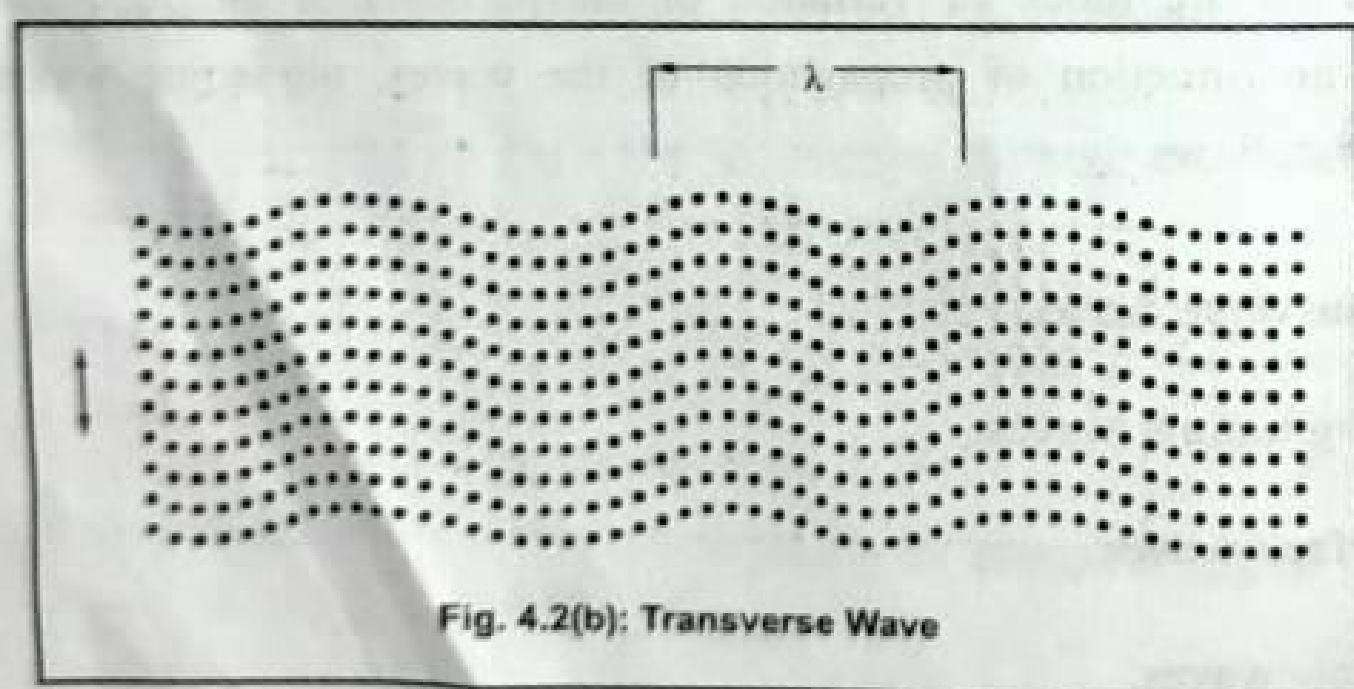
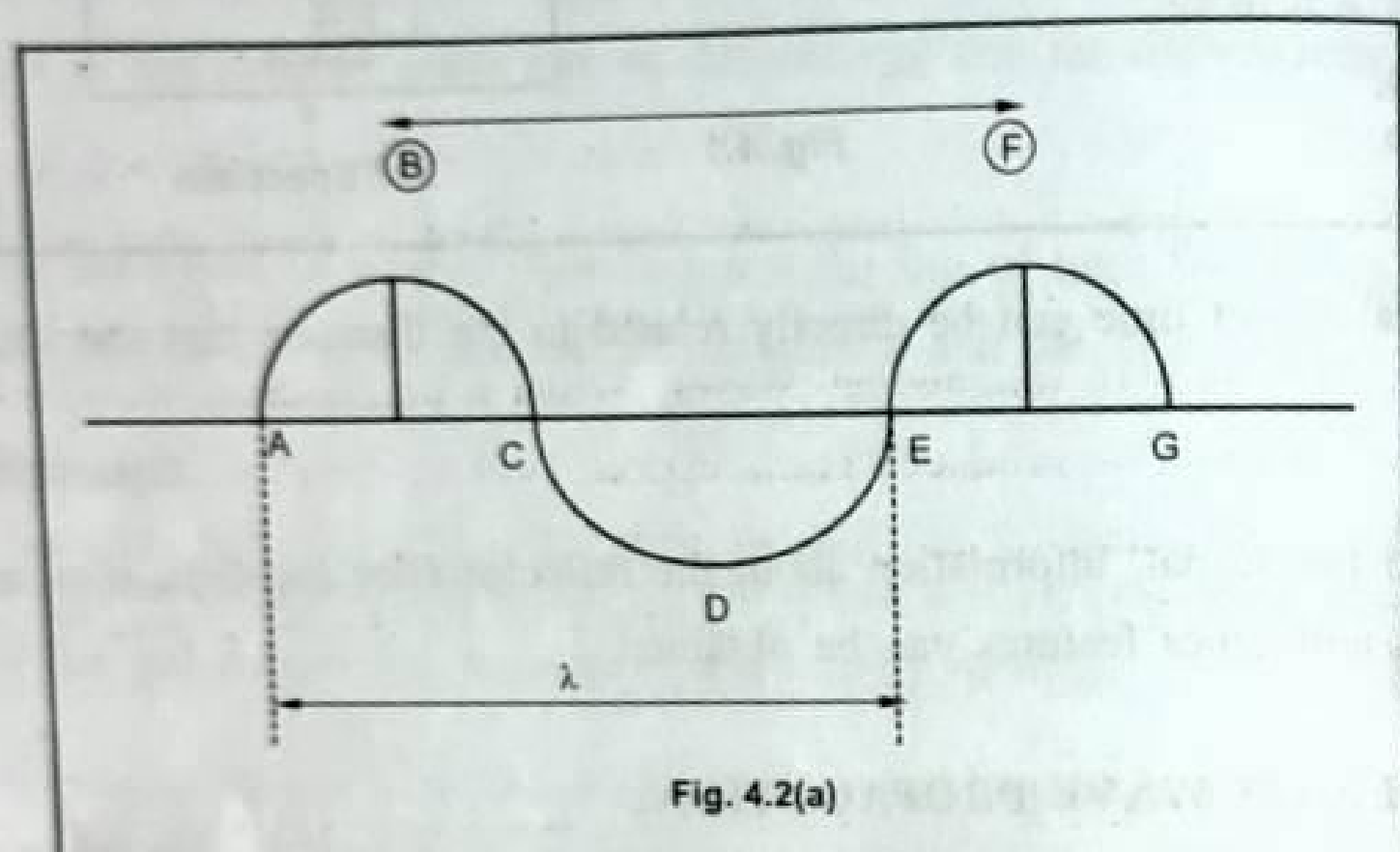
4.2. MODES OF WAVE PROPAGATION:

Based on the mode of vibration of the particles of the medium with respect to the direction of propagation of the waves, ultrasonic waves are classified as follows.

1. Transverse waves.
2. Longitudinal waves.
3. Surface waves.
4. Lamb waves.

4.2.1. Transverse Waves:

These waves travel only in solids and are also used widely in ultrasonic inspection of metals. Transverse wave motion is that wave motion in which particles of the medium execute SHM (Simple Harmonic Motion) about their mean positions in a direction perpendicular to the direction of propagation of the wave. Such waves are called transverse waves. Examples of transverse waves are waves produced by plucked strings of veena guitar or violin and electromagnetic waves. Transverse waves travel in the form of crests and troughs. The maximum displacement of the particle in the positive direction i.e. above its mean position is called crest and maximum displacement of the particle in the negative direction i.e. below its mean position is called trough.



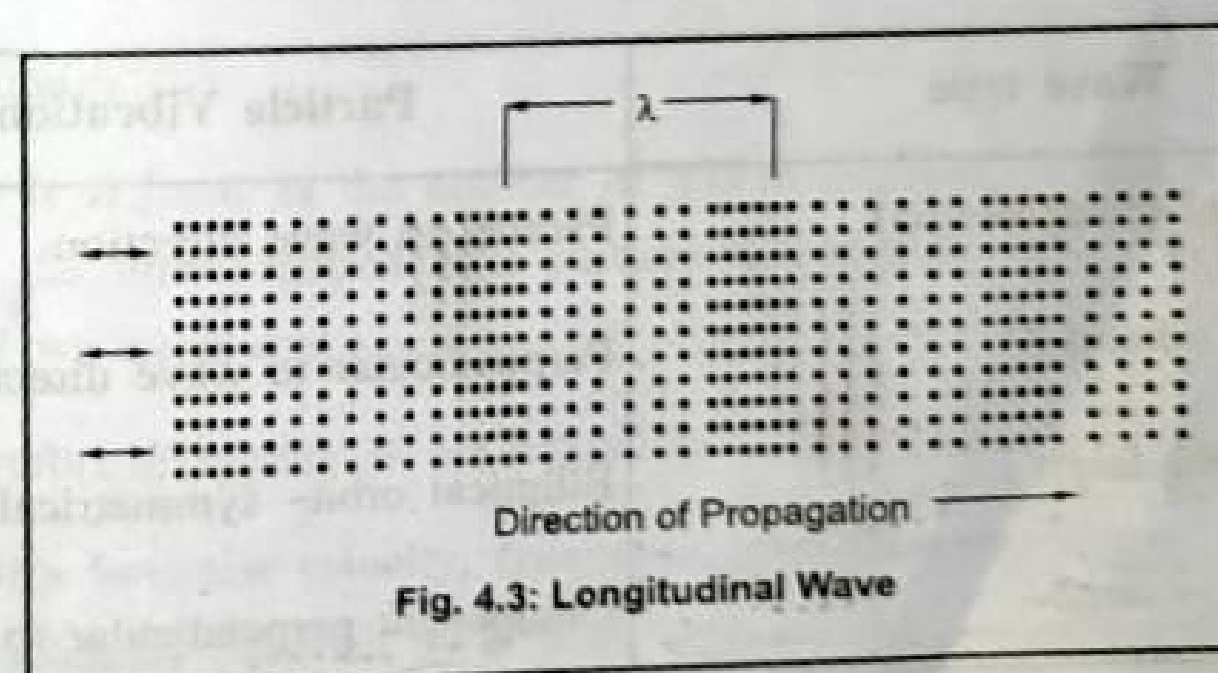
Thus if ABCDEFG is a transverse wave, the points B and F are crests while D is trough.

For the propagation of transverse waves, the medium must possess force of cohesion and volumetric elasticity. Since gases and liquids do not have rigidity, (cohesion), transverse waves cannot be produced in gases and liquids. Transverse waves can be produced in solids and surfaces of liquids only.

4.2.2. Longitudinal Wave:

These waves are the most commonly used ultrasonic waves as they can travel through solid.

Longitudinal wave motion is that wave motion in which each particle of the medium express simple harmonic motion about its mean position along the direction of propagation of the wave. Sound waves in fluids (liquids and gases) are examples of longitudinal waves. When a longitudinal wave travels through a medium, it produces compressions and rarefactions. Longitudinal waves can be produced in all types of material medium, solids, liquids and gases. The density and pressure of the medium in the region of compression are more than that in the region of rarefactions.

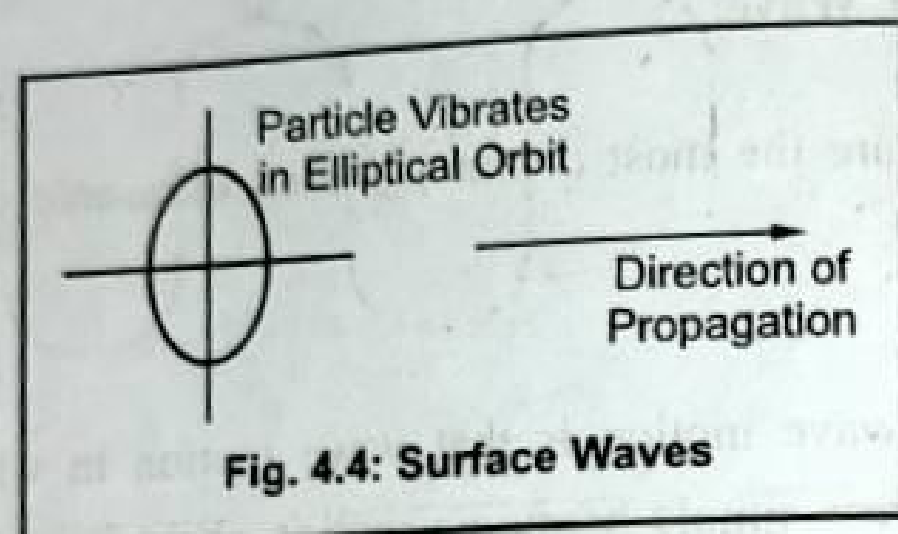


4.2.3. Surface Waves:

Surface waves also known as Rayleigh waves represent an oscillating motion that travels along the surface of a test specimen to a depth of one wavelength.

Velocity and wavelength are similar to that of shear waves.

Surface waves can be used to detect surface breaking cracks in a test specimen.

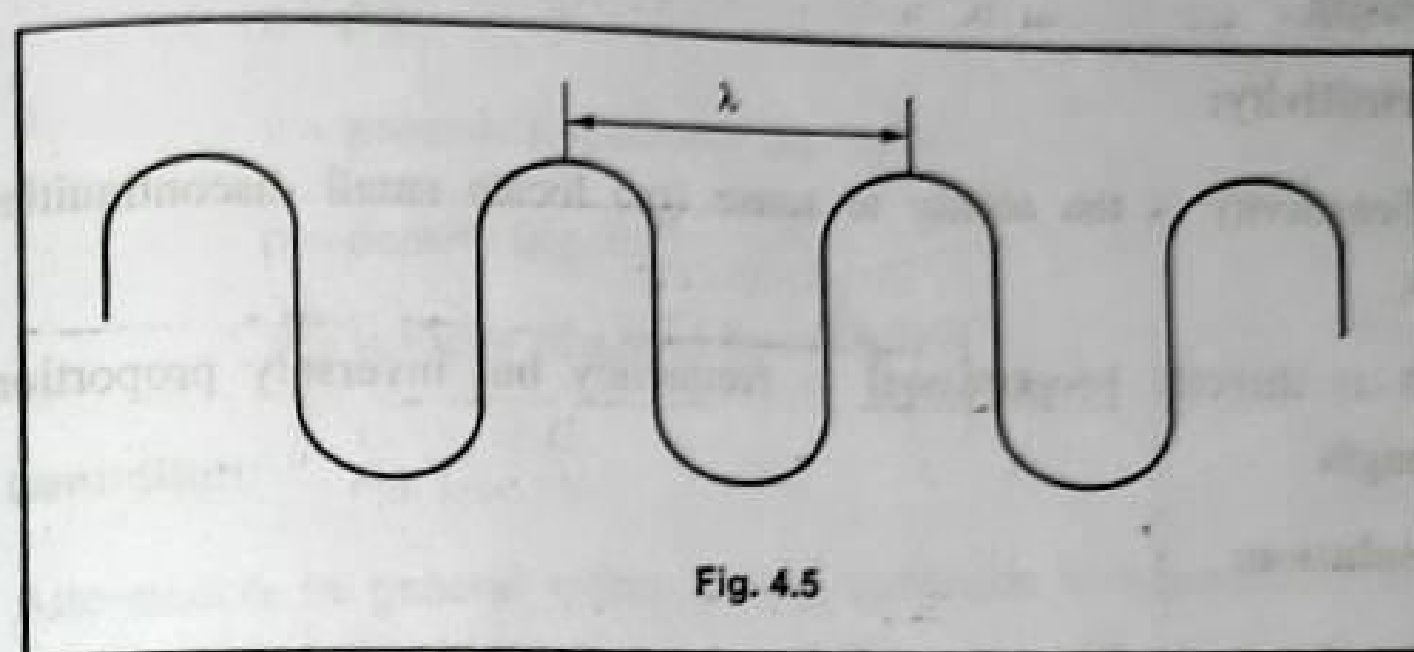
**Fig. 4.4: Surface Waves****4.2.4. Lamb Waves:**

Lamb waves are surface waves propagate parallel to the test surface and have a particle motion that is elliptical. They occur when the thickness of the test material is only a few wavelengths at the test frequency and where the test piece is of uniform thickness.

Wave type	Particle Vibration
Longitudinal (compression)	Parallel to wave direction.
Transverse (shear)	Perpendicular to wave direction.
Surface – Rayleigh	Elliptical orbit– symmetrical mode.
Plate wave – lamb	Component perpendicular to surface

4.3. TERMINOLOGIES USED IN ULTRASONIC TESTING:**(i) Wavelength (λ):**

The distance travelled by a wave during which a particle of the medium completes one vibration is called wavelength. It is also defined as the distance between any two nearest particles on the wave having same phase.

**Fig. 4.5**

Wavelength may also be defined as the distance between two successive crests or troughs in transverse waves, or the distance between two successive compressions or rarefactions in longitudinal waves.

(ii) Time period (T):

The time period of a wave is the time taken by the wave to travel a distance equal to its wavelength.

(iii) Frequency (n):

This is defined as the number of waves produced in one second. If T represents the time required by a particle to complete one vibration, then it makes $1/T$ waves in one second.

Therefore frequency is the reciprocal of the time period (i.e.) $n = 1/T$.

Relationship between velocity, frequency and wavelength of a wave:

The distance travelled by a wave in a medium in one second is called the velocity of propagation of the wave in the medium. If V represents the velocity of propagation of the wave, then

$$\text{Velocity} = \frac{\text{Distance Travelled}}{\text{Time taken}}$$

$$v = \frac{\lambda}{T} = n \lambda \quad [\because n = 1/T]$$

The velocity of a wave (v) is given by the product of the frequency and wavelength.

(iv) Sensitivity:

Sensitivity is the ability to sense (or) locate small discontinuities (or) defects.

It is directly proportional to frequency but inversely proportional to wavelength.

(v) Resolution:

Resolution is the ability of the system to locate defects that are close together within the materials (or) located near the part surface.

Resolution increases with increase in frequency.

(vi) Penetration Depth:

It is the maximum depth in a material, the flaws can be located by the ultrasonic waves in testing.

(vii) Scattering:

Scattering occurs when waves travel in an imperfect medium, they get deflected from their straight path.

Here scattering is the reflection of sound beam from its direction of propagation.

(viii) Absorption:

Absorption is the process by which a material, structure (or) object takes in sound energy. Part of the absorbed energy is transmitted as heat and part is transmitted through the absorbing body.

(ix) Acoustic Impedance:

Acoustic impedance is the resistance to sound wave propagation.

For more dense material, the acoustic impedance is more.

It is also defined as the product of material density and velocity of sound waves in the material.

$$z = \rho v$$

$$z = \text{acoustic impedance (kg/m}^2 \text{ s)}$$

$$\rho = \text{density (kg/m}^3 \text{)}$$

$$v = \text{velocity of sound waves (m/s)}$$

(x) Attenuation:

Attenuation in general refers to any reduction in strength of signal or wave.

It is the measure wave of the energy loss of sound wave propagation in a medium.

When sound wave travels through a medium, its intensity decreases with distance.

It is because of the combined effect of scattering & absorption.

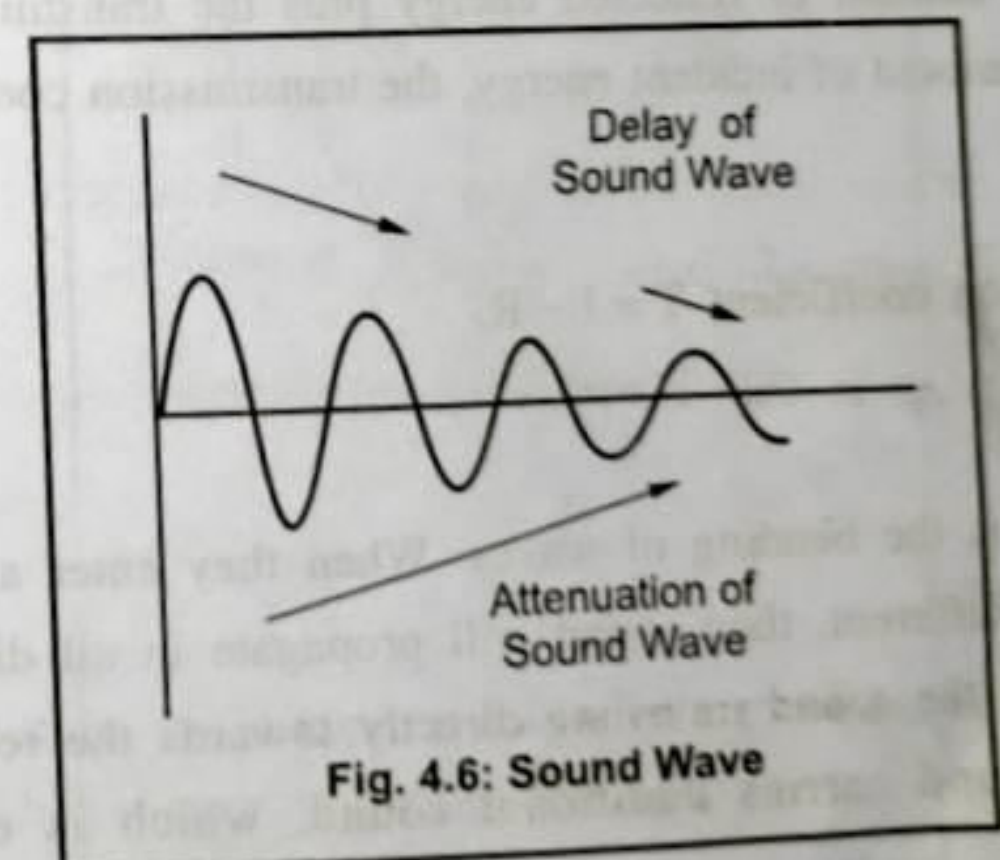


Fig. 4.6: Sound Wave

Amplitude charge, $A = A_0 e^{-\alpha z}$

where A_0 = initial amplitude

α = attenuation coefficient (Np/m)

z = distance (m)

Note:

Np (neper) is logarithmic dimensionless quantity and it can be converted to Decibels by dividing it by 0.1151.

(xi) Reflection & Transmission Coefficient:

The difference in acoustic impedance (z) offers resistance due to which ultrasonic waves are reflected at boundaries.

When the acoustic impedance on both sides of the material are known, the reflection coefficient can be calculated as.

$$\text{Reflection coefficient, } R = \left[\frac{z_2 - z_1}{z_2 + z_1} \right]^2$$

Since the amount of reflected energy plus the transmitted energy must equal the total amount of incident energy, the transmission coefficient is simply calculated as

$$\text{Transmission coefficient } T = 1 - R.$$

(xii) Refraction:

Refraction is the bending of waves. When they enter a medium where their speeds are different, then sound will propagate in all directions from a point source. But the sound travelling directly towards the receiver is heard, the refracted sound carries additional sound, which is effective while amplifying it.

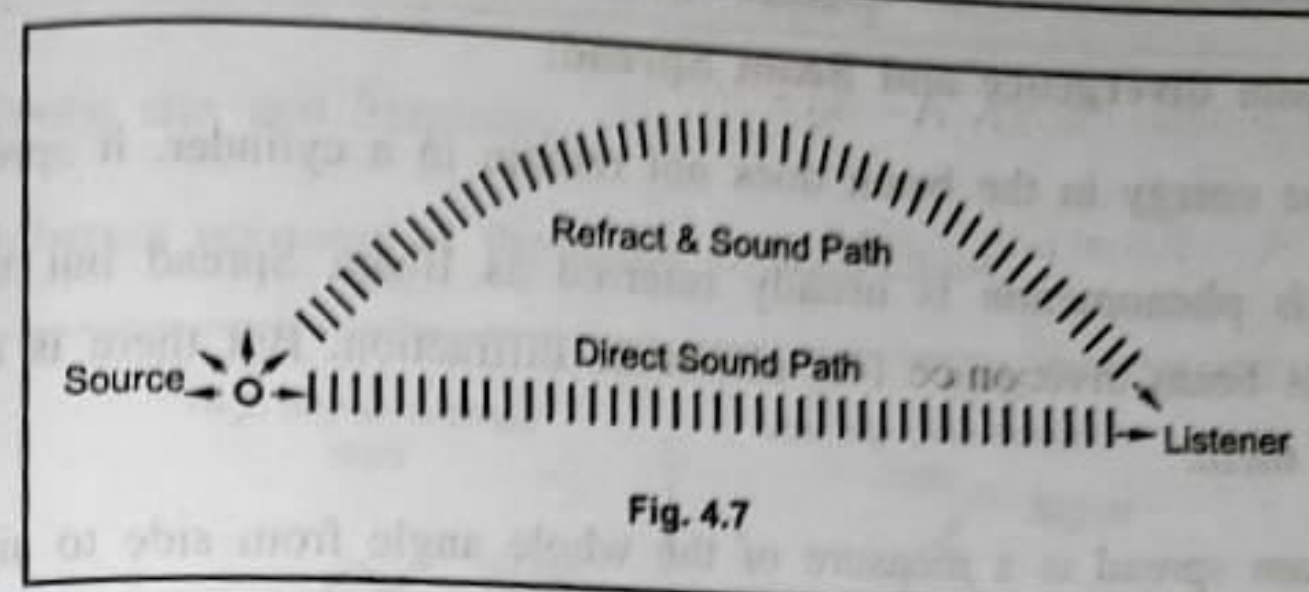


Fig. 4.7

(xiii) Snell's Law:

The relationship between the angle of incidence, the angle of refraction and the velocity of the waves, when sound waves are travelling between two materials, is explained through Snell's law.

Equation of Snell's law is given by

$$\frac{\sin \theta_1}{V_{L1}} = \frac{\sin \theta_2}{V_{L2}}$$

where V_{L1} & V_{L2} = Longitudinal wave velocities in the first & second materials respectively.

θ_1 = Angle of incident wave.

θ_2 = Angle of refracted wave

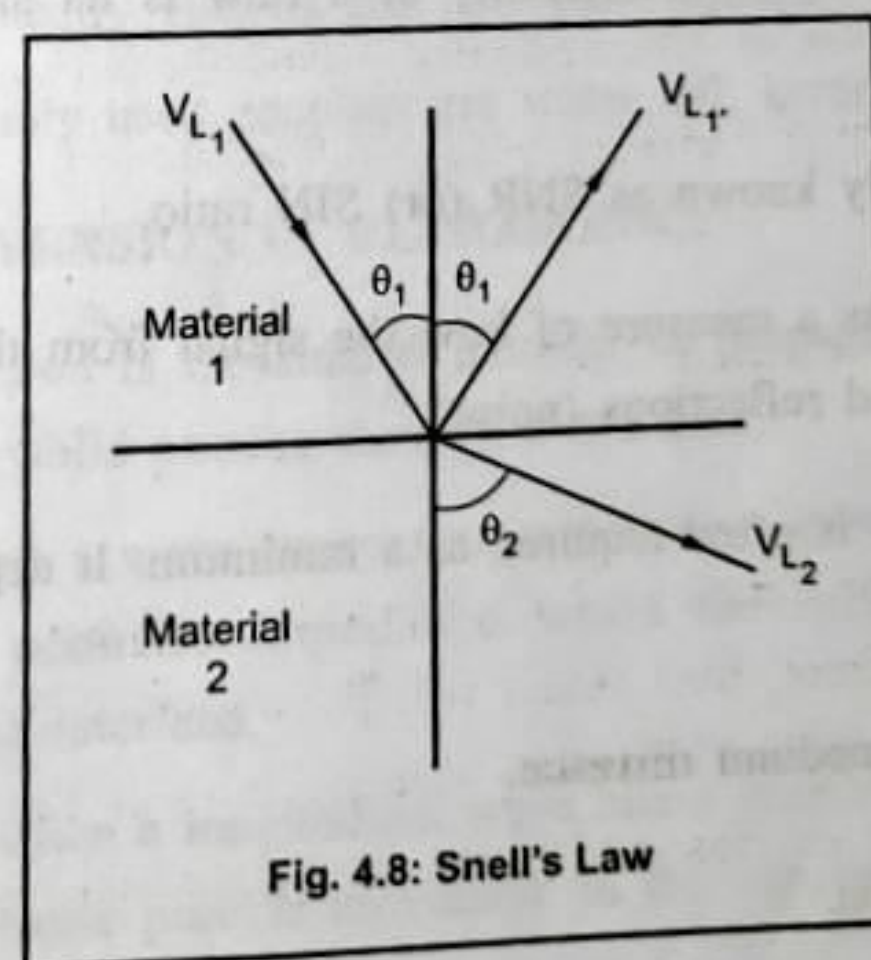


Fig. 4.8: Snell's Law

(xiv) Beam divergence and Beam Spread:

The energy in the beam does not remain in a cylinder, it spreads out.

This phenomenon is usually referred as Beam Spread but sometimes known as beam divergence (or) ultrasonic diffraction. But there is difference between them.

Beam spread is a measure of the whole angle from side to side of the main lobe of the sound beam in the far field.

Beam divergence (α) is a measure of the angle from one side of the sound beam to the central axis of the beam in the far field.

The Beam spread is twice the Beam divergence.

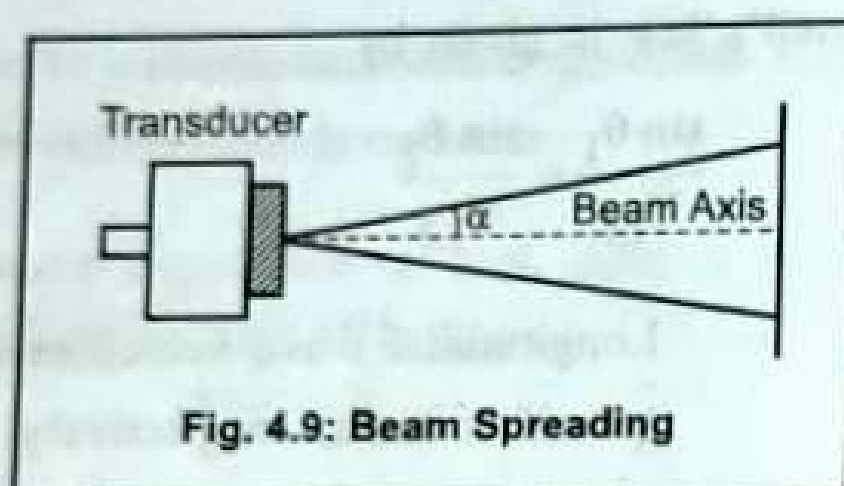


Fig. 4.9: Beam Spreading

(xv) Signal to Noise Ratio (S/N ratio):

A good measure of detectability of a flaw is its signal to noise ratio (S/N).

It is commonly known as SNR (or) SIN ratio.

It is defined as a measure of how the signal from the defect compares to other back ground reflections (noise).

A SNR of 3:1 is often required as a minimum. It depends on following factors:

- ★ Inspection medium distance.
- ★ Flaw location.

- ★ Probe size and frequency.
- ★ Inherent noisiness of the metal microstructure.

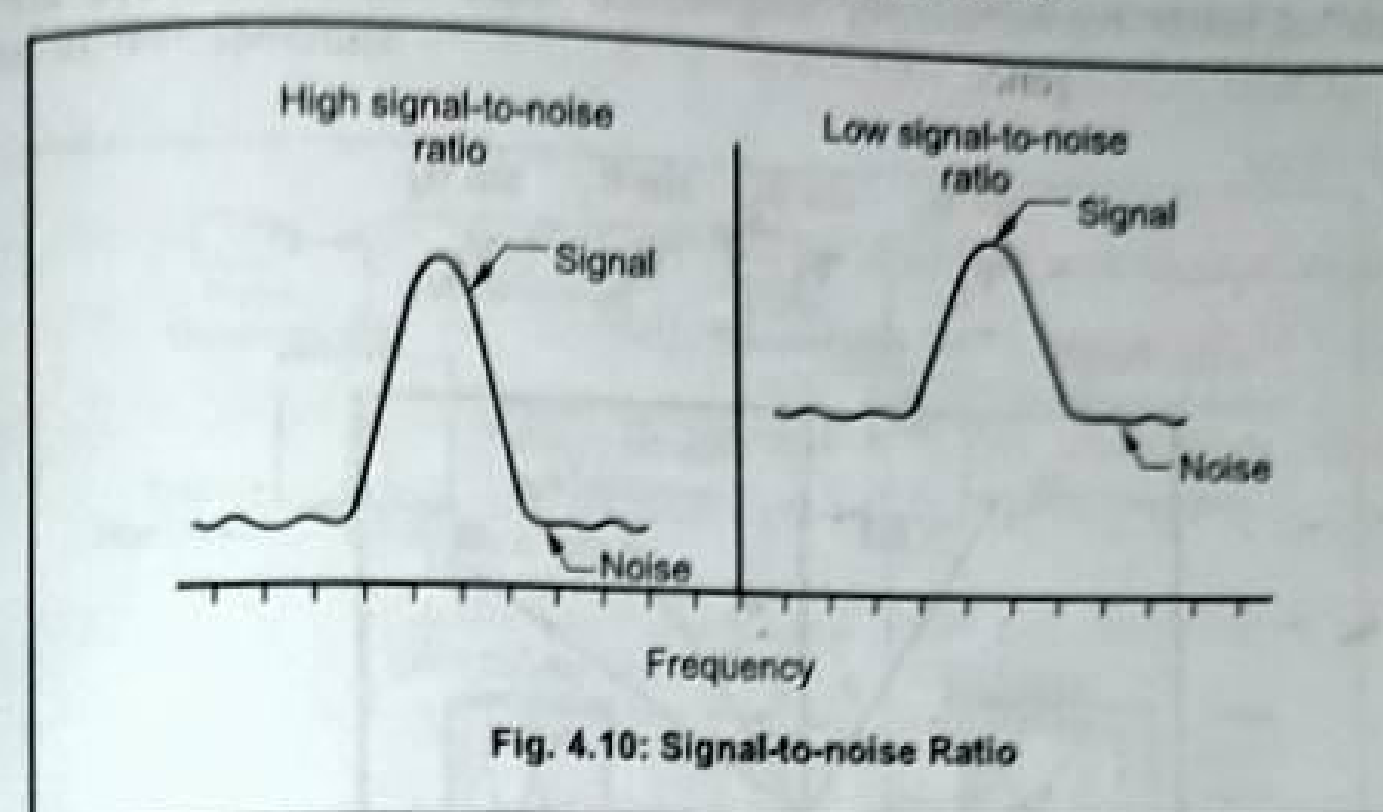


Fig. 4.10: Signal-to-noise Ratio

(xvi) Couplant:

A couplant is a liquid that enhances the transmission of ultrasonic energy from the transducer into the test specimen.

Couplant is necessary due to the large acoustic impedance mismatch between air and solids.

It will be typically viscous and non toxic liquids.

Some commonly used couplant are water, oil, kerosene, glycerin etc.

4.4. MODE CONVERSION IN ULTRASONIC:

Mode conversion is the state of transfer of propagation of sound from one form to other while passing through a material.

It occurs when a wave encounters an interface lying between materials having different acoustic impedance while the incident angle is not perpendicular to the interface.

For instance when a longitudinal wave hits a interface at an angle, some of the energy can cause particle movement in the transverse direction to start a shear wave.

However the converted shear wave is not refracted as much as the longitudinal wave because shear wave travels slower than longitudinal waves.

Law of mode conversion for longitudinal wave and shear wave are as follows.

$$\frac{\sin \theta_1}{V_{L_1}} = \frac{\sin \theta_2}{V_{L_2}} = \frac{\sin \theta_3}{V_{S_1}} = \frac{\sin \theta_4}{V_{S_2}}$$

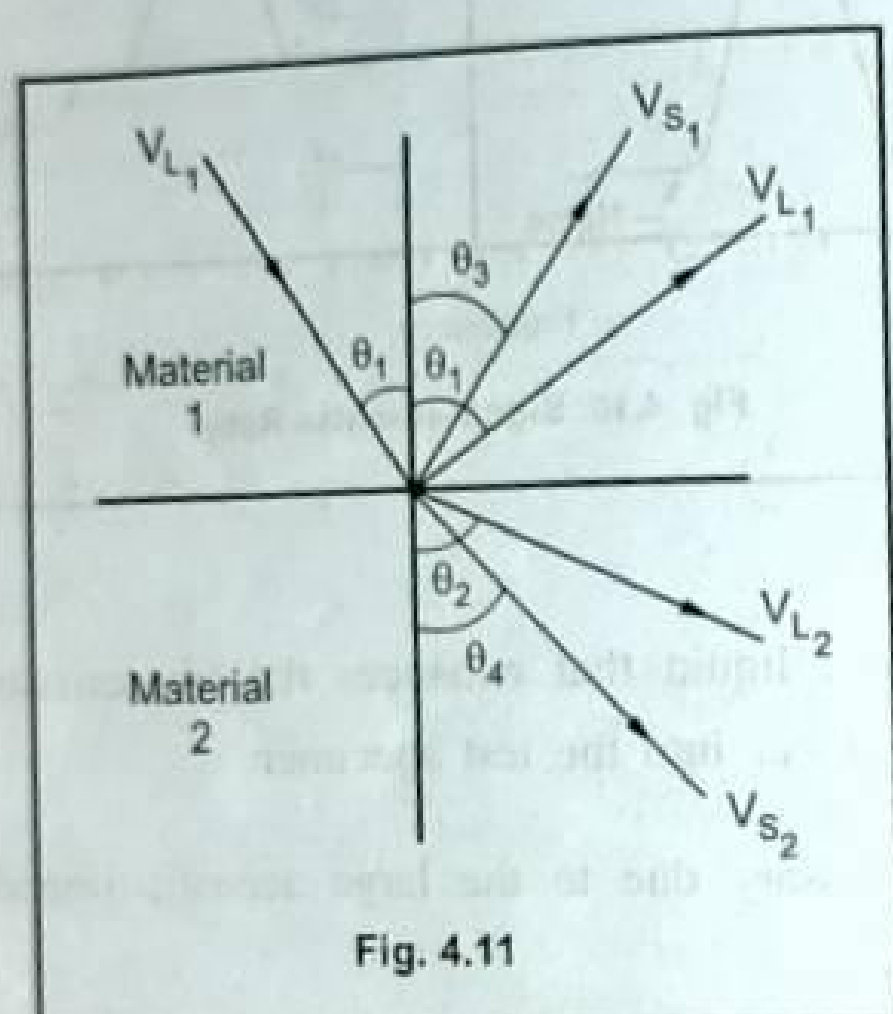


Fig. 4.11

4.5. ULTRASONIC TESTING TECHNIQUES:

The ultrasonic testing can be effectively done in two methods. They are

1. Transmission method.
2. Pulse - echo method.

4.5.1. Transmission Method:

In this method, the defect can be identified on quantifying the received sound waves.

Transmission method consists of two transducers placed on opposite sides, one is to transmit the sound wave and other is to receive them.

Discontinuities provide some obstruction to sound waves so it results in partial (or) total loss in transmitted sound waves.

The decrease in the received signal amplitude indicates the presence of defects in test specimen

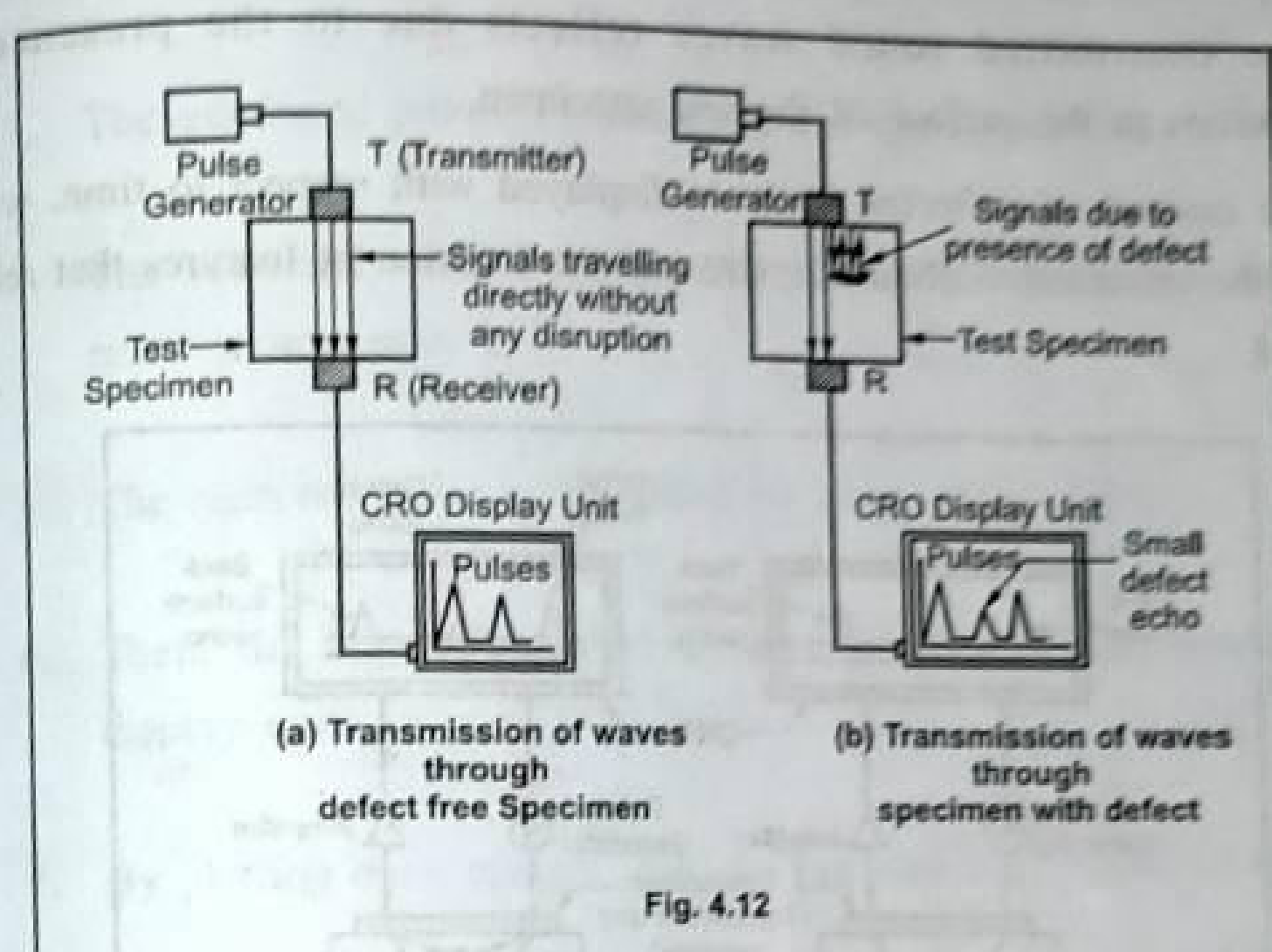


Fig. 4.12

Procedure followed in transmission method:

Two transducers are placed opposite to each other on the surface of the test specimen.

Among two transducers, one is to transmit sound waves and other is to receive them.

The result can be seen through CRT screen display.

The specimen without defect has no loss in transmitted sound waves and the graph will be nearly equal as shown in Fig. 4.12(a).

The specimen with defect has loss in transmitted sound waves so it will reflect in the graph by short pulse as shown in Fig. 4.12(b).

This method can be done efficiently by using couplant to avoid losses in sound waves due to separation between the surfaces.

4.5.2. Pulse – Echo Method:

Unlike transmission method, here only one transducer is used. This transducer acts as both transmitter & receiver (i.e.) it sends out a pulse of energy and the same receives it.

The transmitted sound waves reflects due to the presence of discontinuities at the surface of the test specimen.

The amount of reflected wave is displayed with respect to time, which provides the information about the size and the location of features that reflect the sound.

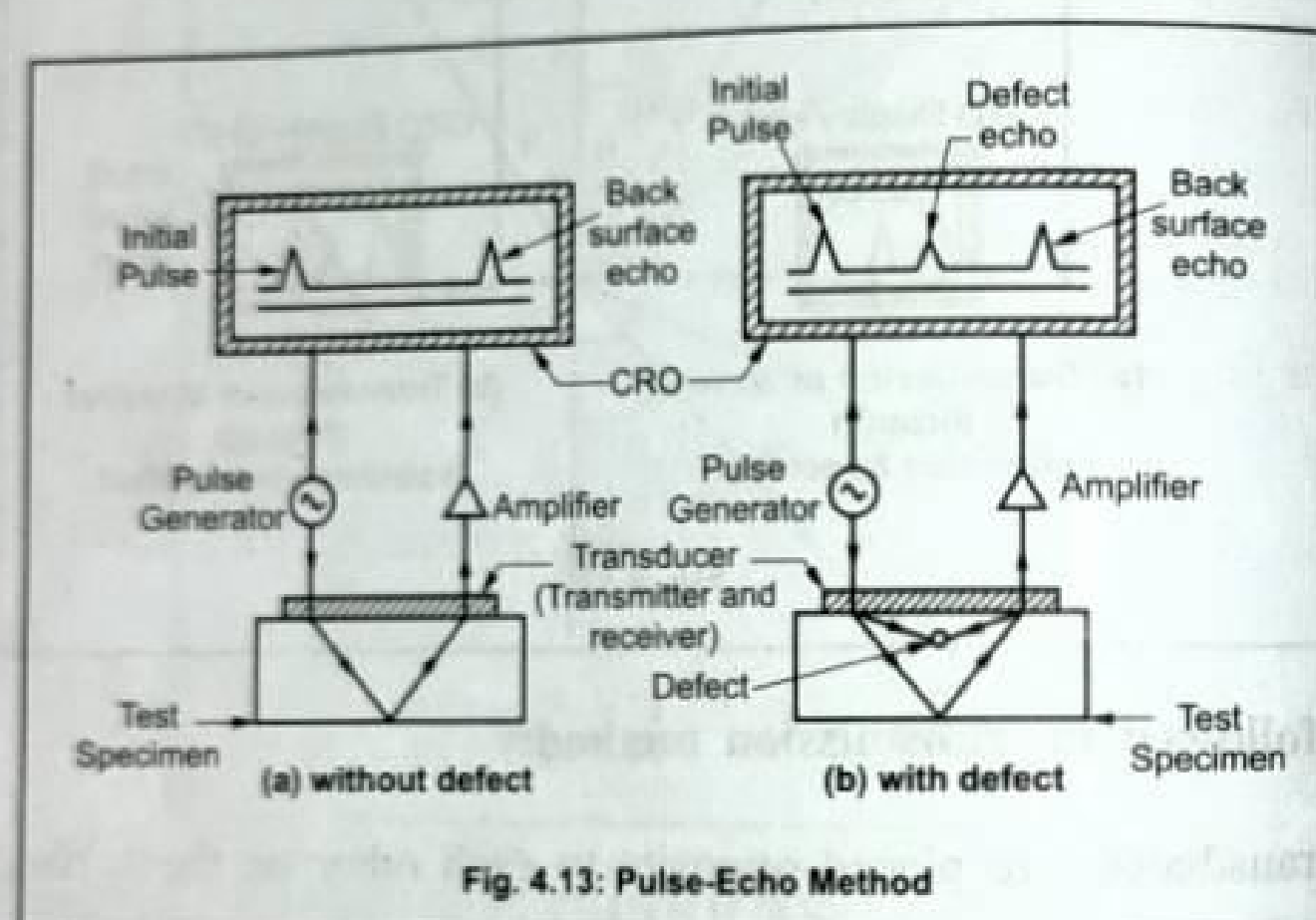


Fig. 4.13: Pulse-Echo Method

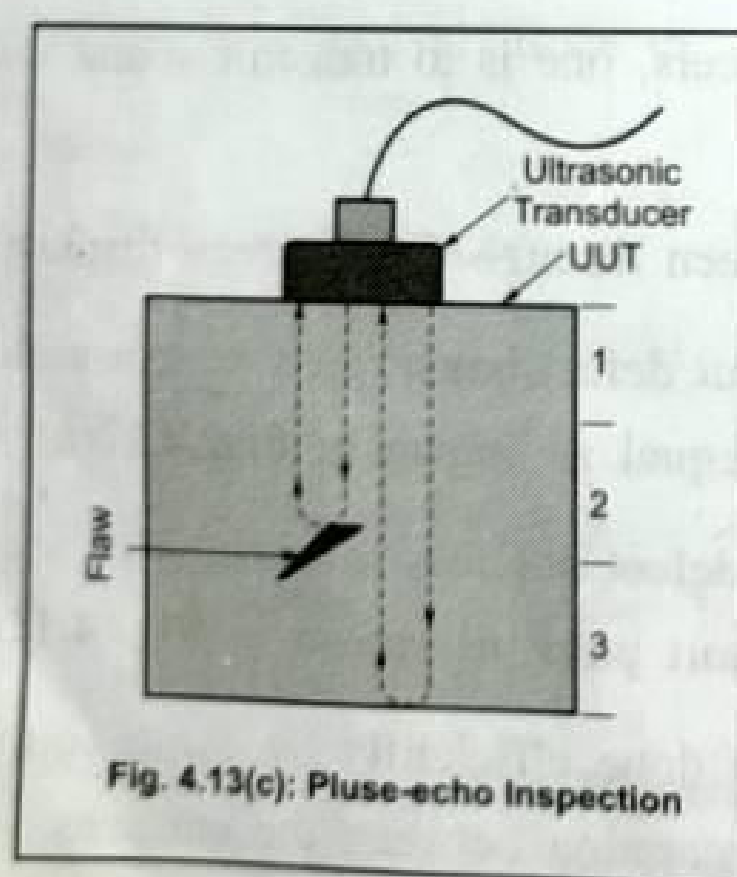


Fig. 4.13(c): Pulse-echo Inspection

Procedure followed in Pulse – echo method:

1. A test specimen is placed to conduct ultrasonic testing.
2. A pulse generator is used to generate pulse of required frequency.
3. The generated pulse is transmitted through transducer.
4. The reflected wave is received by the same transducer which has receiver unit with it.
5. The received pulse is amplified by using an amplifier.
6. Then, the both transmitted & received pulse is compared in CRO display unit.
7. By plotting these against time, we can find the location of the defects.

4.6. TYPES OF TESTING TECHNIQUES:

Testing techniques are also classified according to the transducers used:

4.6.1. Contact Testing Techniques:

Contact techniques are used for direct contact inspections, and are manipulated manually. As the name suggests, this transducer has direct contact with test specimen.

They have elements protected in a rugged casing to withstand sliding contact with a variety of materials.

These transducers are designed in such a manner so that it is easy to grip and move along a surface.

They often have replaceable wear plates to lengthen their useful life.

Coupling materials of water, grease, oil, or commercial materials are used to remove the air gap between the transducer and the component being inspected.

4.6.2. Immersion Testing Technique:

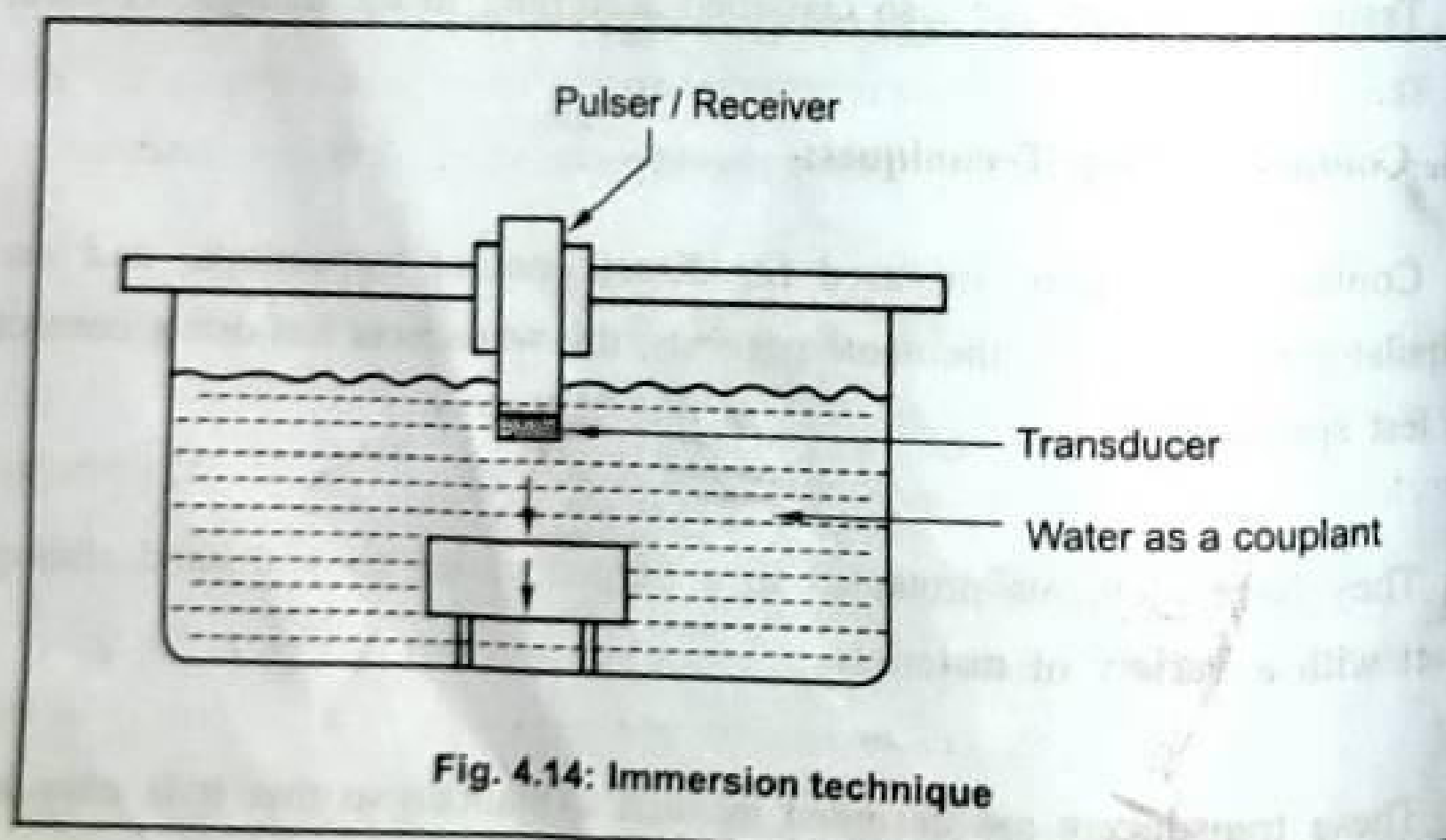
Immersion technique is a non-contact transducer. These transducers are designed to operate in a liquid environment so that all connections are watertight.

Immersion techniques have an impedance matching layer that helps to get more sound energy, into the component being inspected.

Immersion transducer can be purchased with a planer, cylindrically focused or spherically focused lens.

Since it is a well focussed transducer, it has high sensitivity and resolution.

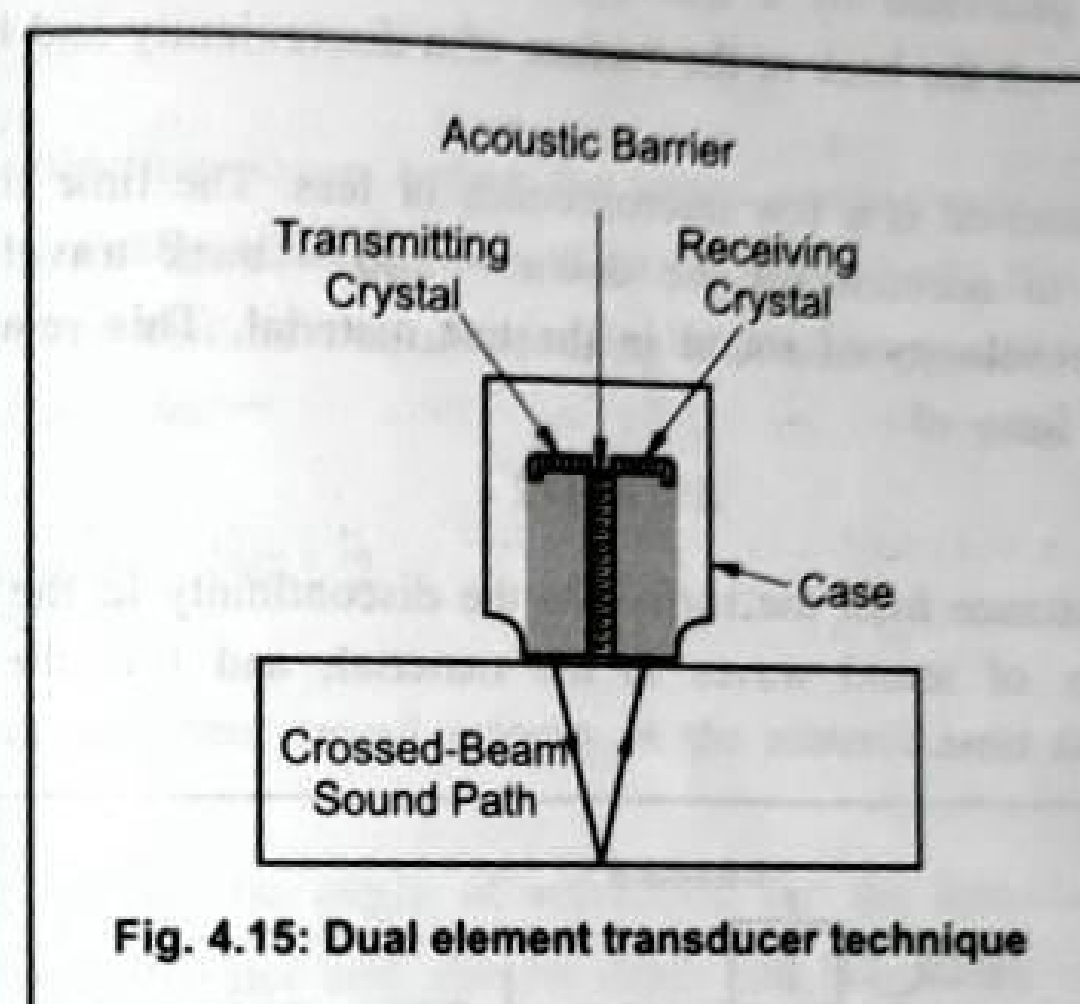
Immersion technique is typically used inside a water tank or as part of a bubbler system in scanning applications.



4.6.3. Dual – Crystal Testing Technique:

Dual – Crystal technique is a crystal based one consisting of two independently operated elements in a single housing.

One of the two elements transmits while other receives the ultrasonic signal.



These transducers are used for special applications such as the inspection of coarse grained material due to their good sending and receiving capabilities.

These transducers are especially well suited for making measurements in applications when reflectors are very near the transducer since this design eliminates the ring down effect that single – element transducers experience.

Dual element transducer is very useful when making thickness measurements of thin materials and when inspecting for near surface defects. The two elements are angled towards each other to create a crossed – beam sound path in the test material.

4.6.4. Straight Beam Testing Technique:

This straight beam technique uses normal beam to inspect material so it is also known as normal beam technique.

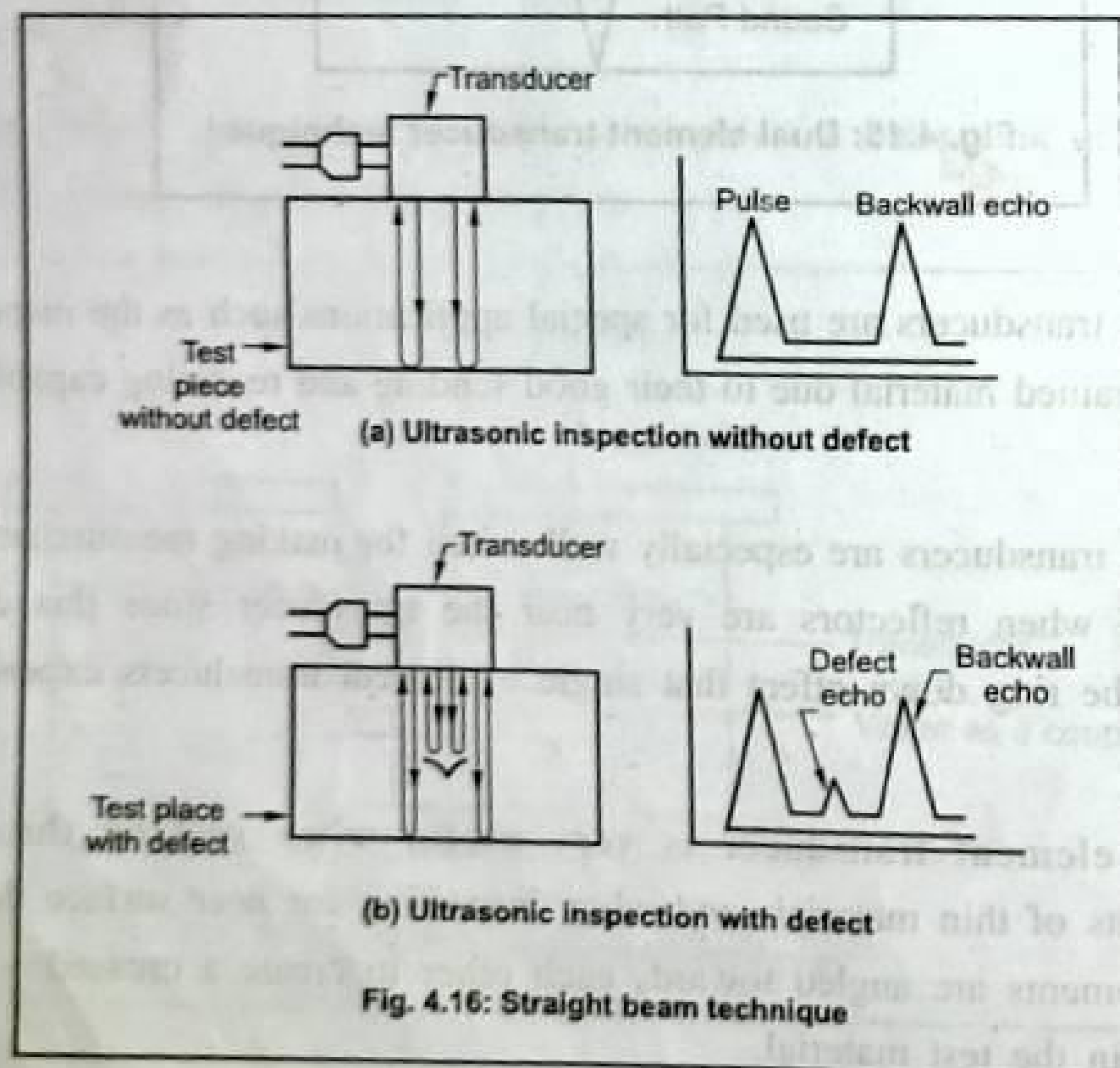
In this technique, mostly transducer is in direct contact with specimen.

In this technique determination of the location of a discontinuity in a part or structure is done by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through a thickness of material, reflect from the back or the surface of a discontinuity and be returned to the transducer.

This time interval is a few microseconds or less. The time measured is divided by two to account for the down – and – back travel path and multiplied by the velocity of sound in the test material. This relationship is expressed in the form of

$$d = V * t / 2$$

where d is the distance from the surface to the discontinuity in the test piece, V is the velocity of sound waves in the material, and t is the measured round-trip transmit time.



4.6.5. Angle Beam Testing Technique:

In this technique, the refracted beam is used to inspect angle beam transducers and wedges are used to introduce a refracted shear wave into the test material.

An angled sound path allows the sound beam to come in from the side thereby improving detectability of defects and flaws in and around test specimen.

If a reflection occurs before the sound waves reach the back wall, the reflection is usually referred to as "first leg reflection". The angular distance to the reflector can be calculated using the same formula used for normal beam transducer as:

$$\text{Sound path} = V_T * t / 2$$

where V_T is the shear sound velocity in the material.

By knowing the angle of refraction for the transducer, the surface distance to the reflector and also its depth can be calculated by:

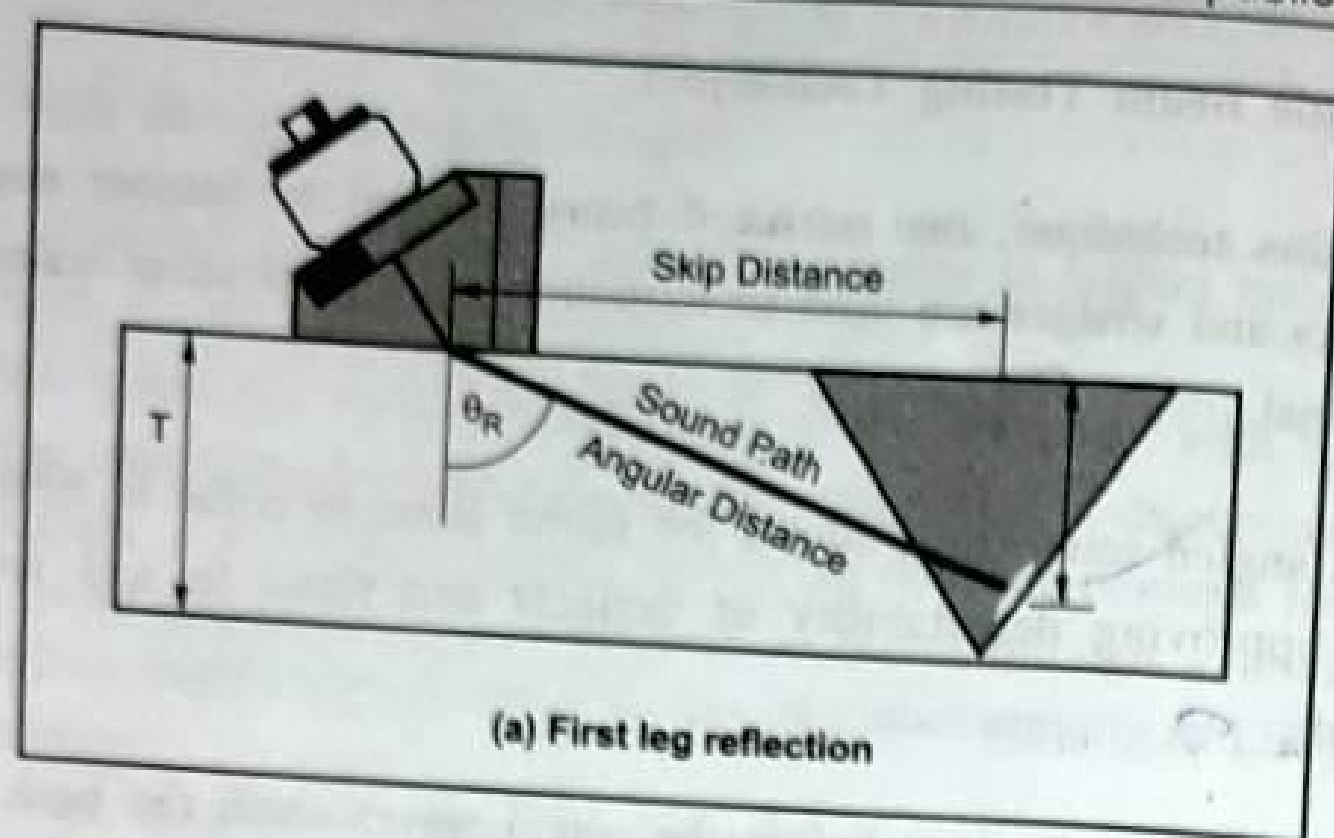
$$\text{Surface Distance} = \text{Sound path} \times \sin \theta_R$$

$$\text{Depth 1st leg} = \text{Sound path} \times \cos \theta_R$$

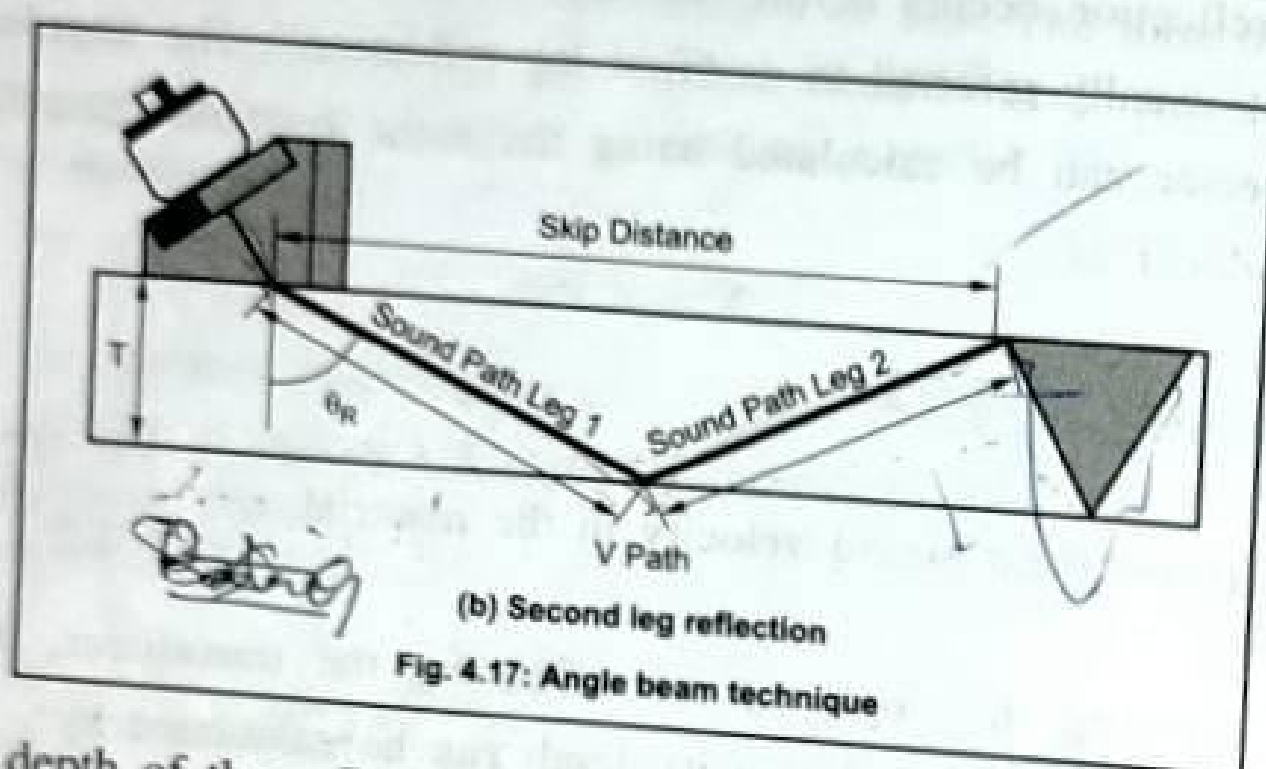
where, θ_R is the angle of reflection.

If a reflection comes across the sound beam after it has reached and reflected off the back wall, the reflection is usually referred to as "second leg reflection".

In this case, the sound path and the surface distance can be calculated using the same equations given for single leg reflection.



(a) First leg reflection



(b) Second leg reflection

Fig. 4.17: Angle beam technique

The depth of the reflector will be calculated as:

$$\text{Depth 2nd leg} = 2T - (\text{Sound Path} \times \cos \theta_R)$$

4.6.6. Resonance Testing Technique:

Resonance is a fast inspection technique and this inspection is different from other ultrasonic techniques. It is basically used to determine the thickness of test specimen

This technique involves in varying the frequency of ultrasonic waves to exit a maximum amplitude in a body (or) part of a body for the purpose of determining thickness and velocity (or) Resonance of laminar discontinuities is called resonance testing.

This technique is used by industries undergoing mass production.

Principle:

This technique is based on the fact that a good bell (or) wine glass will ring with good note, while a cracked bell (or) wire glass will ring with a cracked note (or) will clunk instead of ringing.

So by hitting a material and measuring its response, we can find the discontinuity and also the thickness of the material.

Construction and working:

For resonance inspection, we normally locate the components to be tested on three (or) four piezo transducers.

It is not necessary to scan the component with the transducers, nor to rotate a component as one test will evaluate the whole body (or) complete component.

One transducer acts as a transmitter while others act as receivers, measuring the amplitude of vibration at the specific frequency of the transmitter (or) at one of its harmonics.

These transducers have ceramic tips to prevent wear and to provide a good transfer of energy.

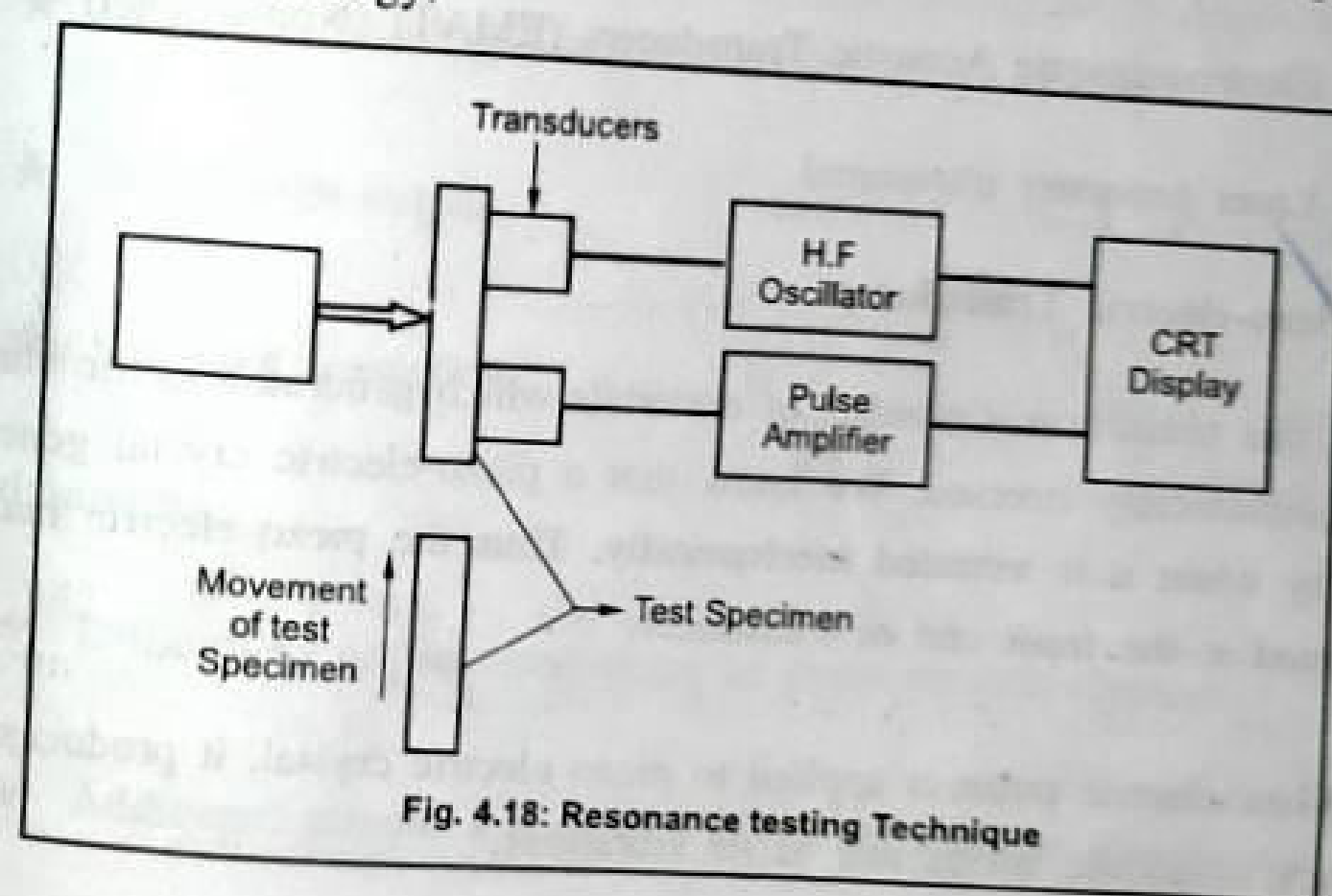


Fig. 4.18: Resonance testing Technique

CRT display shows the presence of defects by change in frequency response.

This method is more suitable for hard materials – not for soft materials.

4.7. ULTRASONIC TRANSDUCERS:

Ultrasonic transducers are used to transfer electrical energy to mechanical energy and vice-versa.

In ultrasonic testing, transducer is a major component to transfer and receive pulses,

It is also called as probes or search units or test heads.

There are wide classifications of transducers.

Some of the transducers are

1. Piezo electric transducers.
2. Polyvinylidene Fluoride transducers.
3. Electromagnetic Acoustic Transducers (EMAT) (Non-contact)
4. Laser generator ultrasound.

4.7.1. Piezo-electric Transducer:

In this transducer, it consists of materials which generate electric charges when mechanically stressed. We know that a piezo-electric crystal generates electricity when it is vibrated mechanically. Thus the piezo electric material is mounted at the front end of transducer.

When electric pulse is applied to piezo electric crystal, it produces high frequency ultrasonic waves due to its vibrations.

This ultrasonic waves are propagated through test material to inspect.

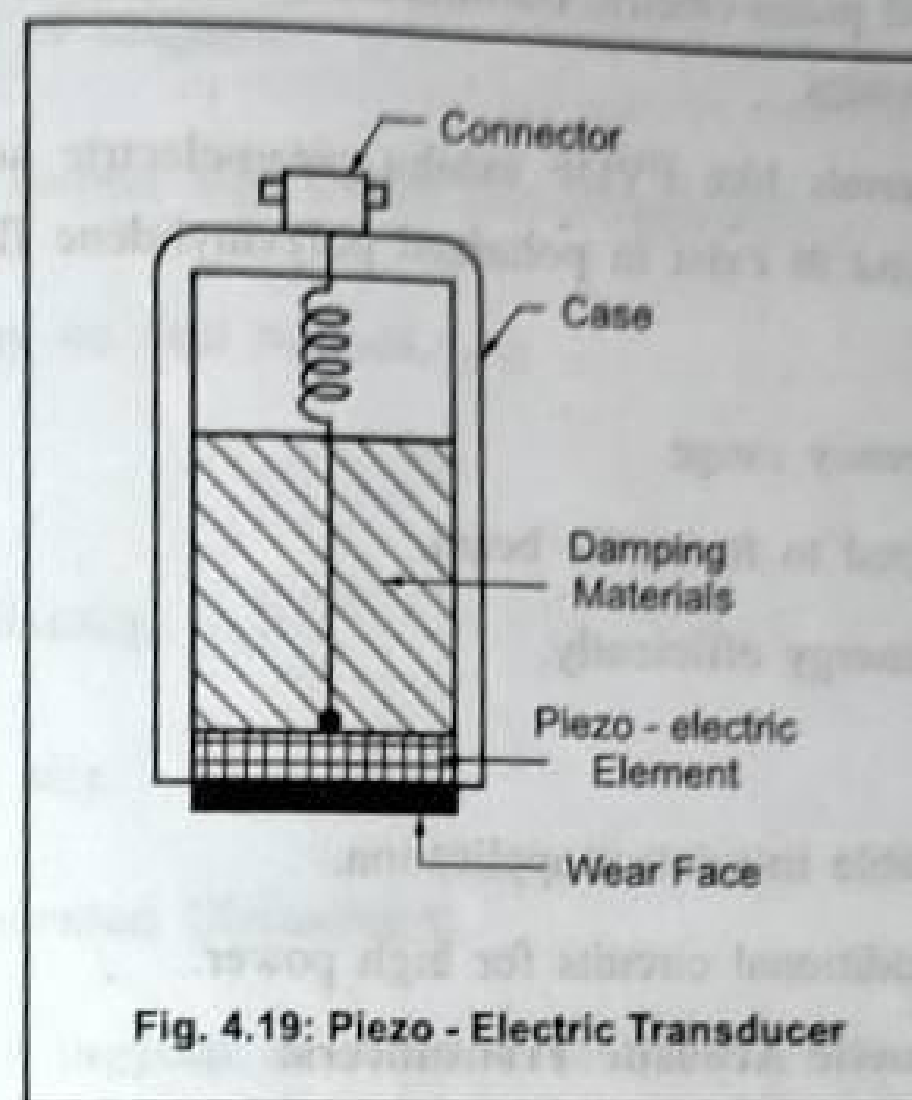


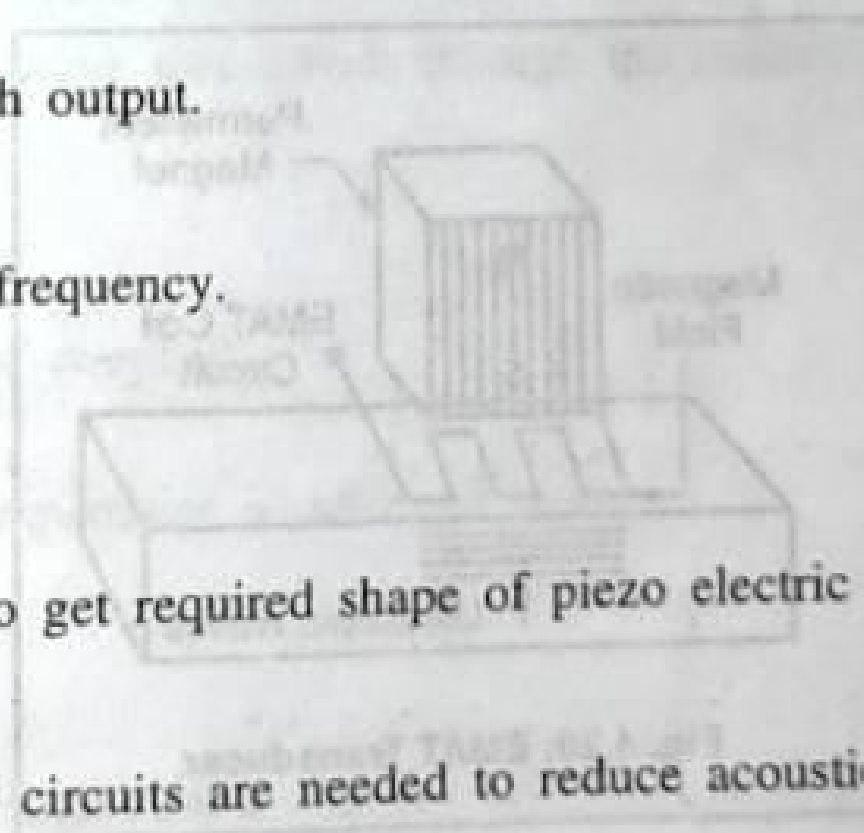
Fig. 4.19: Piezo - Electric Transducer

Advantages:

- ★ Compact.
- ★ Simple in construction.
- ★ Offers high output.
- ★ Has high frequency.

Disadvantages:

- ★ Difficult to get required shape of piezo electric element.
- ★ Additional circuits are needed to reduce acoustic impedance.



4.7.2. Polyvinylidene Fluoride Transducers:

Polymer based piezo-electric transducers are available in Non-destructive testing using ultrasonics.

Polymer materials like PVDF exhibit piezo-electric activity. Relatively high activity is found to exist in polarized polyvinylidene fluoride.

Advantages:

- ★ High frequency range.
- ★ Easily shaped to focus the beam.
- ★ Transfers energy efficiently.

Disadvantages:

- ★ Not applicable in contact application.
- ★ Requires additional circuits for high power.

4.7.3. Electro-Magnetic Acoustic Transducers:

Electro Magnetic Acoustic Transducer is abbreviated as EMAT. It is also a method of generating and receiving ultrasonic energy.

This transducer is made up of coils, which are placed close to test piece. So it is basically non-contact type.

It actually produces a magnetic field that interacts with metal, producing a deformation in the surface of the material which in turn produces ultrasonic energy.

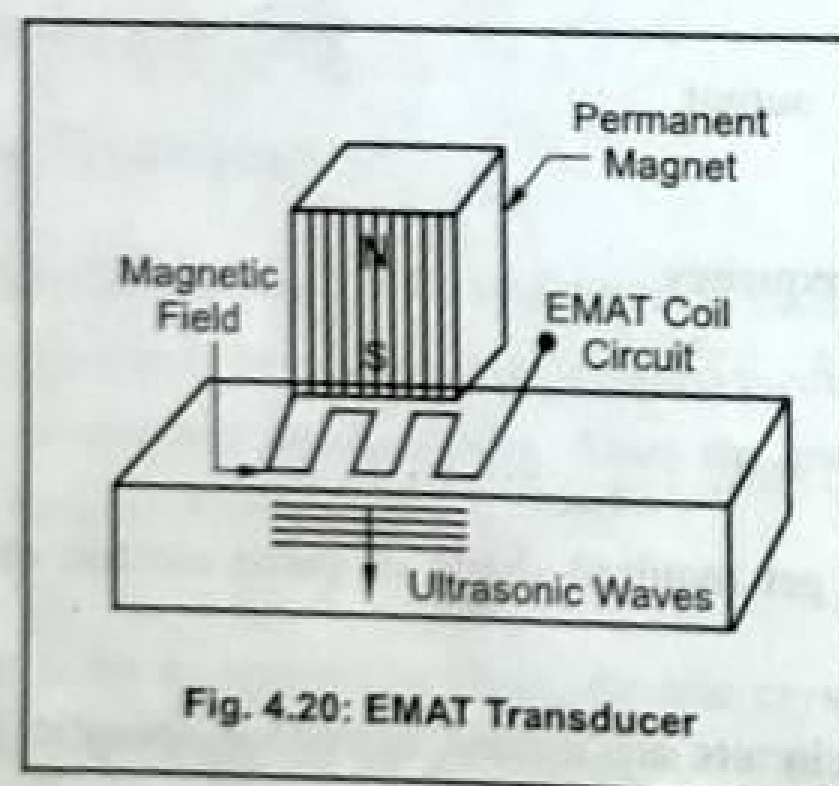


Fig. 4.20: EMAT Transducer

Advantages:

- ★ No need of couplant.
- ★ Used to inspect high temperature component.
- ★ Beam can be well focused.

Disadvantages:

- ★ Low efficiency.
- ★ Large in size.

4.7.4. Laser Generated Ultrasound:

As the name suggests, this method uses laser to produce waves also for inspection purpose.

There are two separate laser, one is to heat the surface and produce the wave and a second is to detect the defects from reflected wave.

Due to this surface heating, acoustic propagation is accomplished.

This heating causes thermal expansion on the surface, which results in the formation of a wave that travels through the material.

Advantages:

- ★ No need of couplant.
- ★ Acoustic impedance is achieved easily.

Disadvantage:

- ★ Relatively high cost.

4.8. INSTRUMENTS USED IN ULTRASONIC TESTING:

Basically ultrasonic equipment comprises of the following components:

- ★ Pulser/Receiver.
- ★ Ultrasonic Transducer.
- ★ Couplant.
- ★ Display (screen) and
- ★ Receiver/amplifier.

Fig. 4.21 shows the various basic components involved in ultrasonic equipment.

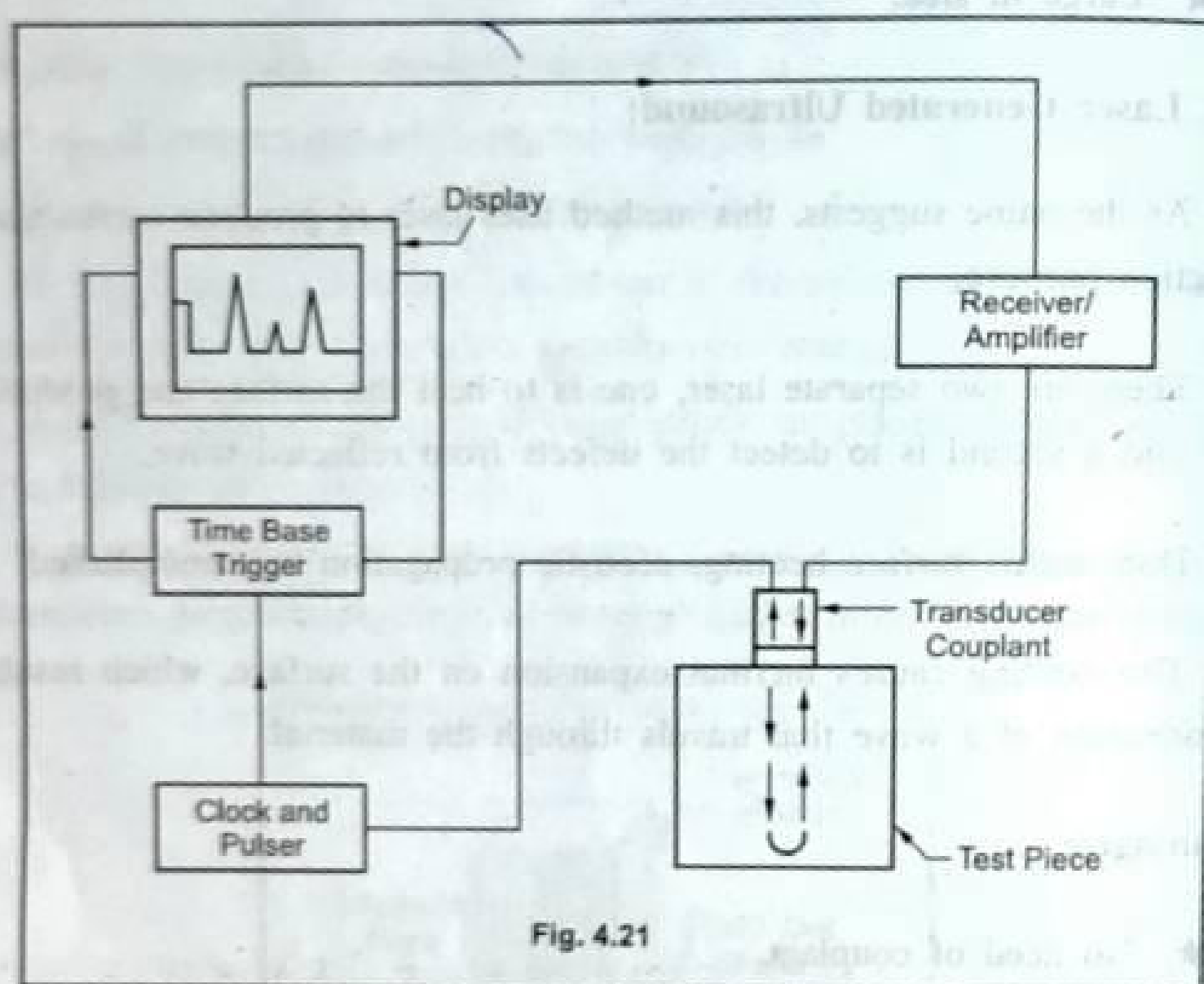


Fig. 4.21

Pulser/Receiver:

High voltage pulse required by ultrasonic transducer is generated by this circuit. Ultrasonic waves are produced by large amplitude electric pulses. A short burst of alternating electrical energy is called as pulse.

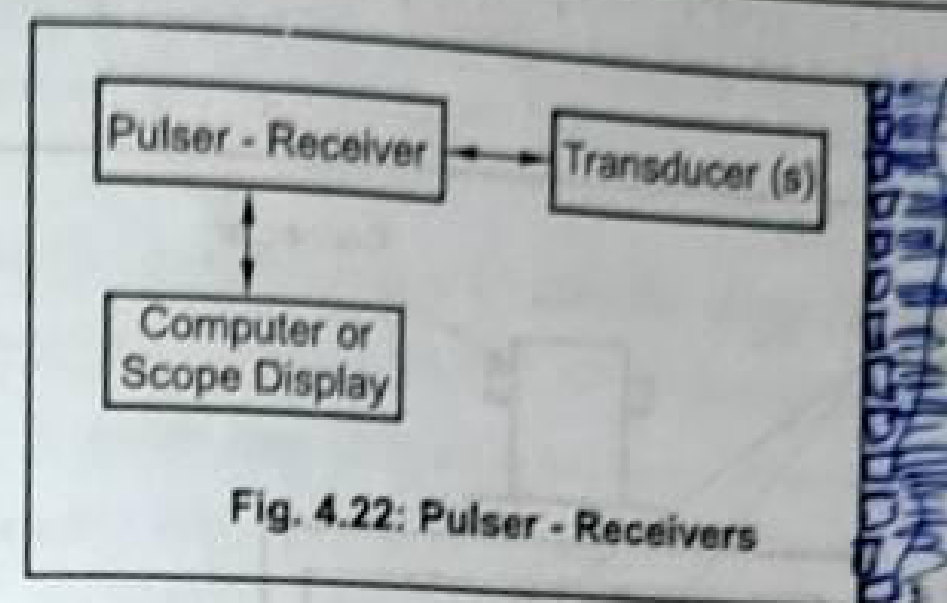


Fig. 4.22: Pulser - Receivers

Apart from generation of pulses, this circuit also acts as a receiver of signals coming from transducer.

Ultrasonic Transducer:

Transducer also called search unit in ultrasonic inspection is pulsed and sending out an ultrasonic wave. The subsequent echoes generate a voltage in the transducer, which is sent back to the pulser/receiver.

Couplant:

Couplant is used to reduce the air gap between the transducer and surface of the part to be inspected.

A very thin layer of air will severely retard the transmission of sound waves from the transducer to the material being inspected.

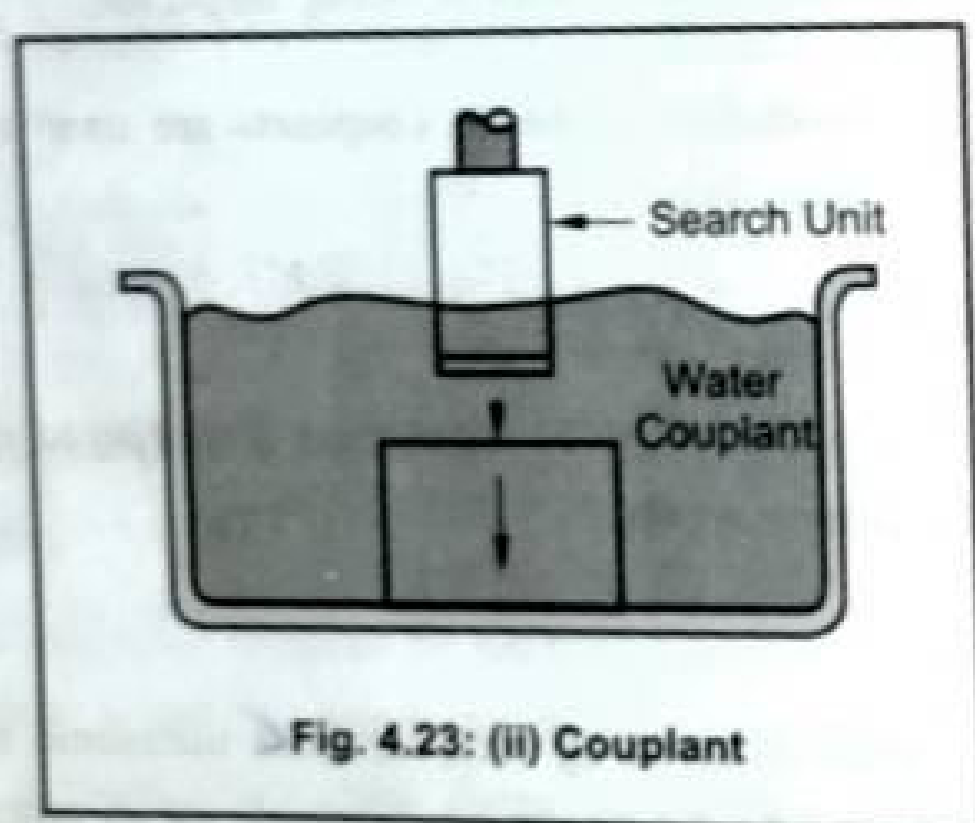
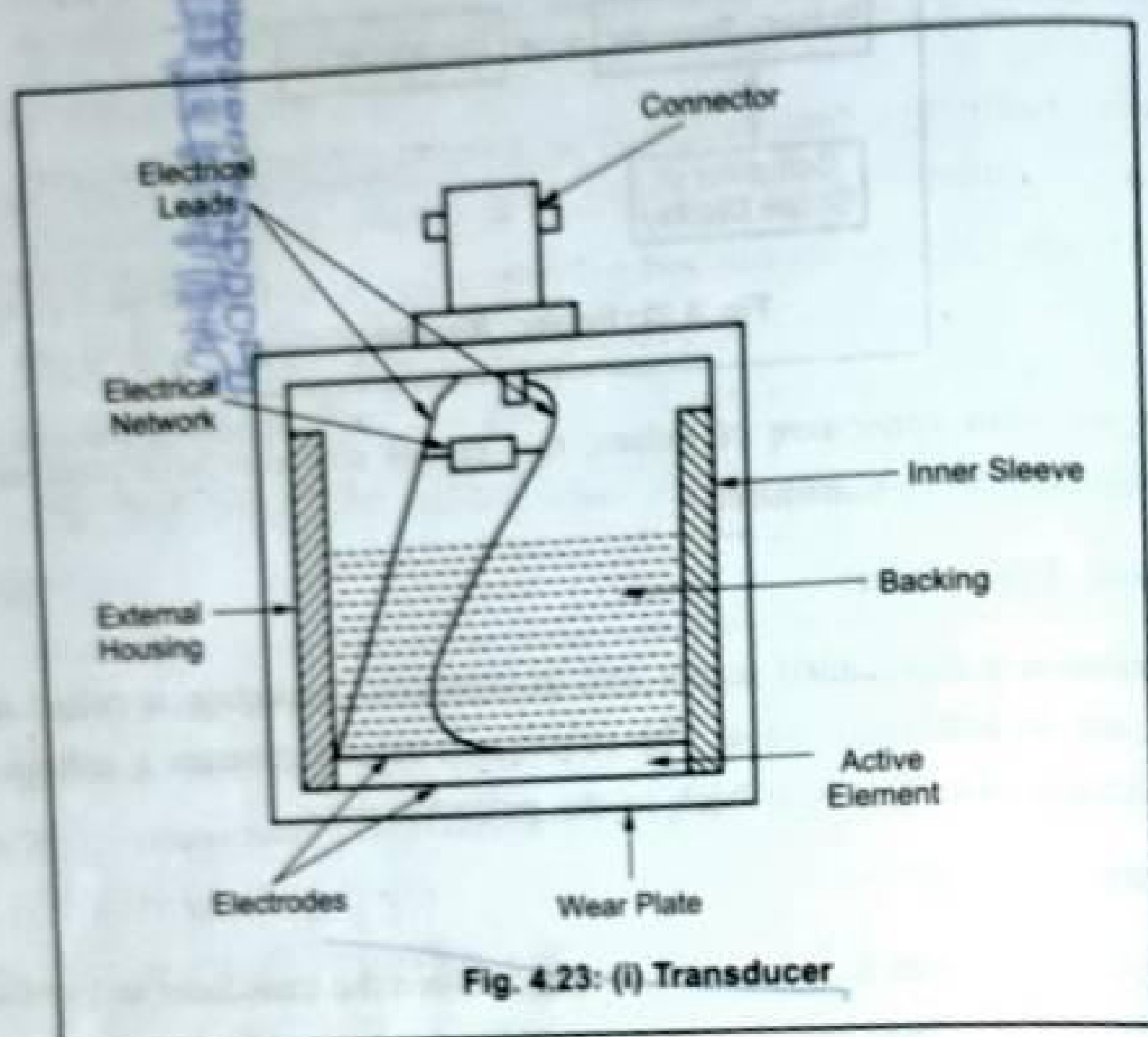
To avoid the transmission problem, couplants are used in both contact as well as immersion techniques.

Display/Oscilloscope:

It is a device on which received data/signal is displayed either in video mode or in radio frequency mode.

Receiver/Amplifier:

The voltage signals received by receiver from ultrasonic transducer are amplified and amplified radio frequency are available as an output display on oscilloscope.



49. REFERENCE BLOCK WITH ARTIFICIALLY CREATED DEFECTS:

For quantitative characterization of material properties and defects, it is important to calibrate the characteristics of an ultrasonic pulse echo instrument, which consists of a search unit and pulser/receiver. A widely adopted practice is the use of ultrasonic reference blocks specified by ASTM, IIW, AWS, etc. Blocks are made of such material as aluminium, steel, titanium, plastic, etc. Artificial defects such as flat bottom holes, side derived holes, notches, and step wedges are usually provided in blocks.

For the calibration of a pulse echo instrument, a search unit is positioned on a surface of a block so as to obtain on a display of the instrument a maximum of an echo reflected from an artificial defect. The sensitivity of the instrument is calibrated by adjusting the gain, so that the echo yields a desired amplitude. The sensitivity thus calibrated is an overall characteristic of the combination of the search unit and the pulser/receiver.

Reference blocks are heavy and bulky. Special care is required to prevent rust and wear. A good ultrasonic coupling between the search unit and the block, and a careful manipulation of the search unit are essential in order to obtain reproducible results. These requirements are not easily met, especially in on-line test instruments. Sometimes, it is desirable to check the performance of components of an instrument. The receiver including a display can be calibrated by purely electrical means, although such auxiliary test instruments as a signal generator and an attenuator are required. The calibration of a pulsar is not so easy, because most pulsers operate properly only when a search unit is connected.

4.10. CALIBRATION OF EQUIPMENTS:

Calibration should be done for the straight beam transducer and also for the angle beam transducer. Calibration is required for evaluating and adjusting the precision and accuracy of measurement equipment. In ultrasonic testing, several forms of calibration must occur. First, the electronics of the equipment must be calibrated to ensure that they are performing as designed.

In ultrasonic testing, there is also a need for reference standards to establish a general level of consistency in measurements, and to help interpret and quantify the received signal. Reference standards are used to validate that the equipment and the setup provide similar results from one day to the next and that similar results are produced by different system.

Reference standards also help the inspector to estimate the sizes of flaws. In a pulse-echo setup, signal strength depends on the both the sizes of flaws and the distance between the flaw and the transducer. The inspector can use a reference standard with an artificially induced flaw of known size at approximately the same distance away for the transducer to produce a signal. By comparing the signal from the reference standard to the received from the actual flaw, the inspector can estimate the flaw size.

Calibration and reference standards for ultrasonic testing come in many shapes and sizes. The type of standard used is dependent on the non destructive examination (NDE) application and the form and shape of the object evaluated. The material of the reference standard should be the same as the material to be inspected and the artificially induced flaw should closely resemble that of the actual flaw. The requirement is a major limitation of most standard reference samples.

4.11. MODES OF DISPLAY:

Communicating the flaw size and shape to others is a very crucial part of the NDT process. In ultrasonic testing, the ultrasonic signals are transferred into the CRT screen to obtain the image of the defects.

The presentation of the image of defects in the CRT screen are of different types

1. A-Scan, 2. B-Scan, 3. C-Scan.

A-Scan:

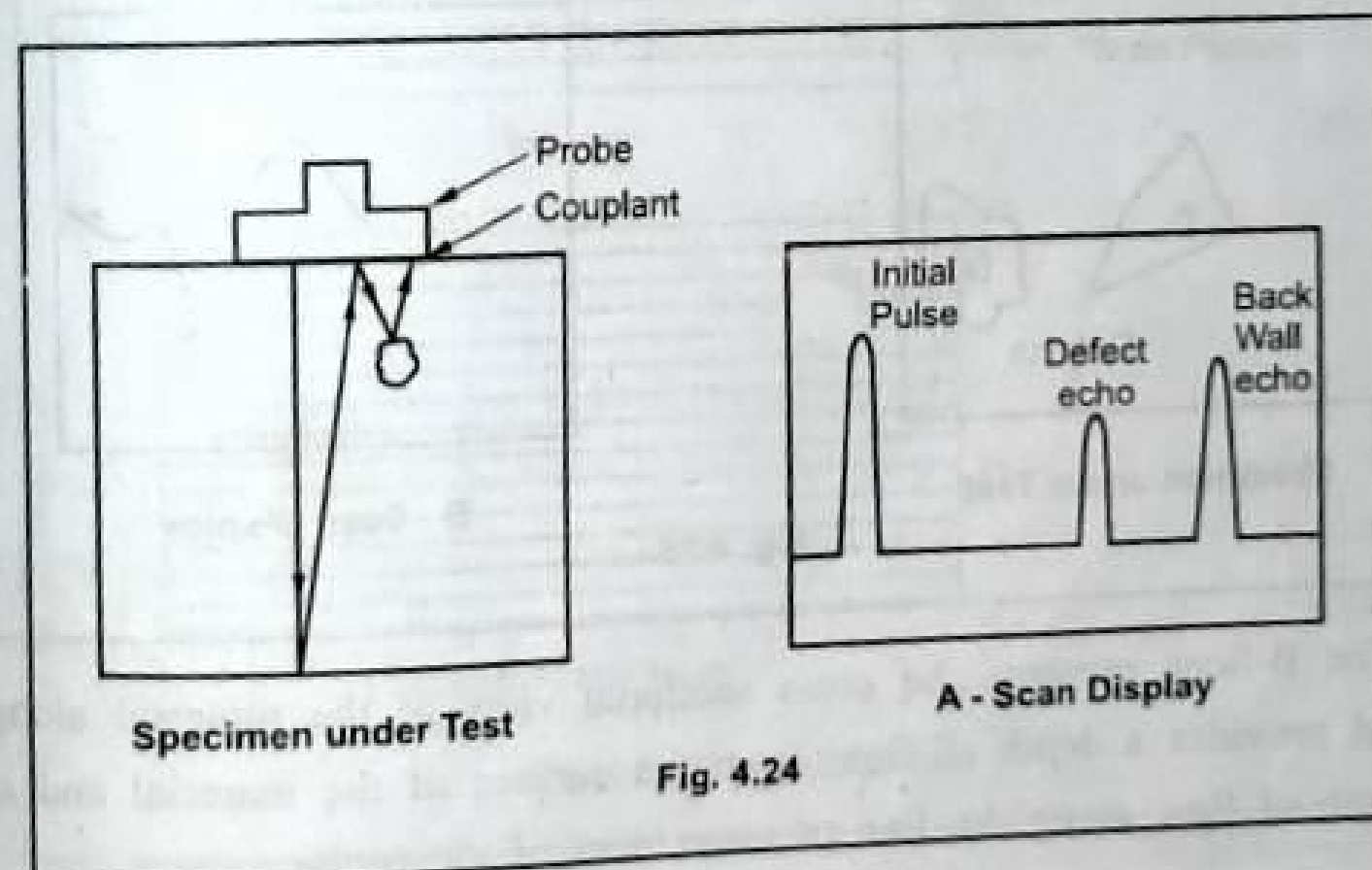
A scan is one of the simplest method of displaying the results of ultrasonic testing.

Here the time of flight of the pulse is represented in x-axis and the amplitude of the echoes are represented in y-axis.

The A-scan shows the size and the position of defect under the probe.

Generally, the probe is moved over the test specimen in a systematic manner. The probe sends pulses of ultrasonic energy into the material.

From this, a certain amount of ultrasonic energy is reflected at the top and bottom faces of the material. The echoes from the top and bottom faces give the initial and back wall peaks on the CRT.



Suppose if a defect is present under the probe in the material it is indicated as small echoes in CRT. This corresponds to a defect peak on the surface of CRT screens.

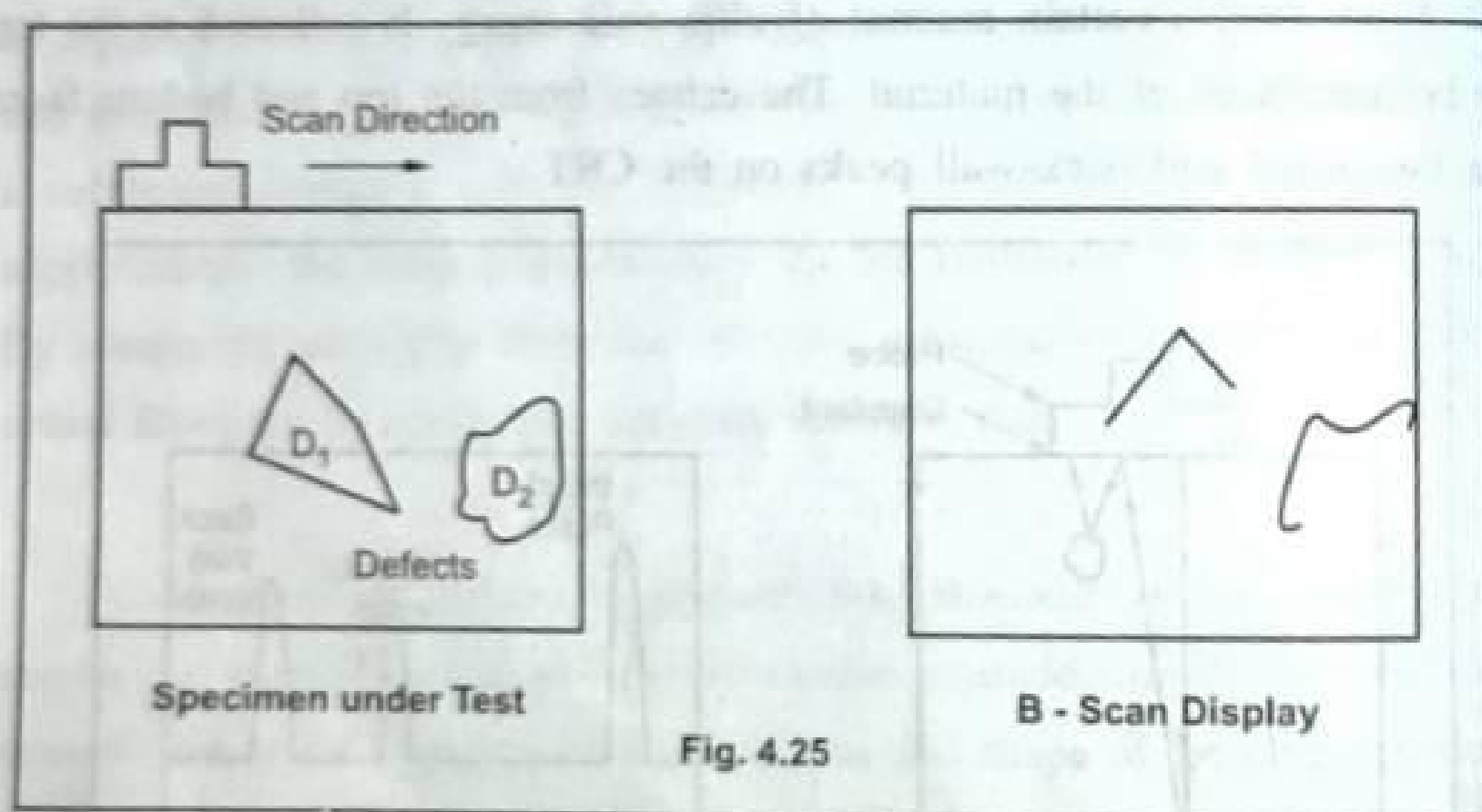
The size of the defect is proportional to the height of the defect peak and the depth of the defect from the top of the material is proportional to the position of the defect peak on the horizontal sweep of CRT.

B-Scan:

B-Scan presents a two dimensional image of a stationary specimen.

Here, the dimension of the specimen is displayed in the x-axis, while the travel of the ultrasonic pulse in the specimen is displayed in the y-axis.

In this scan, the ultrasonic probe is moved along a line on the top face of the material. This scan shows the reflection of ultrasonic pulse energy from the top and bottom faces of the testing material, also from the defects as the ultrasonic probe moves along a line of the surface of the material.



The B-Scan presents the cross sectional view of the material along a line and provides a depth of flaw from the surface of the material and also the length of flaw along the line of movement of the probe.

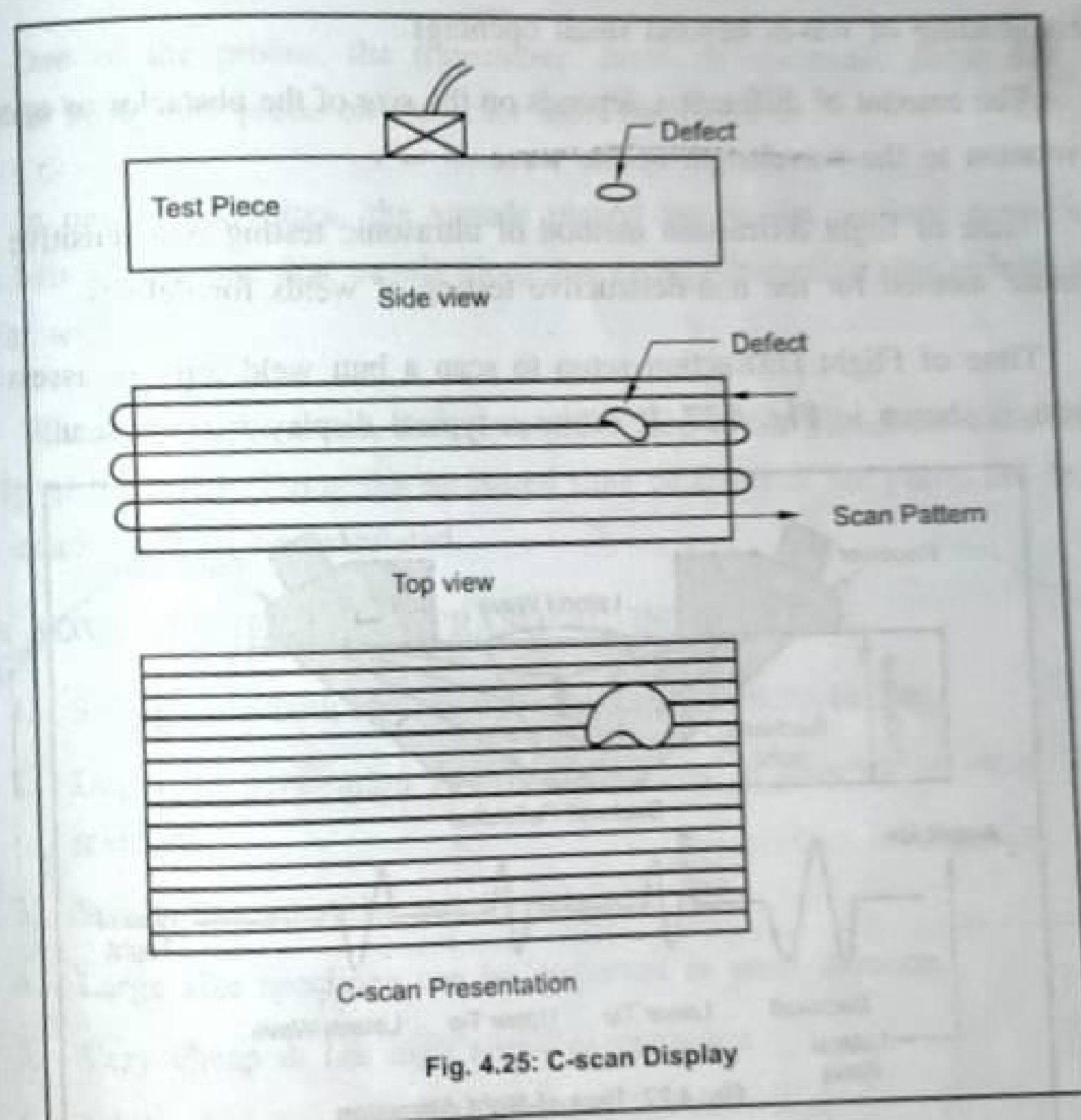
Here, echoes produced are displayed in the form of bright spots.

The position of spot can be indicated on screen by moving oscilloscope from one end to another end with B-scan presentation and it is possible to measure depth and dimension of the flaws.

The brightness of the echo is proportional to the echo-amplitude.

C-Scan:

C-Scan display is the best method to display the flaw depth. In order to determine the accurate depth of the flaw, the probe is moved on the test specimen.



The echo of the scan output produces a shaded line with varying intensity which indicates the absence of flaw. The echo of the scan output without any shading indicates the flaw shape.

In this scan, the ultrasonic probe is swept continuously line by line on the complete top face. This scan produces a plan view of the material and this is similar to radiograph.

C-scan has been particularly used in corrosion detection in pipes and pressure vessels and in the detection of delaminations in composite materials.

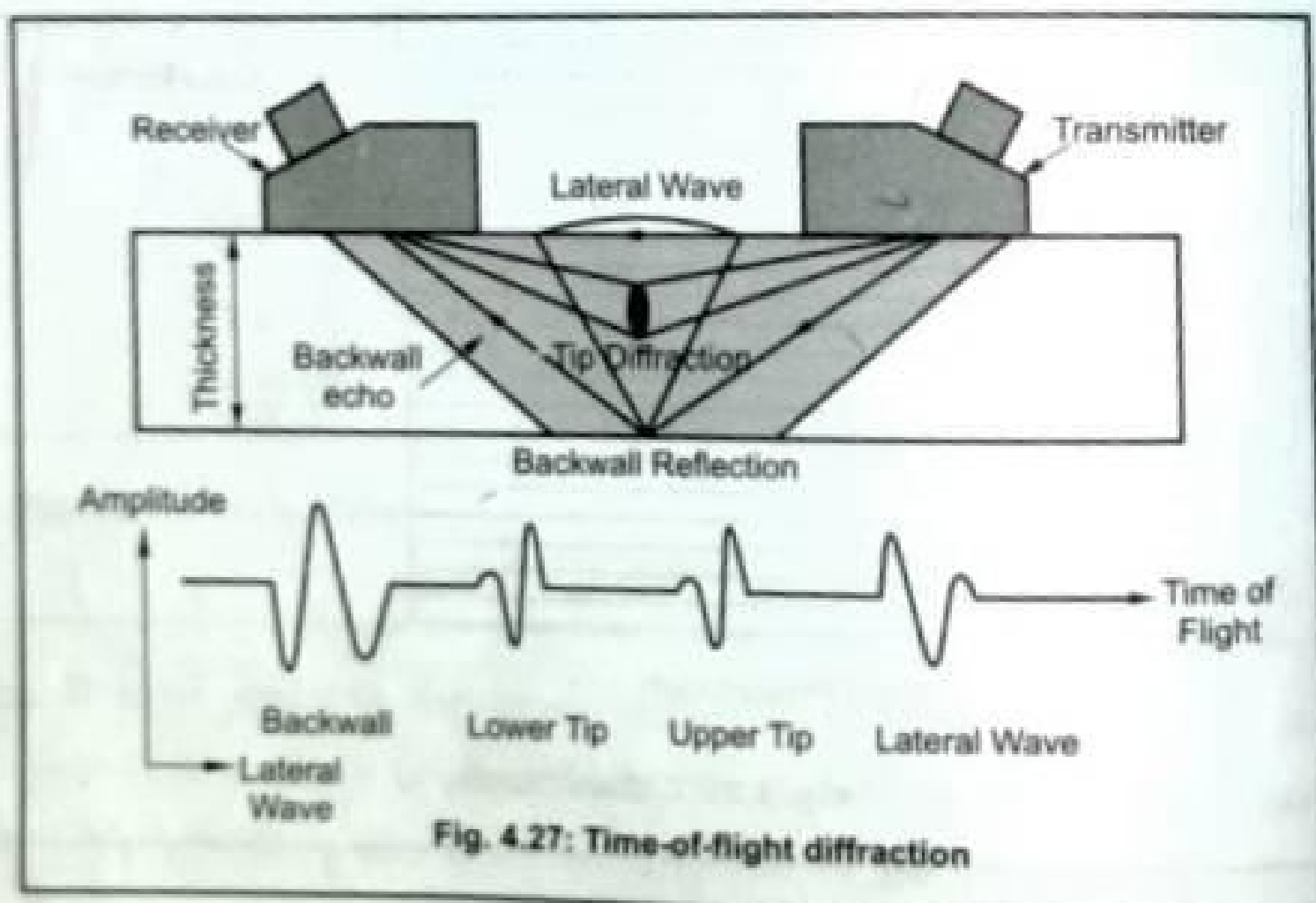
4.12. TIME OF FLIGHT DIFFRACTION (TOFD):

Diffraction is the blending of sound waves around small obstacles and the spreading of waves beyond small openings.

The amount of diffraction depends on the size of the obstacles or opening in relation to the wavelength of the wave.

Time of flight diffraction method of ultrasonic testing is a sensitive and accurate method for the non-destructive testing of welds for defects.

Time of Flight Diffraction setup to scan a butt weld joint to assess the defects is shown in Fig. 4.27. It shows a typical display from A-scan.



The probe pair is continuously moved along the weld seam. Depending on the equipment, the scan is performed either manually or by use of an automated manipulator.

Time of Flight Diffraction is performed using longitudinal waves as primary detection method. Two angle beam transducer (usually 45°) are placed as a transmitter - receiver arrangement and connected together. The distance of the transducer is calculated based on the wall thickness.

In time of flight diffraction technique, a pair of ultrasonic probes are placed on opposite sides of a weld.

One of the probes, the transmitter, emits an ultrasonic pulse that is received up by the probe on the other side, the receiver.

In undamaged pipes, the signals picked up by the receiver probe are from two waves: one that travels along the surface and other that reflects off the far wall.

When a crack is found, there is a diffraction of the ultrasonic wave from the tip of the crack. Using the measured time of flight of the pulse, the depth of a crack tips can be calculated.

4.13. ADVANTAGES OF ULTRASONIC INSPECTION:

1. Sensitive to both surface and sub-surface discontinuities.
2. Depth of penetration for flaw detection is superior to other NDT methods.
3. Small discontinuities can be detected.
4. Large size specimen can be inspected in short duration.
5. Very cheap & has high speed of operation.
6. Minimal part preparation is required.
7. Inspection can be done from one surface of the object.

8. Highly sensitive and has a greater accuracy than any other methods in determination of internal defects.
9. Non-hazardous operation.
10. Electronic Equipments provide instant results.

4.14. LIMITATIONS OF ULTRASONIC TESTING:

1. Surface must be accessible and smooth.
2. Complex geometries are difficult to inspect.
3. Reference standards are required for both equipment calibration and the characterization of flaws.
4. Not suitable for coarse grained surfaces
5. Linear defects oriented parallel to the sound beam may go undetected.
6. Requires a coupling medium to promote the transfer of sound energy into the test specimen.
7. Skilled operator is required.
8. Interpretation can be difficult.

4.15. APPLICATIONS OF ULTRASONIC TESTING:

Ultrasonic Testing (UT) is widely used for:

- (i) Testing ferrous and non-ferrous pipes, rods and bars.
- (ii) Detecting corrosion in various petroleum and gas supply lines.
- (iii) Erosion & corrosion thickness gauging.
- (iv) Testing welds in pressure vessels, pipes, structures, bridges, aircraft, marines etc.
- (v) Fatigue detection in welds and boilers.

- (vi) Assessment of bond integrity in adhesively joined and brazed components.
- (vii) Inspecting large castings, forgings, rails and rolled steel sections.
- (viii) Estimation of void content in composites and plastics.
- (ix) Detecting stages, blow holes, inclusions, porosity and grain size.
- (x) Inspecting the structural integrity of aircraft parts.

4.16. IMPORTANT STANDARDS RELATED TO ULTRASONIC TESTING:

1. IS 9664:1981 Code of practice for ultrasonic pulse echo testing by contact and immersion methods.
2. IS 4225:1979 Recommend practice for straight beam ultrasonic testing of steel plates.
3. IS 4904:1982 Calibration block for evaluation of ultrasonic flaw detection equipment.
4. IS 6394:1986 Code of practice for ultrasonic testing of seamless metallic tubular products by contact and immersion methods.
5. ASTM E1065-87a Guide lines for evaluating characteristics of ultrasonic search units.
6. ASTM E317-85 Practice for evaluating performance characteristics of ultrasonic pulse-echo testing system without the use of electronic measuring instruments.

7. ASTM E1001-84 Practice for detection and evaluation of the discontinuities by the immersed pulse-echo ultrasonic method using longitudinal waves.
8. ASTM E214-68 (1985) Practice for immersed ultrasonic examination by the reflection method using pulse longitudinal waves.
9. ASTM E578-82 (1988) Practice for ultrasonic angle beam examination by the contact method
10. ASTM E797-87 Practice for measuring thickness by manual ultrasonic pulse echo contact method.
11. ASTM E500-86b Terminology relating to ultrasonic examination.

4.17. ACOUSTIC EMISSION TESTING (AET):

Introduction:

- ★ Acoustic Emission Testing (AET) is a NDT method which is used to detect flaws in the mechanically loaded structure by releasing elastic waves through plastic deformation, crack initiation and fracture.
- ★ The specimen which is under study will be subjected to continuous or repetitive stress.
- ★ It is preferable than other NDT methods because of its ability to monitor continuously the materials, entire volume can be examined easily.

4.18. PRINCIPLE:

Acoustic Emission Testing (AET) is based on the principle that when a specimen (or) component is subjected to an external stimulus such as change in load (or) temperature, the release of energy in the form of stress waves are triggered.

These AE signals will propagate through the surface which is detected using the sensor. By analysing properly these signals, we can detect the location of these discontinuities and structural integrity.

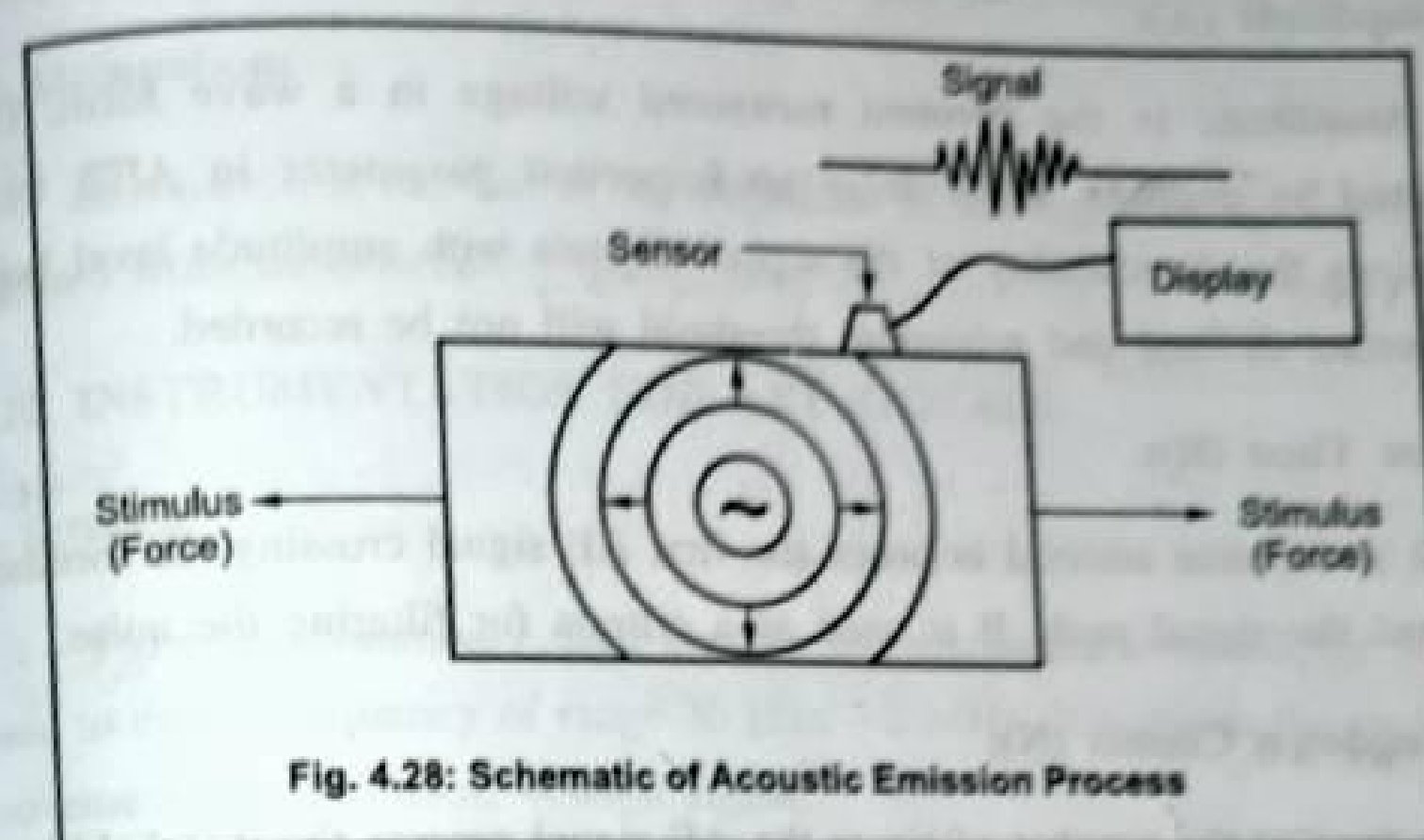


Fig. 4.28: Schematic of Acoustic Emission Process

Kaiser Effect:

Kaiser effect states that "when a material is loaded to a certain stress value and unloaded, there will not be any emission of AE signals when it is reloaded, until the stress value for the old load has been exceeded by the new load".

Irreversibility is an important feature of AET.

Types of AET:

(i) Continuous Emission:

It is characterised by low amplitude AE signal emission. It is applicable to metals and alloys where AE signals are produced due to plastic deformation, diffusion controlled phase transformation etc.

(ii) Burst Emission:

It is characterised by high amplitude AE signal emission which occurs for short duration (10 μ s to few milliseconds). Here AE signals are produced due to diffusionless phase transformations, crack initiation and propagation, etc.

4.19. ACOUSTIC EMISSION PARAMETERS:

Various AE parameters are used for interpreting the experimental results.

(i) Amplitude (A):

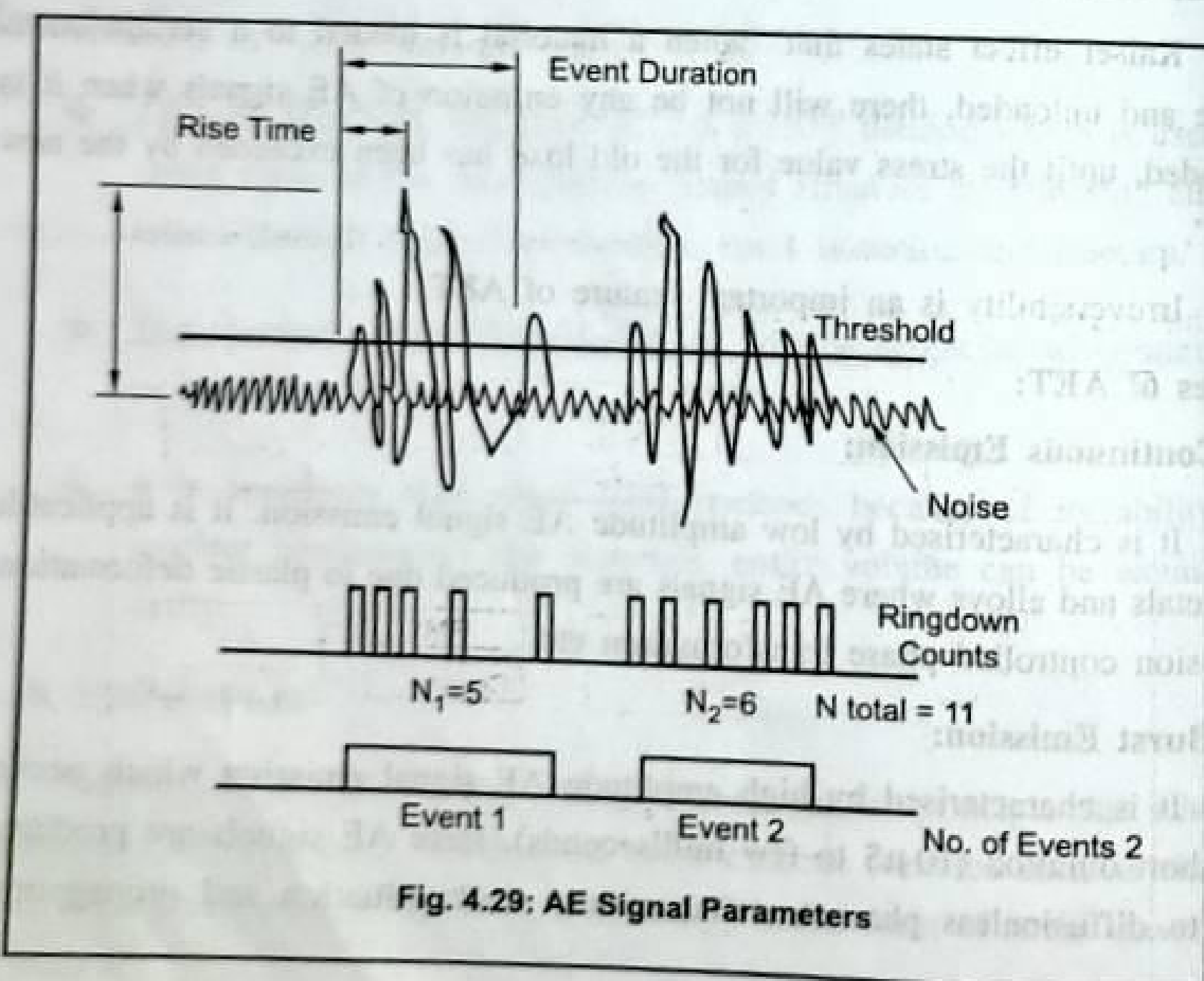
Amplitude is the greatest measured voltage in a wave form. It is measured in decibels (dB). It is an important parameter in AET which determines the detectability of the signal. Signals with amplitude level below the operator-defined and minimum threshold will not be recorded.

(ii) Rise Time (R):

It is the time interval between the first AE signal crossing the threshold level and the signal peak. It is used as a criteria for filtering the noise.

(iii) Ringdown Counts (N):

It denotes the number of times the AE signal crosses the threshold level to eliminate the noise.



(iv) Event Duration (D):

It is the time difference between the first and last threshold crossings. It depends upon the magnitude of the signal and the acoustics of the material.

(v) Attenuation:

Attenuation is the loss of the amplitude of the signal as the wave travels outward from the source.

4.20. INSTRUMENTATION FOR AET SIGNALS:

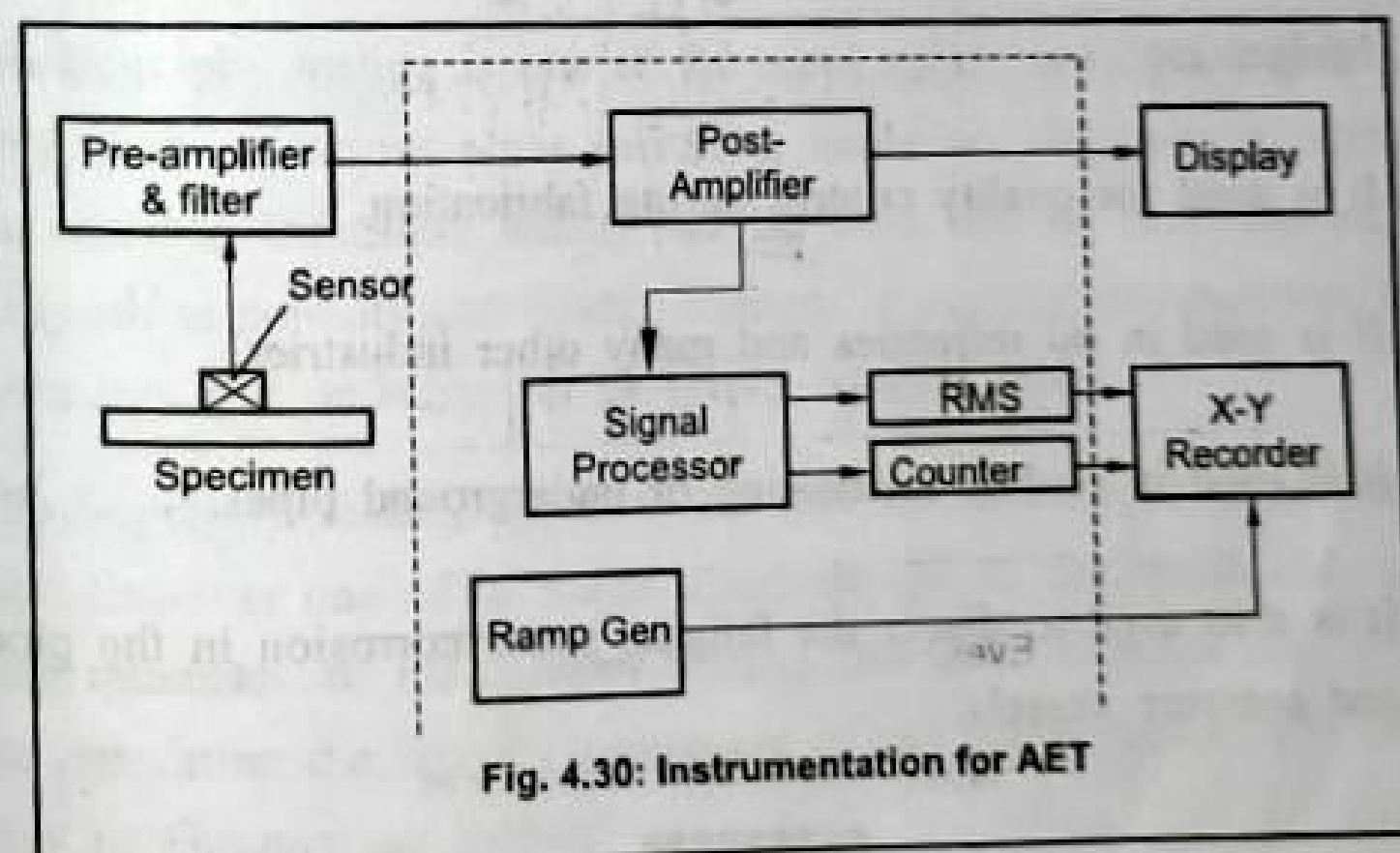
1. Sensors:

The most commonly used sensors are piezoelectric transducer which is used to detect frequency of range 30 kHz – 2 MHz. It converts the mechanical movement into electrical voltage signal.

2. Pre-amplification and filtering:

Signal from the sensor goes to the pre-amplifier. It has the characteristics like low noise, high power gain and input impedance which should match with the transducer.

Each filter is designed for a particular bandwidth and it allows signal of that particular bandwidth only.



3. Post-amplification and threshold:

As the signal coming from the pre-amplifier is of low amplitude, it should be amplified using the post-amplifier. Certain threshold level is maintained which eliminates the background noise.

4. Data acquisition unit:

In data acquisition unit, for off-line analysis, video recorders and analog magnetic recorders are used. For on-line analysis, transient recorders with computer interface are used.

5. Processing and analysis:

It is used to convert the analog data into digital one. It depends on the types and quantity of raw data.

6. Display devices:

It is used to display and record the analysed data. X-Y monitor is the most commonly used recording device.

4.21. APPLICATIONS:

- ★ It is used to detect and locate the leakage.
- ★ It is used for weld monitoring, detecting flaws in gas trailer tubes, bridges etc.
- ★ It is used for quality control during fabrication.
- ★ It is used in oil refineries and many other industries.
- ★ It is used in on-line monitoring of underground pipes.
- ★ It is also used to detect the fatigue, stress corrosion in the pipelines and pressure vessels.

MODULE – 5

RADIOGRAPHY TESTING

Principle – Electromagnetic radiation sources – X-ray source – production of X-rays – High energy – X-ray source – Gamma ray source – Properties of X-rays and gamma rays – Inspection techniques like SWSI, DWSI, DWDI – Panoramic exposure – Real time radiography – Films used in industrial radiography – Types of film – Speed of films – Qualities of film – Screens used in radiography – Quality of a good radiograph – Film processing – Interpretation – Evaluation of test results – Safety aspects required in radiography – Applications – Advantages and limitations of RT.

5.1. INTRODUCTION:

Radiography testing is one of the most widely used NDT techniques. It is highly used in various areas including medicine, engineering, security etc. It is a versatile technique which can be used for the detection of internal defects (such as porosity and voids), changes in material composition, thickness measurements and unwanted or defective components.

Radiography testing offers a number of advantages over other NDT methods, however one of its major disadvantages is the health risk associated with the radiation. In radiography testing, X-ray or Gamma ray is generally used to determine the internal soundness of the metal, hence it is also called as X-ray or Gamma ray testing

5.2. PRINCIPLE:

Before discussing the principles involved in radiography, it is necessary to establish the principles of electromagnetic radiations of shorter wavelength i.e., X-ray and Gamma ray.

X-rays are electromagnetic radiations which can be generated in an X-ray tube when a beam of electrons is accelerated into a target by a high voltage and stopped suddenly on striking a target. The X-rays produced have different wavelengths and different penetrating powers according to the accelerating voltage. Gamma rays in turn, have the same physical nature as X-rays and are emitted by certain radioactive substances.

In radiography testing, the part to be inspected is placed between the source of penetrating radiation (X-ray or Gamma ray) and a detector of radiation (sensitive film).

On passing through the material, some of the radiations gets absorbed in the material itself and the amount of absorption is a function of the density and thickness of the material. Therefore, the beam of radiation will have less material to pass through than in the solid material, if there is a cavity or discontinuity in the interior of the material. Also there will be a variation in

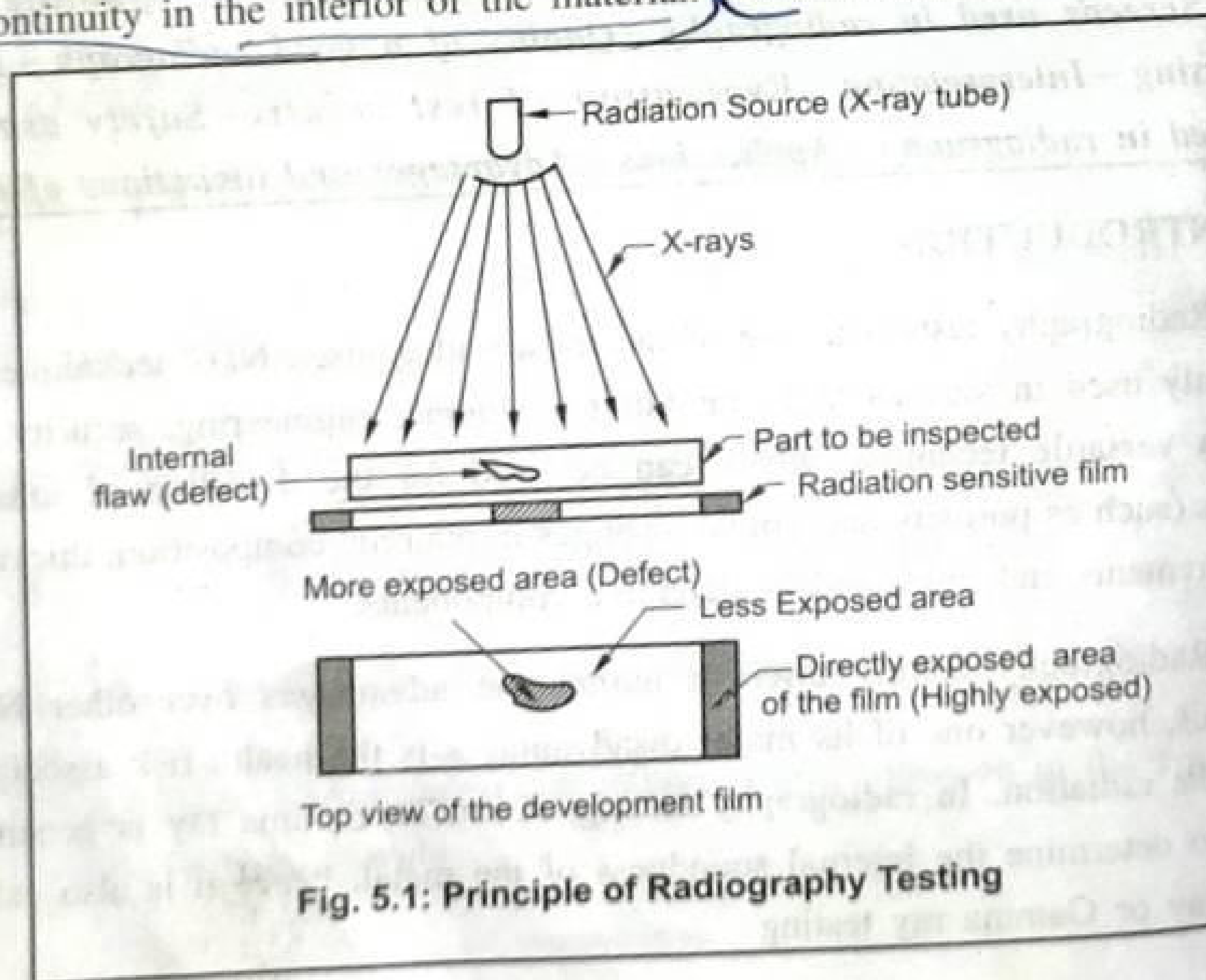


Fig. 5.1: Principle of Radiography Testing

the absorption of the rays, by the material in the defective area. These variations are recorded in the form of image on a film, that will indicate the presence of a defect. The image obtained on the film is nothing but the X-ray shadow of the interior of the material. Thus radiography is essentially based on the principle of shadow projection and such a shadow picture is called radiograph.

5.3. ELECTROMAGNETIC RADIATION SOURCES:

5.3.1. X-Ray Source:

The source of radiation of X-ray, is an X-ray tube. An X-ray tube is an energy converter. It receives electrical energy and converts into two terms i.e., X-radiation and heat. The heat is generally considered as an undesirable by-product. Therefore, X-ray tubes are designed and constructed to maximize X-ray production & to dissipate heat as rapidly as possible.

X-ray tube consists of a glass bulb under vacuum enclosing a positive electrode or 'anode' and a negative electrode or 'cathode'. The cathode provides a source of electrons and anode acts as the target to electrons and releases X-rays.

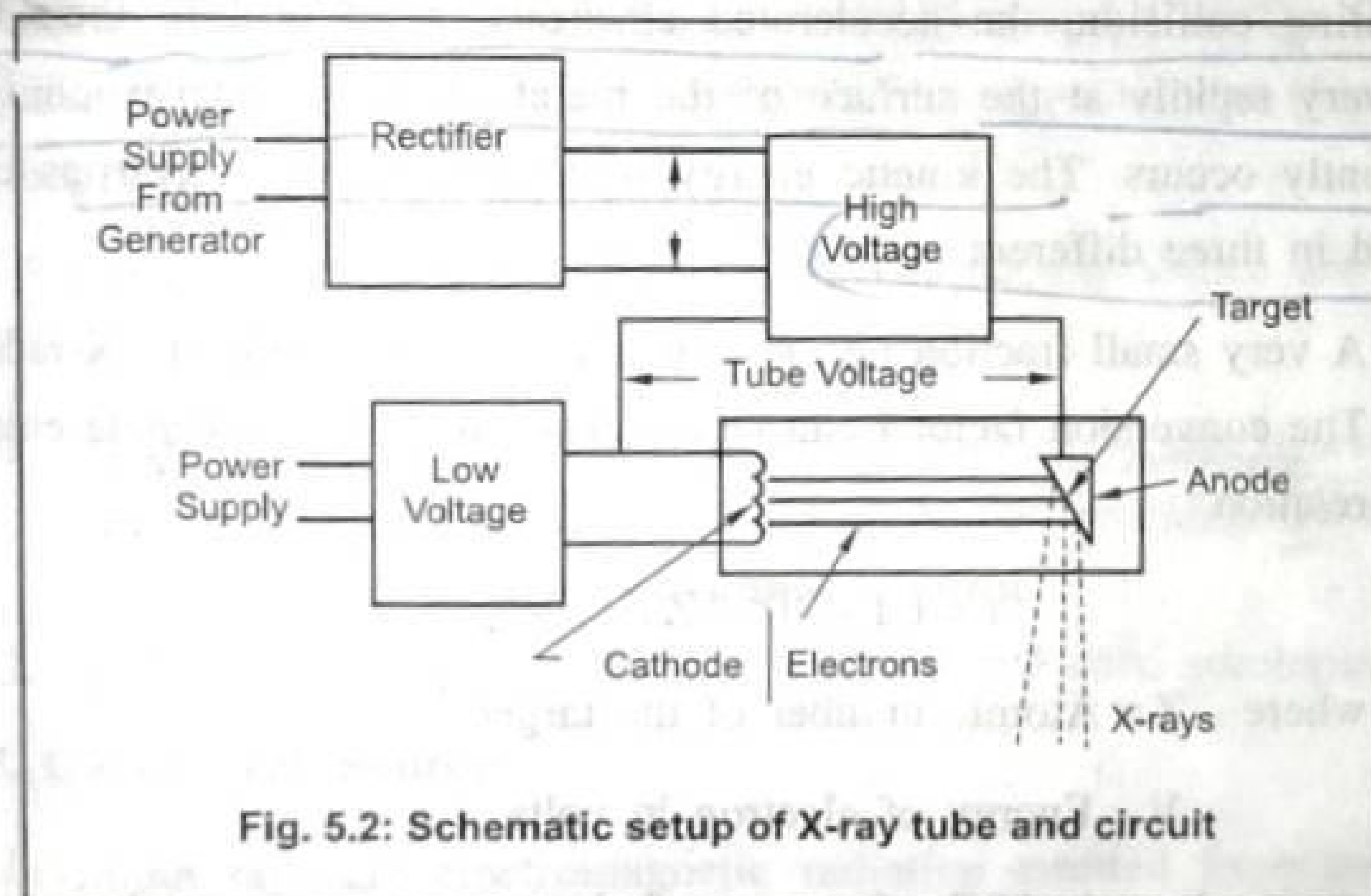


Fig. 5.2: Schematic setup of X-ray tube and circuit

Note: X-ray tube is most often created from glass, although some tubes contain envelopes made of ceramic (or) metal.

The energy required for this process is provided from the generator, which is connected to an electrical circuit system. A rectifier is also provided in the electrical system, to convert the electrical energy from the generator into the direct current (DC), which is being the adequate form to be applied to the X-ray tube.

The quality and the quantity of the X-ray generation are usually controlled by adjusting the electrical parameters (such as the voltage applied to the tube or current flows through the tube) and exposure time (usually a fraction of a second).

5.3.1.1. Production of X-rays:

The production of X-rays was first performed by Roentgen in 1895, using a device that accelerated electrons between an anode and a cathode. Even today, the basic principles of X-rays production are the same, although some refinements have been made, to improve its characteristics.

Normally X-rays, are produced when fast moving electrons are suddenly brought to rest by colliding with matter.

During collision, the accelerated electrons therefore lose their kinetic energy very rapidly at the surface of the metal plate and energy conversion consequently occurs. The kinetic energy of the accelerated electrons can be converted in three different ways.)

- (i) A very small fraction i.e., less than 1% is converted into X-radiation. The conversion factor f can be estimated by an approximate empirical relation

$$f = 1.1 \times 10^{-9} ZV$$

where Z = Atomic number of the target

V = Energy of electron in volts

- (ii) Approximately 99% of energy of electrons is converted into heat by increasing the thermal vibrations of the atoms of the target, the temperature of which may consequently rise considerably.

- (iii) Some of the electrons have sufficient energy to eject orbital electrons from the atoms of the target material which are ionised. The secondary electrons produced in this way, may escape from the surface of the target and subsequently be recaptured by it producing further heat or secondary radiation.

Finally, the most important distinguishing characteristics of an X-ray beam are its intensity and quality, where the term 'intensity' refers to how much radiation i.e., quantity of radiation and the term quality refers to the kind of radiation i.e., how penetrating the radiation is.

5.3.2. High energy X-ray Source:

High-energy X-rays or HEX rays are very hard X-rays whose energy value is 1 MeV or more, which is about one order of magnitude higher than conventional X-rays. This high energy X-rays are generally used when examining thicker sections Also, by using high energy X-rays, the possibilities of large distance to thickness ratios with correspondingly low geometrical distortion, short production times and high production rate can be achieved.

High energy X-rays are produced by a number of machines such as synchrotron, betatron, electron linear acceleration and Van De Graff type electrostatic generators out of which, electron linear accelerator (Linac) is the most popular.

Some of the benefits of using high energy X-ray source are described as follows.

1. High energy X-ray source has small focal spot size which reduces the amount of high angle scattered X-rays reaching the film, thus resulting in radiographs with good contrast.
2. It has excellent penetrameter sensitivity and good resolution.

5.3.3. Gamma ray Source:

Gamma rays are electromagnetic radiation emitted from an unstable nucleus. It was first observed by a French chemist Paul Villard in early 1900s and the name 'Gamma rays' was proposed by physicist Ernest Rutherford, after the discovery of alpha & beta rays.

5.6

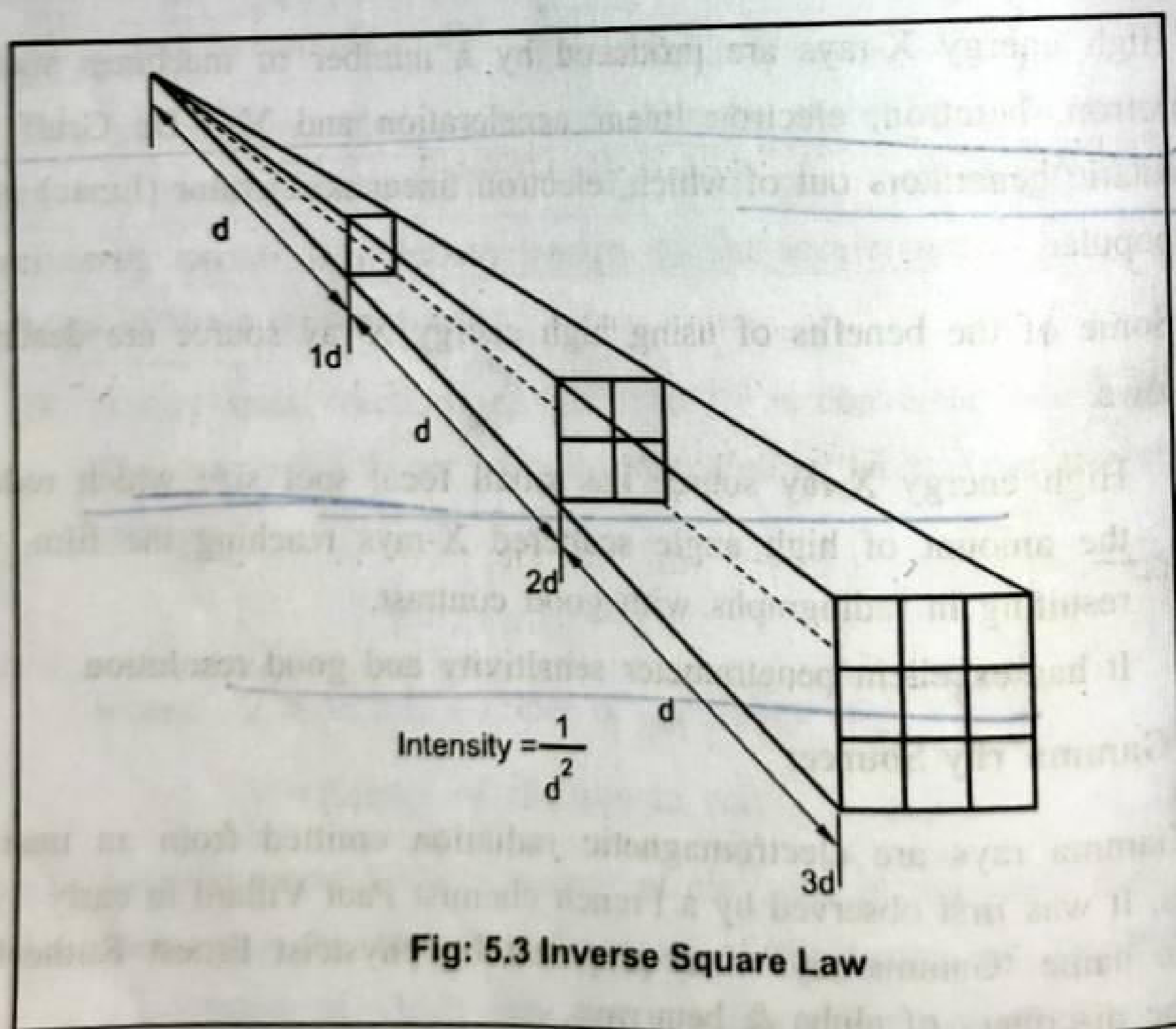
Gamma rays can be produced by four different nuclear reactions namely fusion, fission, alpha decay and gamma decay. During these reactions, a variety of radioisotopes are produced in a nucleus reactor. Each radioisotope with unstable nucleus will have characteristic nuclear energy levels and intensities for the emitted radiation. However, the gamma ray energy levels remain constant for some of the isotope but its intensity decays with time as indicated by the half life.

Some of the benefits of gamma ray source are given as follows:

In contra-distinction to X-ray machines, (which emit a broad band of wavelengths) gamma ray sources emit one or few discrete wavelength. This compactness of radiation source makes the gamma rays suitable for the examination of pipe, pressure vessels and assemblies in which the access to interior is difficult.

5.3.4. Inverse Square Law:

The radiation spreads out as it travels away from the gamma or X-ray source. Therefore, the intensity of the radiation follows Newton's Inverse Square Law. As shown in the Figure 5.3, this law accounts for the fact that



the intensity of radiation becomes weaker as it spreads out from the source since the same amount of radiation spreads over a larger area. The intensity is inversely proportional to the square of the distance from the source.

In industrial radiography, the intensity at one distance is typically known and it is necessary to calculate the intensity at a second distance. Therefore, the equation takes on the form of:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

where,

I_1 = Intensity 1 at D_1

I_2 = Intensity 2 at D_2

D_1 = Distance 1 from source

D_2 = Distance 2 from source.

5.4. PROPERTIES OF X-RAY AND GAMMA RAY:

X-rays and Gamma rays are part of the electromagnetic spectrum. Similar to light waves, X-rays and Gamma rays are electromagnetic radiations except that their wavelength is much shorter. Some of the properties of X-rays and Gamma rays are described as follows:

- ★ They are invisible and travels at the speed of the light.
- ★ They propagate in a straight line and pass through space without transference of matter.
- ★ They are not affected by electric and magnetic fields.
- ★ They are capable of ionizing gases and also changes the electrical properties of solids and liquids.

- ★ They are capable of blackening photographic film.
- ★ They can damage and kill living cells & produce genetic mutation.
- ★ They exhibit wave properties and are reflected, refracted, diffracted & polarized.

Note: Despite of its wave properties, X-ray and Gamma rays cannot be deflected by means of lens or prism. Although their path can be diffracted (bent) by a crystalline grid.

5.5. INSPECTION TECHNIQUES IN RADIOGRAPHY:

Radiographic inspection techniques are employed for inspecting various engineering structures including tubular and plate construction pressure vessels pipelines and boilers etc.

5.5.1. Single Wall Single Image (SWSI) Technique:

This technique is applicable in case when the material to be inspected is in the form of cylinders, e.g: pipes, shells etc. there are two ways to do the inspection. They are

1. To keep the radiographic source outside and the film inside – flat technique.
2. To keep the radiographic source inside and the film outside – panoramic technique.

SWSI Flat Technique:

In Single Wall Single Image Flat technique, the radioactive source is kept outside the pipe and the film is kept inside the pipe. In this technique, the density of the film reduces from centre to outside due to the increase in thickness of the weld penetrated from centre to outside.

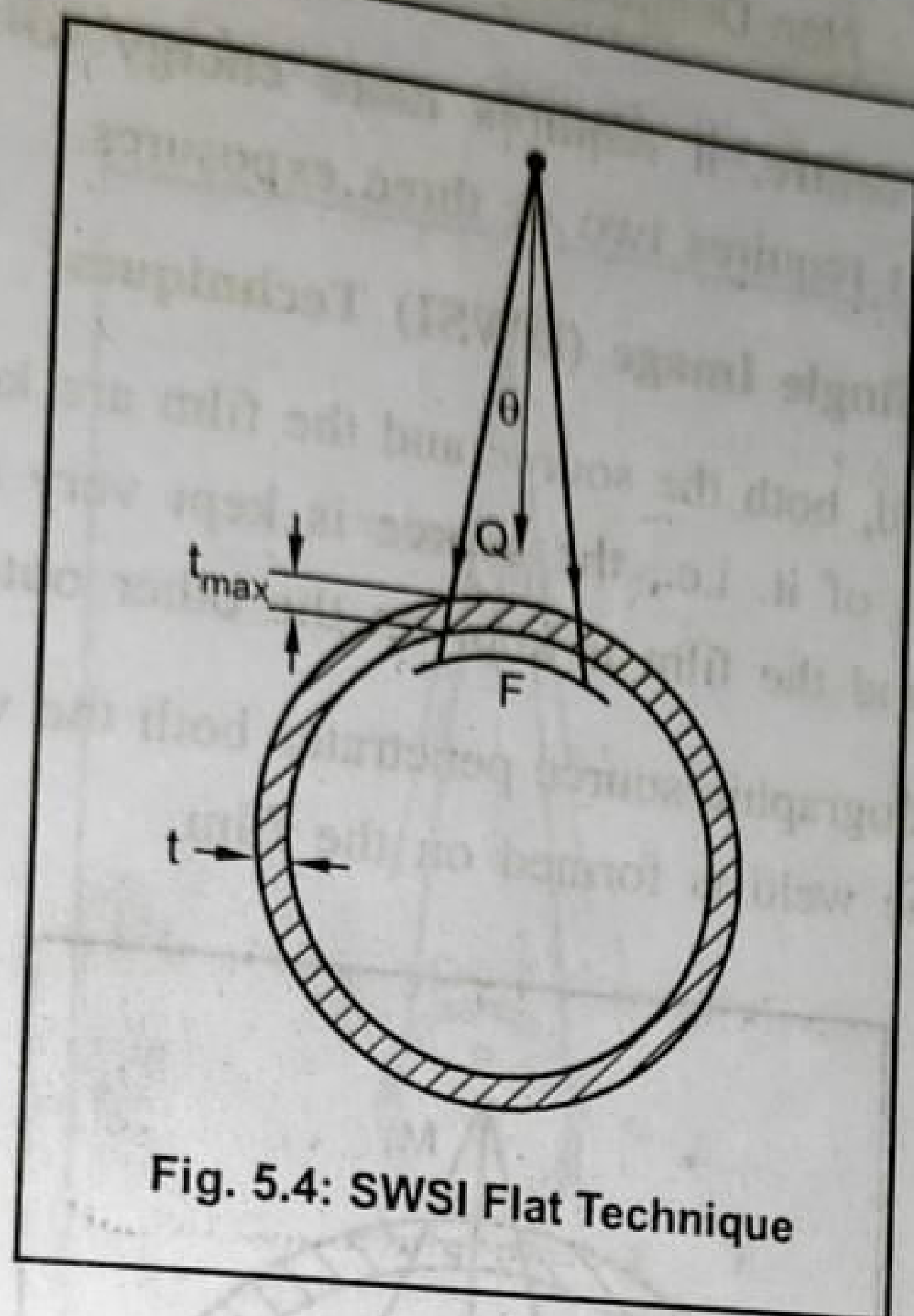


Fig. 5.4: SWSI Flat Technique

SWSI Panoramic Technique:

In Single Wall Single Image Panoramic technique, the source is kept inside the pipe and the film cassettes are placed outside the pipe. The source can be fixed in two ways, namely at the centre and off centre.

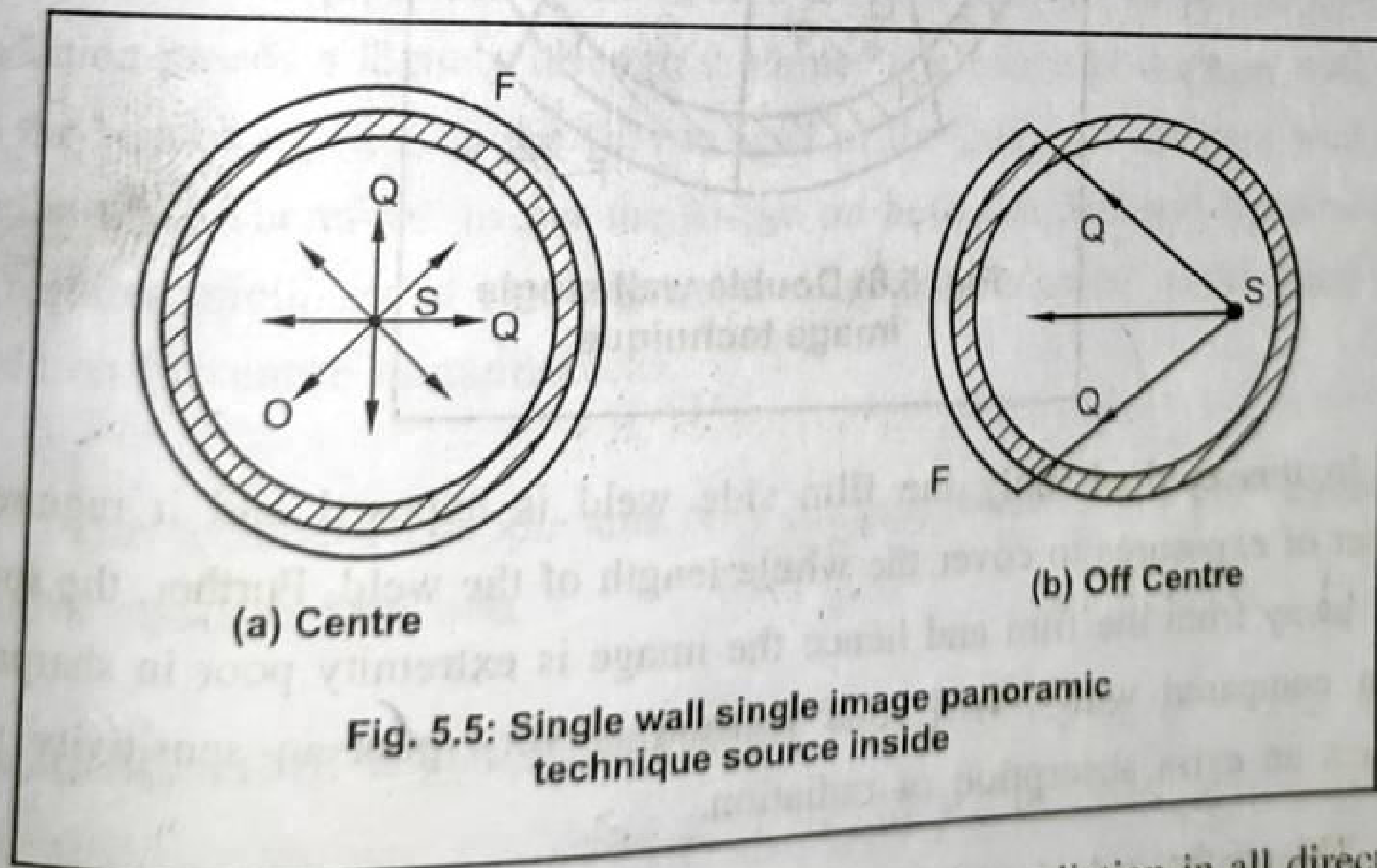


Fig. 5.5: Single wall single image panoramic technique source inside

When the source is at the centre and if it emits radiation in all directions, the total circumferential weld is exposed at one exposure. On the other hand,

if the source is off centre, it requires more energy to penetrate the weld thickness and hence it requires two or three exposures.

5.5.2. Double Wall Single Image (DWSI) Techniques:

In DWSI method, both the source and the film are kept outside the pipe, but on opposite sides of it. i.e., the source is kept very close to the outside surface of the pipe and the film is kept on the other outer side of the pipe.

A powerful radiographic source penetrates both the walls of the pipe and then the image of the weld is formed on the film.

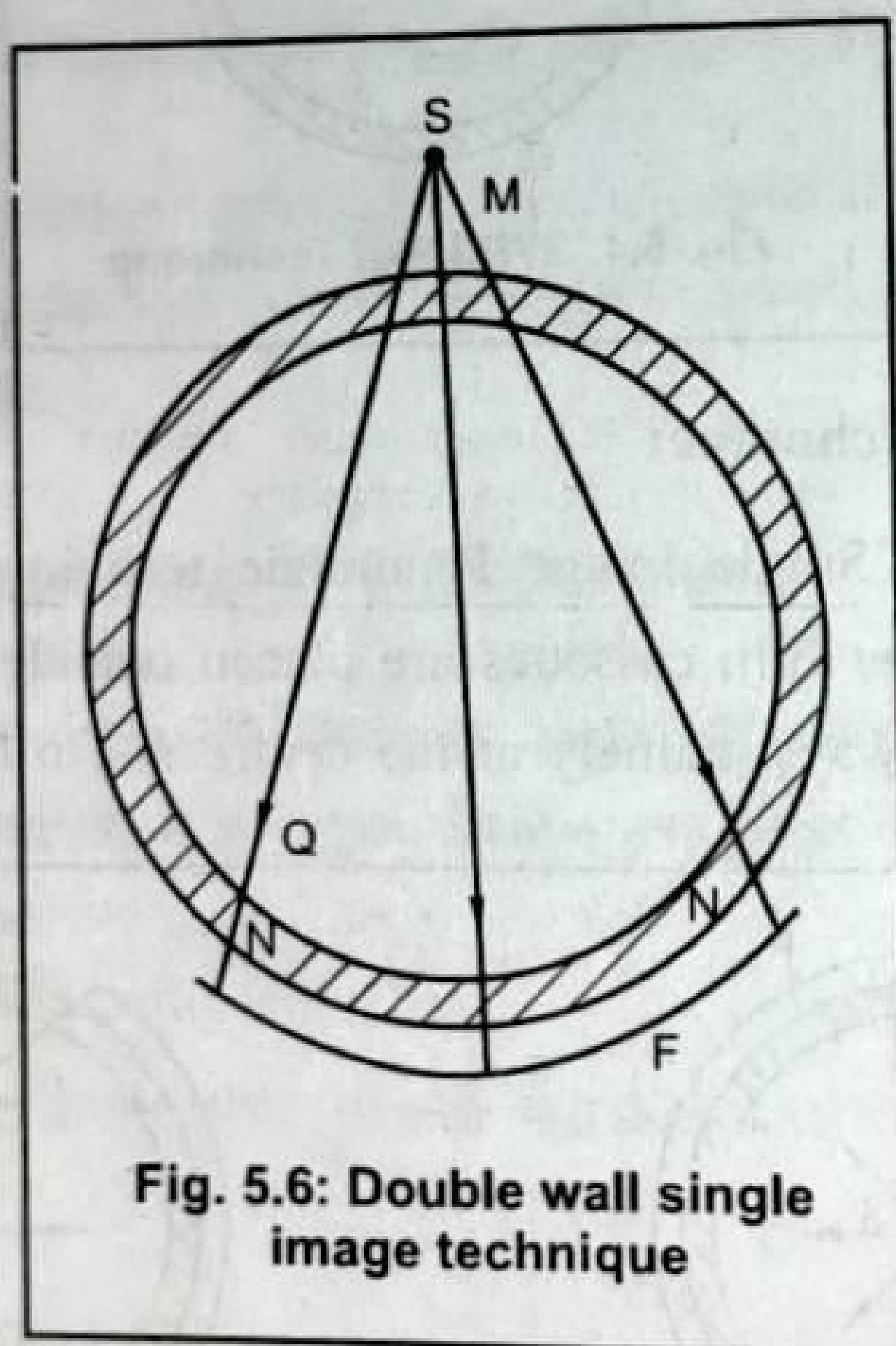


Fig. 5.6: Double wall single image technique

In this method, only the film side weld is exposed and it requires a number of exposures to cover the whole length of the weld. Further, the source is far away from the film and hence the image is extremely poor in sharpness. When compared with SWSI, this method is very poor in sensitivity as it requires an extra absorption of radiation.

This technique is suitable for pipes welds with outer diameter greater than 88.9 mm.

5.5.3. Double Wall Double Image (DWDI) Technique:

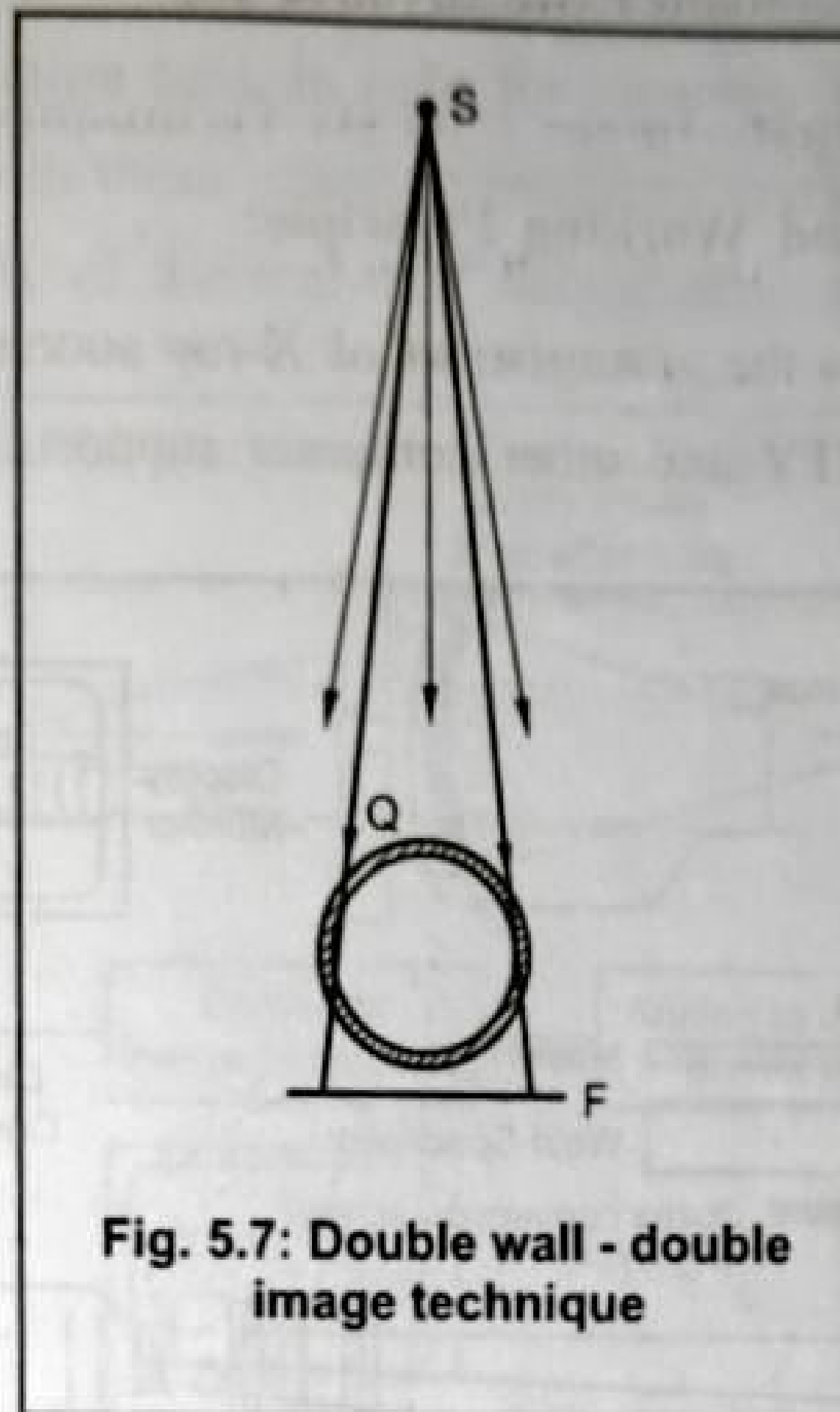


Fig. 5.7: Double wall - double image technique

In DWDI method, the source and film are kept, again on opposite sides and outside the pipe. Here, the source and the film are displaced so that the radiation passes obliquely through the pipe. The image of the pipe wall nearest to the source appears on the film instead of the image of the pipe wall nearest to the film. Therefore, to get the image on both the film and the source side, it requires minimum of two exposures each perpendicular to the image of the weld on the entire circumstances.

This technique is applicable only for pipe welds with outer diameter less than or equal to 88.9 mm.

5.6. REAL TIME RADIOGRAPHY:

Real Time Radiography (RTR) also known as fluoroscopy, is a technique in which the X-ray radiation is converted into light by using a fluorescent screen in the place of the film.

5.12

The process of obtaining the image of the object by converting the X-rays into light on the fluorescent screen is known as fluoroscopy (or) Real Time Radiography.

5.6.1. Arrangement and Working Principle:

Figure 5.8 shows the arrangement of X-ray source, materials under test, fluorescent screen, CCTV and other computer supports.

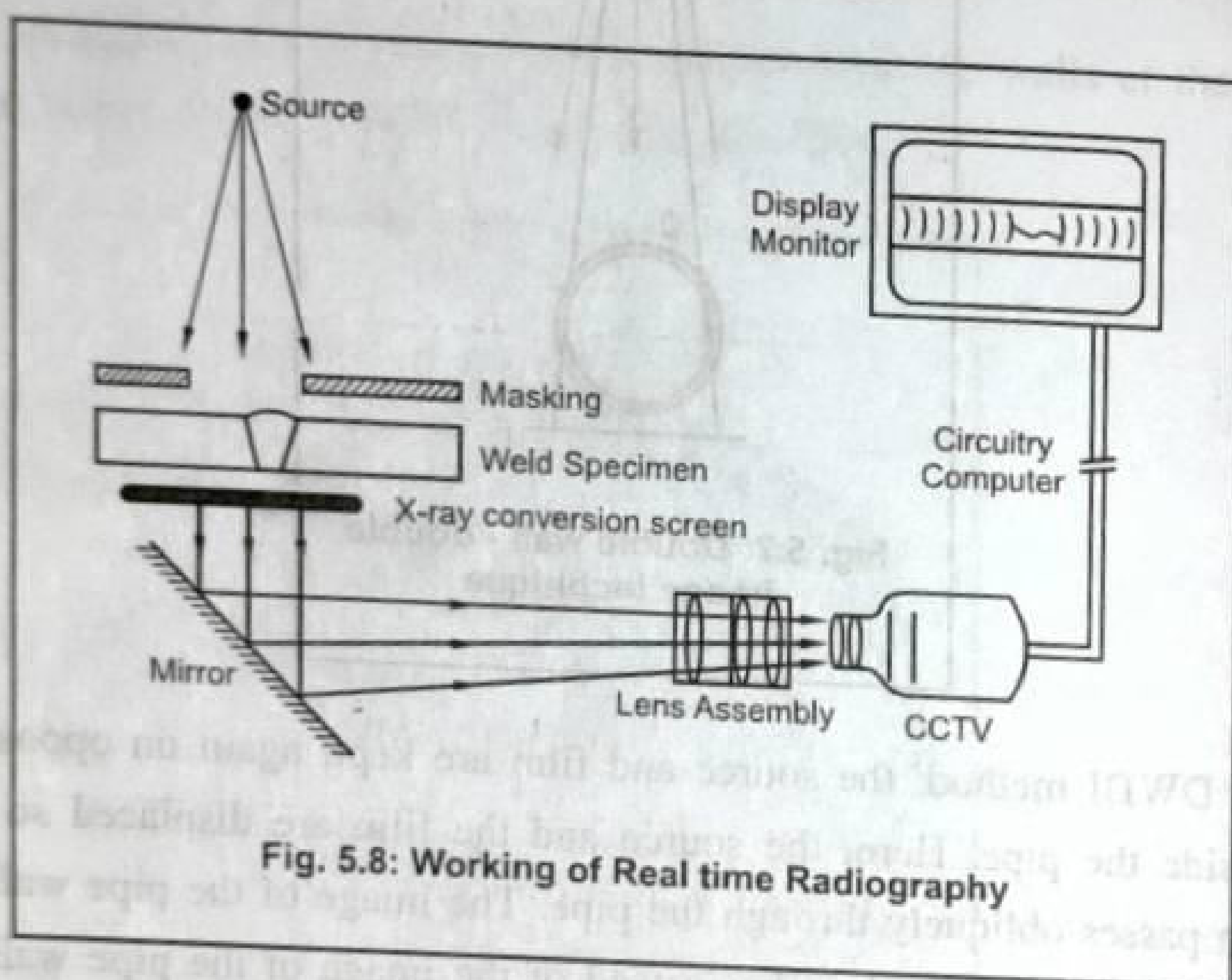


Fig. 5.8: Working of Real time Radiography

In this method, the radiation after passing through the material is recorded on the fluorescent screen. The image of the test piece which is obtained by the fluorescent screen, is received by the CCTV and is then amplified using the amplification circuit associated with the camera. The amplified circuit is then processed by the computer. The processed image, is then displayed on the monitor. The monitor is operated by means of a remote from the X-ray source to avoid the exposure to radiation.

The image obtained using the fluoroscopy method is usually faint and hence the sensitivity of the flaw (defect) characterisation is very poor. Therefore, to improve the quality of image, one should employ the image intensifier equipment.

The image intensifier is a large glass enclosed electron tube. The function of image intensifier is to convert radiation to light, light to electron for intensification and electron back to light for viewing. The use of fluoroscopic units in conjunction with these image intensifying system greatly enhances the versatility and sensitivity of the real-time radiographic setup.

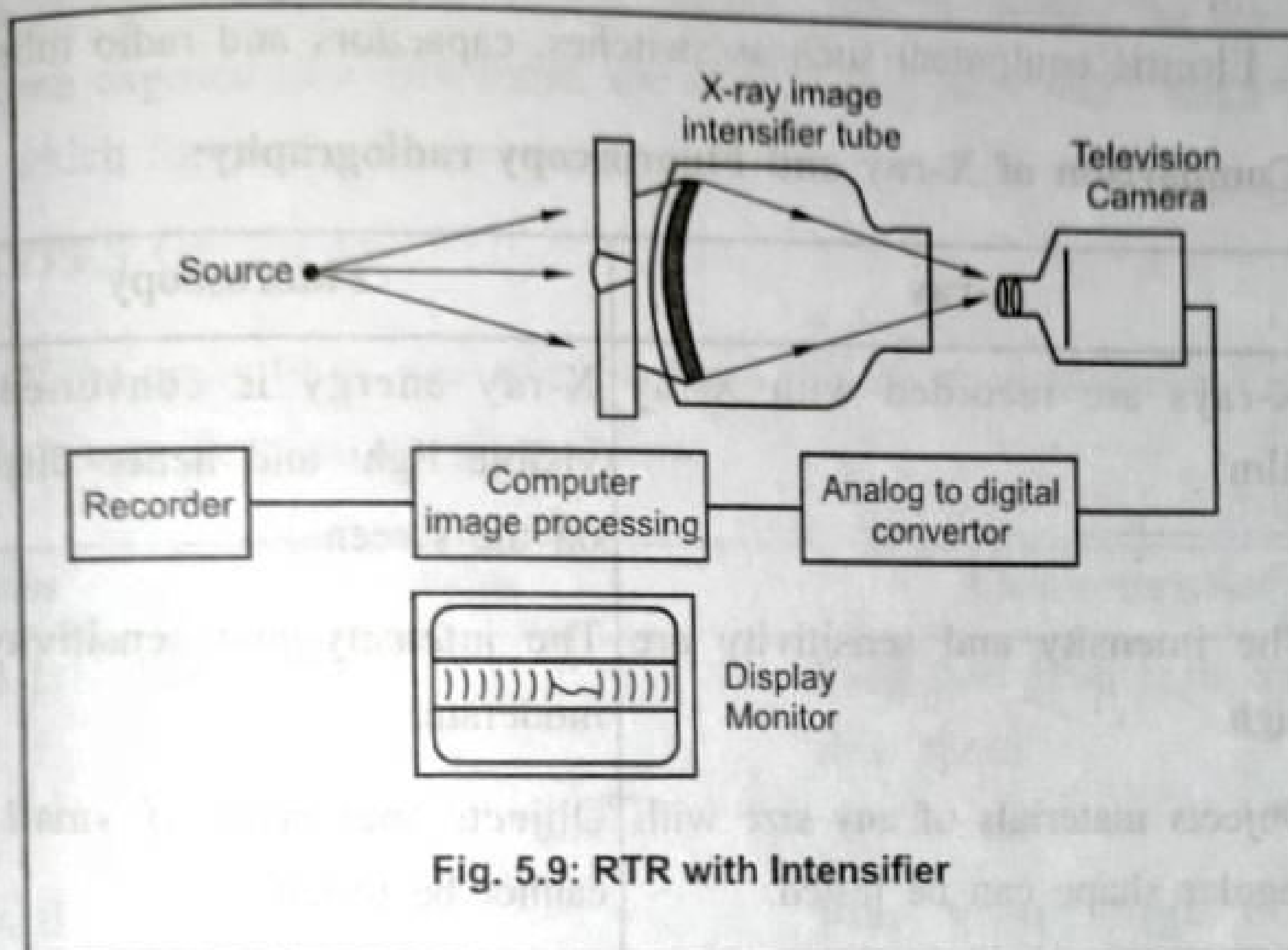


Fig. 5.9: RTR with Intensifier

5.6.2. Advantages of Real Time Radiography:

1. Real time radiography can take place at high speed i.e., it provides immediate viewing of the objects for defects.
2. Low cost for inspection.
3. Ability to study moving parts in action.

5.6.3. Disadvantages of Real time radiography:

1. Initial cost of equipments is very high.
2. Not portable as gamma ray testing.
3. Special cabinet is required to keep exposure to radiation within regulations.

5.6.4. Applications of real time radiography:

Real time radiography can be widely used for the inspection of

1. Laser welds in thin wall sections.
2. Electron beam welds in thin pipes.
3. Electric equipment such as switches, capacitors and radio tubes.

5.6.5. Comparison of X-ray and Fluoroscopy radiography:

	X-ray	Fluoroscopy
1.	X-rays are recorded with X-ray film	X-ray energy is converted into visible light and hence displayed on the screen.
2.	The intensity and sensitivity are high.	The intensity and sensitivity are moderate.
3.	Objects materials of any size with regular shape can be tested.	Objects materials of small size cannot be tested.
4.	Radiation hazards will exist.	It is free from radiation hazards
5.	Remote operation is not possible.	Remote operation is possible.
6.	It is a slow processing technique and hence, immediate inspection is not possible.	It is a faster processing technique and hence, immediate inspection is possible.

5.7. FILMS USED IN INDUSTRIAL RADIOGRAPHY:

One of the most widely used and oldest imaging medium in industrial radiography is radiographic film.

In Radiographic film, the film base is normally made of thin sheet of polyester type material. This is normally transparent and serves as the carrier for the chemically reactive material that forms the emulsion. Emulsion consisting of a silver halide recording medium such as the silver bromide or

silver chloride with a binder (gelatin) applied to the both the sides of the base. Additionally, a protective layer may also be applied over the emulsion. The silver halide is a granular material and its grain size has a significant, effect on the exposure as well as the resolution ability of the film.

Once exposed to radiation, a change in the emulsion takes place. This change is referred to as the 'Latent' image upon processing the grains, that have been exposed in a dark room, the silver halide turns into a black metallic silver which forms the image.

5.8 TYPES OF FILM:

Of the many films available, the films that are referred in many standards and their classification are given below.

Class	Film	Characteristics
Class I	Kodak RR. Kodak M. Structurix D 2	Extra fine grain high contrast, slow speed.
Class II	Kodak AA Structurix D4 Structurix D 7	Fine grain, high contrast, medium speed.
Class III	Kodak Kodirex X Structurix D 10	High speed.
Class IV	They are screen type films used in conjunction with fluorescent screens. These films are not recommended in industrial radiography.	

5.9. SPEED OF THE FILM:

The film speed is an important parameter in film radiography. Based on grain size and exposure time, the films are classified into two types namely,

(i) High speed film

(ii) Low speed film.

(i) High speed film:

A film is called high speed film when its grains would begin reacting to the exposure considerably sooner than other films. High speed films will have larger grains and therefore may not be able to produce the minute detail. As exposure is the product of time and intensity, the exposure time will be shorter for a high speed film.

(ii) Low speed film:

A film is called low speed film when its grains would begin reacting to the exposure considerably slower than other films. Slow films will have extra fine grain or fine grain, which gives better quality. As grain size affects the quality and time of exposure, the exposure time will be longer for a slow speed film.

5.10. QUALITY OF THE FILM:

The quality of the film depends on two factors. i.e.,

1. Film density.
2. Film graininess.

1. Film density:

Film density is a measure of the amount of exposure seen by the developed film. It is also called as light transmission density or optical density. Film density (D) is generally expressed as

$$D = \log_{10} \frac{I_0}{I_t}$$

where I_0 = Light intensity which strikes the film.

I_t = Transmitted Light intensity.

D = Film density (usually ranges from 1.5 to 3.3).

All radiographs must have a readable density (Blackening of the film). To check the density in a radiograph, a densitometer is used.

2. Film graininess:

A fine grain film is capable of producing an image with higher level of definition than a coarse grain film. Thus, the quality of the image (radiograph) depends on the quality of the film. i.e., higher the graininess of the film, higher will be the quality of the radiograph.

5.11. SCREENS USED IN RADIOGRAPHY:

Radiographic film emulsion, when exposed to radiation, absorbs only a small amount of radiation. In order to fully utilize the radiation and enhance the photographic effect, screens are used in combination with films. Screens are of two types: Metal foil screens and Fluorescent salt screens.

(i) Metal foil screens:

Metal foil screens are usually lead foil screens, consisting of lead foil mounted on cardboard or plastic. These are used in pairs by sandwiching the film between them. One of the screens facing the source side is called the front screen and the other, the back screen – which is placed behind the film.

The main advantages of using lead screens are:

- ★ Enhancement of photographic action on the film by emission of photoelectrons and secondary radiations generated in the lead.
- ★ Soft scattered radiation is absorbed more than the primary radiation.
- ★ Photographic effect of the primary radiation is intensified at higher energies.

★ The harmful effect of scattered radiation is reduced, thereby producing greater contrast and clarity in the radiographic image.

★ Higher intensification reduces exposure time.

Besides lead intensifying screens, other metal screens such as copper, tantalum and tungsten screens are also used.

(ii) Fluorescent intensifying screen or salt screens:

Fluorescent intensifying screens or salt screens consist of a powdered fluorescent material, such as calcium tungstate or barium lead sulfate, of which a thin uniform layer is spread with a suitable binder on a cardboard or a plastic support. The fluorescent material emits visible or ultraviolet light when exposed to X-rays or Gamma rays. The intensity of emitted light depends on the intensity of incident radiation. The main advantage of using fluorescent salt screens is to drastically reduce the exposure time since the intensification factor is very high compared to lead intensifying screens. However, the intensification factor diminishes both at lower as well as very high energies. The use of these screens is limited in the field of industrial radiography because they produce poor definition and grainy images.

Fluorescent screens are not used in gamma radiography, as intensification is poor with long exposures, usually common in gamma ray radiography.

Foreign particles such as dirt, dust, etc. should be prevented from accumulating between the screen and the film, as they tend to cast their shadow on the film. Further, the screen should not be exposed to the primary beam and should be stored away from chemicals and other sources of contamination.

5.12. QUALITY OF A GOOD RADIOGRAPHY:

The quality of a radiograph is generally assessed using four criteria they are

1. Density.

2. Contrast.

3. Definition.

4. Sensitivity.

$$D = \log \frac{I_0}{I_t} \quad 5.19$$

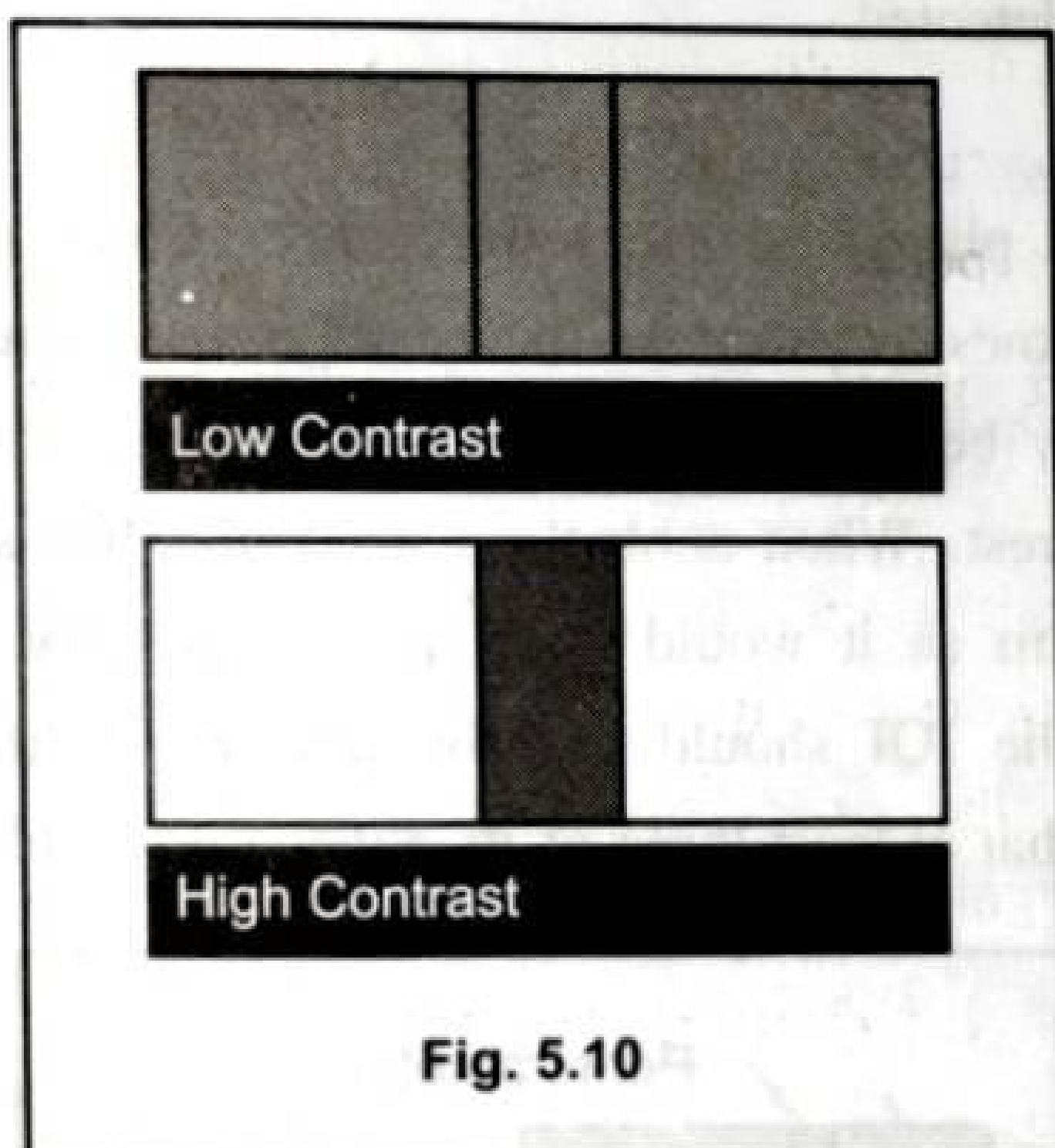
1. Density:

Radiographic density is a measure of the degree of film darkening. It is also called as optical, photographic or film density. Radiographic density is the logarithm of two measurements i.e., the log of the ratio of the intensity of light incident on the film (I_0) to the intensity of light transmitted through the film (I_t).

$$\text{Density (D)} = \log \frac{I_0}{I_t}$$

2. Contrast:

Contrast is the degree of density difference between adjacent areas on a radiography. The contrast between different parts of the image is what forms the image. The greater the contrast, the more visible the feature becomes. Radiographic contrast has two main contributors namely, subject contrast and film contrast.



3. Definition:

Radiographic definition is the abruptness of change from one density to another. Geometric factors of the equipment film and screen factors of the radiographic setup all these factors will have an effect on definition.

4. Sensitivity:

Radiographic sensitivity is a measure of the quality an image in terms of the smallest detail or discontinuity that may be detected. The higher the sensitivity, the higher is the quality of radiography.

5.12.1. Controlling Radiographic Quality:

One of the methods of controlling the quality of a radiograph is through the use of Image Quality Indicators (IQIs), which are also referred to as **penetrameters**. IQIs provide means of visually informing the film interpreter of the **contrast sensitivity and definition of the radiography**. The IQI indicates that a specified amount of change in material thickness will be detectable in the radiography, and that the radiograph has a certain level of definition so that the density changes are not lost due to unsharpness. Without such a reference point, consistency and quality could not be maintained and defects could go undetected.

IQIs should be placed on the **source side of the part** over a section with a material thickness equivalent to the region of interest. If this is not possible, the IQI may be placed on a block of similar material and thickness to the region of interest. When a block is used, the IQI should be the same distance from the film as it would be if placed directly on the part in the region of interest. The IQI should also be **placed slightly away from the edge of the part** so that at least three of its edges are visible in the radiograph.

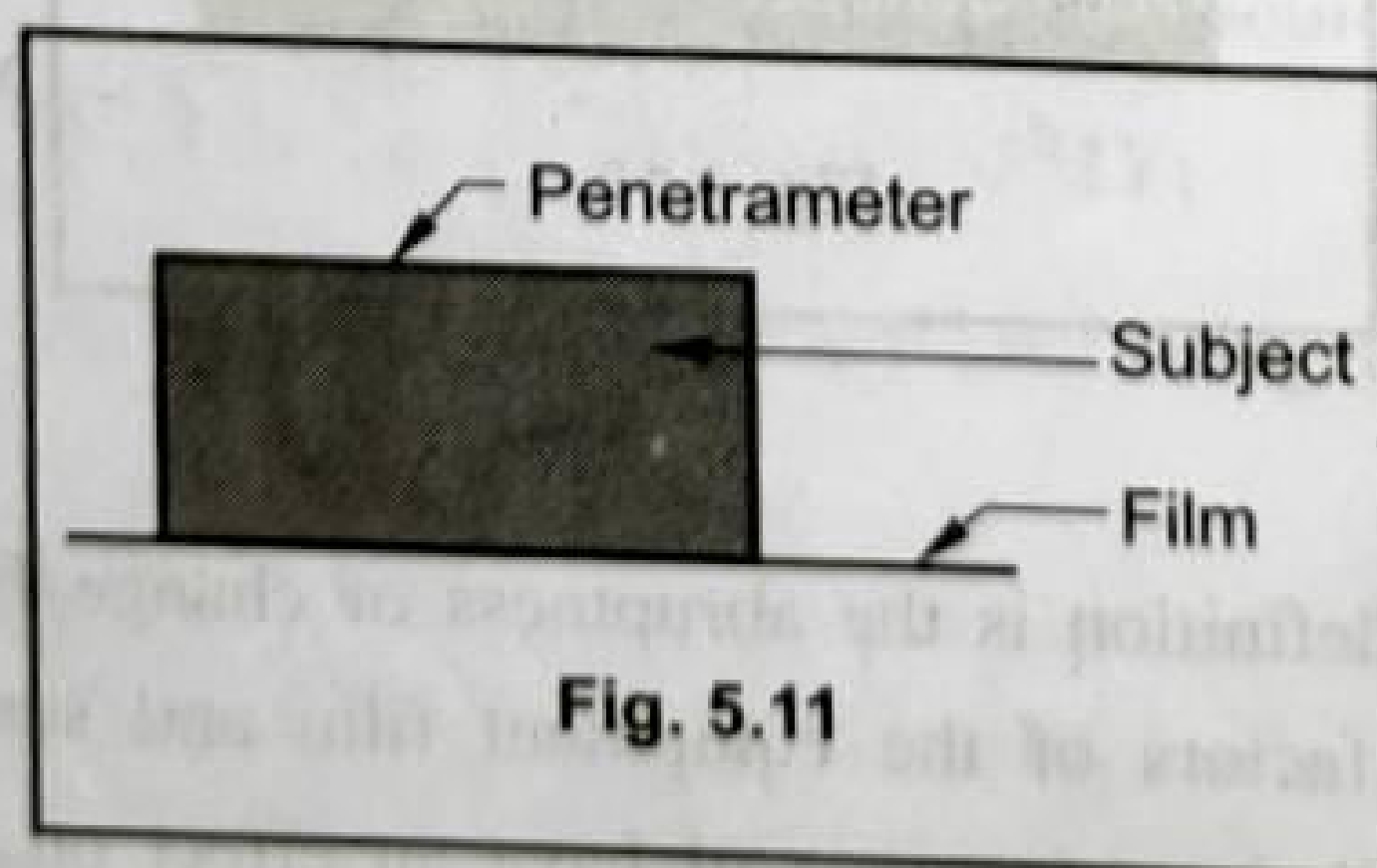


Image quality indicators take many shapes and forms due to the various codes or standards that invoke their use. IQIs come in a variety of material types and designs so that one with radiation absorption characteristics similar to the material being radiographed can be used. Some of the most commonly used (IQIs) are described as follows.

1. Step type:

This type of IQI is essentially a step wedge having 4 or 5 steps. The thickness of these steps increases either in geometric or arithmetic progression. In the following list of standards, step type IQI are used and the thickness of which increases in geometric progression.

1. Bureau of Indian Standard (BIS) – BIS 3657.

2. AFNOR – French IQI – A04-304.

3. IIW and ISO (similar to AFNOR).

2. Wire type:

Among the wire type IQIs, DIN wire type IQI are most common. These are available in two types:

(i) DIN 54109: This type of IQI consists of a series of equidistance parallel wires whose diameter increases in geometric progression. Three indicators form the series.

(ii) DIN 54110: This type of IQI consists of 4 indicators each having series of equidistance parallel wires, the diameter of which increases in arithmetic progression. BIS has also prescribed wire type IQIs in BIS-3657.

3. Plaque type:

All the American IQIs are plaque type, also called strip type. This type of IQI has three holes drilled on a strip having thickness of usually 2% of the specimen.

5.13. FILM PROCESSING:

As mentioned previously, radiographic film consists of a transparent, blue-tinted base coated on both sides with an emulsion. The emulsion consists of gelatin containing microscopic, radiation sensitive silver halide crystals, such as silver bromide and silver chloride. When X-rays, gamma rays or light rays strike the crystals or grains, some of the Br^- ions are liberated leaving the Ag^+ ions. In this condition, the radiograph is said to contain a latent (hidden) image because the change in the grains is virtually undetectable, but the exposed grains are now more sensitive to reaction with the developer.

When the film is processed, it is exposed to several **different chemical solutions for controlled periods of time**. Film processing basically involves the following five steps:

1. **Development:** The developing agent gives up electrons to convert the silver halide grains to metallic silver. Grains that have been **exposed to the radiation develop more rapidly**, but given enough time, the developer will convert all the silver ions into silver metal. Proper temperature control is needed to convert exposed grains to pure silver while keeping unexposed grains as silver halide crystals.
2. **Stopping the development:** The stop bath simply stops the development process by diluting and washing the developer away with water.
3. **Fixing:** Unexposed silver halide crystals are **removed** by the fixing bath. The fixer dissolves only silver halide crystals, leaving the silver metal behind.
4. **Washing:** The film is washed with water to remove all the processing chemicals.
5. **Drying:** The film is dried for viewing.

Film processing is a science governed by rigid rules of chemical concentration, temperature, time, and physical movement. Whether processing done by hand or automatically by machine, excellent radiographs require a high degree of consistency and quality control.

1. INTERPRETATION OF RADIOGRAPHS:

The purpose of interpreting a radiograph is to identify the discontinuities in the radiograph and correlate them with their appearance and location in the actual component, with a view to assessing the serviceability of the component.

During interpretation, films are viewed in a semi-dark enclosure. The interpreter needs to get adapted to subdued lighting. Extraneous light in the viewing room and direct light from the illuminator should be avoided. Further, it is important that the interpreter has good eyesight, to be able to see the finest detail on the radiograph. Any deficiency in vision should be corrected by using glasses certified by an ophthalmologist. Another important requirement for viewing a radiograph is appropriateness of light intensity from the illuminator, which depends upon the optical density of the radiograph.

In industrial radiographs, the normal working density varies from 1.5 to 3.5. Therefore, the illumination requirement is to provide sufficient light of an intensity to read this range of density. Thus, the requirements of illumination for viewing a radiograph are critical. Failure to use the correct illumination will result in missing fine details that have been brought out on the radiograph by adopting the best exposure techniques.

1.1. Interpretation of welding Radiographs:

1. Gas porosity appears as round or elongated smooth dark spots, occurring individually or in clusters or distributed throughout the welding. This is caused by gas formation during welding process.

2. Slag inclusion and slag lines appear on the radiograph as dark, irregular shapes. These may be isolated, clustered or randomly distributed. A slag line appears as a linear dark shade, continuous or intermittent along the edge of the weld. Slag inclusions occur due to entrapment of foreign materials in the cavities during welding.
3. Incomplete penetration appears on the radiograph as continuous or intermittent dark lines, usually of uniform width, occurring in the middle of the weld. This is caused by the failure of the weld metal to fill the root gap.
4. Lack of fusion appears on the radiograph as a thick, dark line. It may also appear as diffused and wavy, depending upon the defect orientation with respect to the radiation beam. This defect is caused by the failure of the weld metal to fuse with the parent metal or previously deposited weld metal. In case of lack of sidewall fusion, the radiographic image shows the appearance of a straight, dark band parallel to the weld bead.
5. Cracks appear on the radiograph as sharp, straight or jagged dark lines with tapered ends. Cracks may appear in longitudinal or transverse directions. Cracks may occur in the weld and heat affected zones. The effect is caused by the rupture of the weld metal during solidification due to shrinkage or by fracture when cold, due to uneven stresses and poor handling.
6. Undercuts appear on the radiograph as dark lines of uneven width along the edge of the weld. This defect is caused by the formation of a groove or a channel on the surface of the base metal at the toe of the weld bead due to high temperature.
7. Burn through appears on the radiograph as a dark, round or elongated area surrounded by a lighter ring. This is caused by the melting of metal from the root of the weld or through the backing strip.

8. Icicles appear on the radiograph as isolated, white, rounded indications, occasionally with a small, dark spot in the center. This is caused by fused droplets of weld metal extending beyond the root of the weld.
9. Tungsten inclusions appear on the radiograph as white areas of round or irregular shape, either isolated or in clusters. This is caused by the entrapment of tungsten particles in the weld metal. These particles are broken pieces from the tungsten electrode.

5.15. EVALUATION OF TEST RESULTS:

The radiographic image of a discontinuity in a component shows a variation of density compared to its surroundings. The density may be higher or lower, depending on the nature of the discontinuity. A void in a component results in a darker image (high optical density) than its surroundings. A foreign object of higher material density causes a lighter image (low optical density) on the radiograph. However, it should be realized that if the density of an entrapped inclusion in a component is the same as that of the component, such an inclusion might not be revealed on the radiograph. Further, radiography is not an effective tool for detecting planer type of discontinuities.

The discontinuity may be on the surface of the component or inside it. Surface imperfection such as rough surface, pits, flash lines, excess material, tool mark, etc. should be correlated with radiographic indications. Other defects could be due to manufacturing process and material characteristics.

An understanding of the material and the manufacturing process goes a long way in correlating radiographic indication with the exact nature and origin of the discontinuity. International agencies such as ASTM, IIW, BS, etc. have published reference radiographs for various radiographic indications in different materials. Each indication on the radiograph is due to a specific mechanical or metallurgical process. By establishing the identity of indication by comparison with reference standards, a radiographer should be able to identify the cause of occurrence of the discontinuity.

Evaluation of defects is done by comparing the test object radiograph with the known standard reference radiographs having different degrees of each defect. The limit of acceptance/rejection, however, is based on the service application of the component keeping in view the service environment and the design stipulated mechanical property requirement. Therefore it may be necessary to generate a defect-property data for this purpose.

5.16. SAFETY ASPECTS REQUIRED IN RADIOGRAPHY:

An important, aspect to be considered in the radiographic inspection is the hazards involved and the safety of biological effects of ionizing radiation. There are two main aspects of safety

1. Monitoring radiation dosage.
2. Protection of personnel.

1. Monitoring Radiation dosage:

Radiation dose is a measure of energy imparted by any ionizing radiation in any medium like tissue. The absorbed dose is normally expressed in a unit called G_{ray} (G_y). One G_{ray} is equal to one joule per kg. Sometimes, the absorbed dose is expressed as rad where $1 G_{ray} = 100 \text{ rad}$.

The effective way of monitoring involves controlling of the exposure when working with radiography sources. The methods implemented to control exposure are

- (i) **Time:** Don't stay near a radiation source any longer than you have to. Time of handling can be reduced by proper training, adopting fast work technique, mock-up practices and efficient administrative control.
- (ii) **Distance:** Stay as far as possible from source. As the radiation intensity decreases with distance following the inverse square law, equipment design and operating procedure must take into account this factor.

(iii) **Shielding:** Yet another important way to reduce the dose is to place a shielding material between the source and the operator. Denser the shielding material, more effective it will be in bringing down the dose from X-rays and Gamma rays. The commonly used shielding materials in the radiographic installations/equipment are steel, lead concrete and depleted uranium.

2. Protection of Personnel:

The objective of personnel protection is to protect the individuals working in radiation area by effectively measuring the radiation dose received by individual during their period of work. The most commonly used measuring devices are

- (i) Film badge.
- (ii) TCD (Thermoluminescent) dosimeters.
- (iii) Direct reading or pen dosimeters.

5.17. ADVANTAGES OF RADIOGRAPHY TESTING:

1. Thicker plates can be inspected (eg: Greater penetrating power).
2. Both surface and internal discontinuities can be detected.
3. Wide variety of materials can be inspected.
4. Permanent record of inspection is possible.
5. Surface preparation required is minimum.
6. Ability to inspect assembled components.
7. Gamma ray sources are portable and highly suitable to field radiography.

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5.18. DISADVANTAGES OF RADIOGRAPHY TESTING:

1. Hazardous to operators and other nearby personnel.
2. High degree of skill and experience is required for exposure and interpretation.
3. X-ray source equipment is expensive.
4. The process is generally slow.
5. Determination of flaw depth is impossible without additional angled exposures.
6. It requires a two sided access to the component.

5.19. APPLICATIONS OF RADIOGRAPHY TESTING:

1. Radiography can be used to inspect most types of solid materials both ferrous and non-ferrous alloys as well as non-metallic materials and composites.
2. It can be used to inspect the condition and proper placement of components for liquid level measurement in sealed component.
3. This method is used extensively in castings, weldments and forgings when there is a critical need to ensure that the object is free from internal flaws.
4. Radiography is well suited to the inspection of semi conductor devices for detection of cracks, broken wires, unsoldered connections, foreign material and misplaced components, whereas other methods are limited in ability to inspect semiconductor devices.

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MODULE – 6**EDDY CURRENT TESTING**

Principle, Physics aspects of ECT like conductivity, permeability, resistivity, inductance, inductive reactance, impedance. Field Factor and life off effect, edge effect, end effect, impedance plane diagram in brief, depth of penetration of ECT, relation between frequency and depth of penetration in ECT. Equipments and accessories, various applications of ECT such as conductivity measurement, hardness measurement, defect detection, coating thickness measurement, advantages and limitations of eddy current testing.

6.1. INTRODUCTION:

- ★ Eddy currents are defined as oscillating electrical currents induced in a conductive material by an alternating magnetic field, due to electromagnetic induction.
- ★ Eddy current testing (ECT) is used for sorting materials, measurement and control of dimensions of tubes, sheets and rods, coating thickness and for pre-service and in-service examination of heat exchanger tubes for detection of defects.
- ★ Eddy current testing is one of the electromagnetic testing methods used in non-destructive testing (NDT) making use of electromagnetic induction to detect and characterize surface and sub-surface flaws in conductive material.

6.2. EDDY CURRENT:

Whenever relative motion occurs between a metal conductor and magnetic lines of force, electric currents are induced in the surface of the metal conductor.

6.2.1. Properties of Eddy Currents:

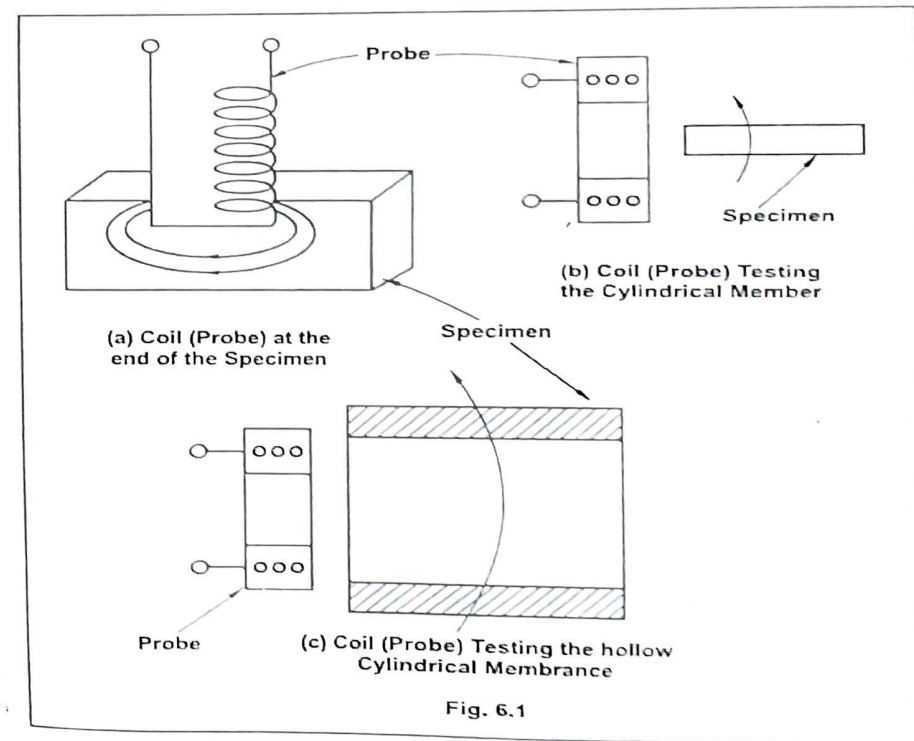
1. Eddy current density decreases with the depth exponentially. This phenomenon is known as the skin effect.
2. Eddy currents are closed loops of induced current circulating in planes perpendicular to the magnetic flux.
3. Eddy currents normally travel parallel to the coil's windings and the flow is limited to the area of inducing magnetic field and perpendicular to the axis of the coil's flux field.

6.2.2. Generation of Eddy currents:

- ★ Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor, due to Faraday's law of induction.
- ★ A probe is used to generate eddy currents for an inspection. Inside the probe is of length of electrical conductor which is formed into a coil at a frequency according to the type of test involved.
- ★ A dynamic expanding coil collapsing magnetic field forms in and around the coil as the alternating current flows through the coil.
- ★ When an electrically conductive material is placed on the coil's dynamic magnetic field, electromagnetic induction will occur and eddy currents will be induced in the material.

- ★ Eddy currents flowing in the material will generate their own "secondary" magnetic field which oppose the coil's "primary" magnetic field.
- ★ This entire electromagnetic induction process to produce Eddy currents may occur from several million times per second depending upon inspection frequency.

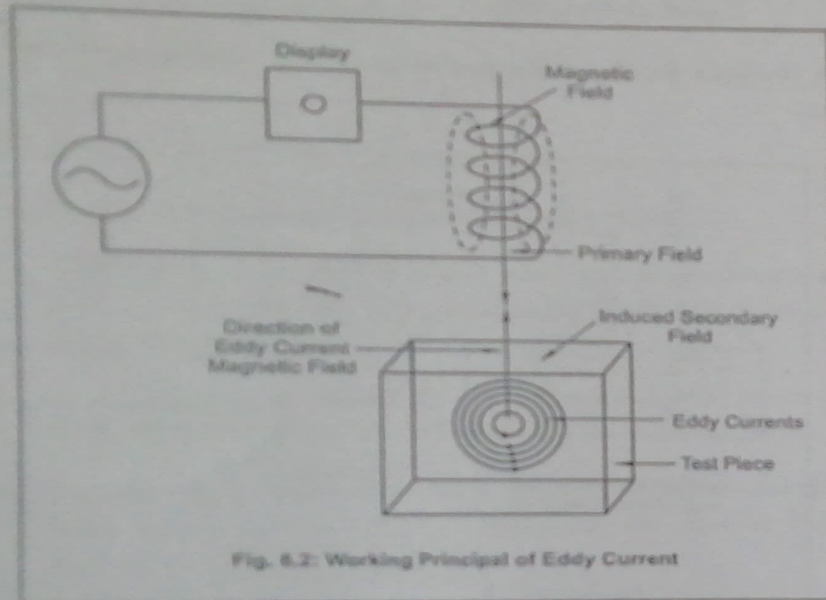
Figure 6.1 shows the generation of eddy current in different types of coil.



6.3. PRINCIPLE OF EDDY CURRENT TESTING:

In Eddy current testing, an alternating current (A.C) of frequency 1 kHz - 2 MHz is made to flow in a coil which in turn, produces an alternating magnetic field around it.

This coil when brought close to the electrically conducting surface of a metallic material to be inspected, induces an eddy current flow in the material due to electromagnetic induction as shown in Figure 6.2.



- ★ These eddy currents are generally parallel to the coil winding. The presence of any defect or discontinuity in the material disturbs the eddy current flow.
- ★ These eddy currents in turn generate an alternating magnetic field which may be detected either as a voltage across a secondary coil or by the perturbation of the impedance of the original coil.

Eddy Current Testing

- ★ When a flaw is introduced in the conductive material to be tested, the eddy currents are disrupted and is sensed through suitable instrumentation.
- ★ Eddy current testing can detect very small cracks of any physical complex geometry with minimal surface penetration.

6.4. PHYSICS-ASPECTS OF EDDY CURRENT TESTING:

- ★ Since eddy current testing and inspection makes use of electromagnetic induction, so it is important to know about the scientific principles of electricity and magnetism.
- ★ A number of factors, apart from flaws, will affect the eddy current response from a probe.
- ★ Successful assessment of flaws or any of these factors rely on holding constant, or eliminating their effect on results.

The factors influencing eddy current testing are:

1. Conductivity.
2. Permeability.
3. Frequency.
4. Resistivity.
5. Inductance.
6. Inductive Reactance.
7. Impedance.
8. Electricity.
9. Electromotive force.
10. Design or geometry of the coil.

6.4.1. Conductivity:

- ★ The material in which eddy current can be induced should be of conductive nature.
- ★ All materials have characteristic resistance to the flow of electric current depending on which they can be classified into three categories:
 1. Insulators.
 2. Semi-conductors.
 3. Conductors.
- ★ Conductivity is the reverse of resistivity and is the measure of how easily the current can flow through the material.
- ★ Conductivity is often measured by an eddy current technique, and inferences can then be drawn about the different factors.

In general conductivity of material is affected by the

- (i) Chemical composition.
- (ii) Heat treatment.
- (iii) Temperature.

Eddy current testing can be used to detect changes in any one of these properties in isolation.

6.4.2. Permeability:

- ★ Magnetic permeability is the ratio of magnetic flux density to the magnetizing force of the coil.
- ★ The magnetic permeability of a metal affects the ease with which magnetic lines will flow through it.
- ★ In a material with a high permeability, a large density of these lines will be created for a given source and the lines will tend to concentrate in the material.
- ★ This has two effects – Firstly a greater amount of magnetic energy can be stored in the coil which increases inductance.
- ★ Secondly plenty of eddy currents are generated which increase the “lift off” effect. The tendency of the lines of force to concentrate in the material causes very little penetration.
- ★ As material permeability increases, noise signals resulting from permeability variations increasingly mask eddy current signal variations. Permeability thus limits effective penetration of eddy current.

Magnetic permeability of various materials which affect the eddy current testing are given below:

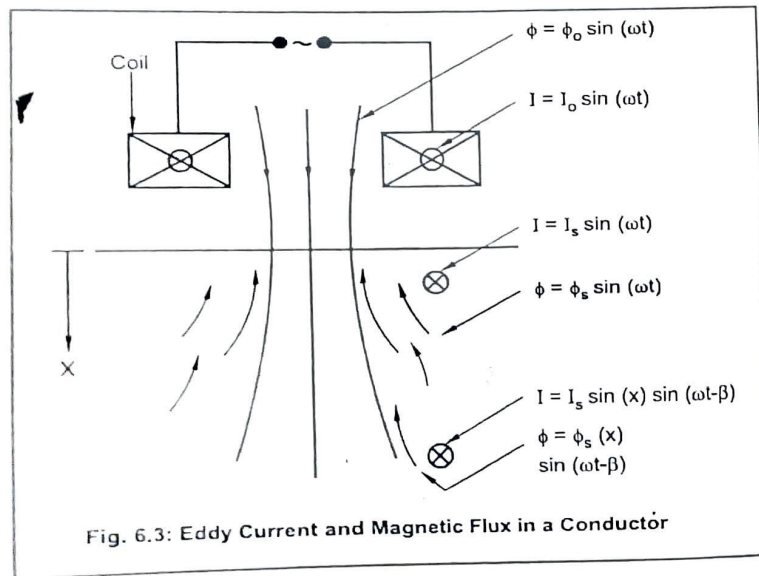
1. Paramagnetic materials like aluminium has a relative magnetic permeability slightly greater than unity. (i.e.) $\mu_r \geq 1$.
2. Diamagnetic material such as copper and lead create a magnetic field in opposition to an externally applied magnetic field, thus causing repulsive effect. Magnetic permeability is less than unity. i.e. $\mu_r \leq 1$.

3. Ferromagnetic materials like iron, nickel, cobalt and their alloys are strongly attracted by magnetic fields and concentrate the flux of magnetic field. Their relative permeability is much greater than unity. i.e., $\mu_r \gg 1$.

6.4.3. Frequency:

- ★ The importance of test frequency is that it determines the depth of penetration of eddy currents in the material.
- ★ The eddy current density decreases exponentially from the material surface but the rate of decreases depends on the test frequency, the electrical conductivity and the magnetic permeability of the test material.

Fig. 6.3 shows the eddy current and magnetic flux distribution with depth, into a conductor.



Eddy Current Testing

- ϕ → Magnetic flux density.
- I → Applied current
- I_s → Induced current / secondary.
- ω → Angular frequency ($2\pi f$).
- β → Phase change.
- t → Time
- x → Thickness (variable)

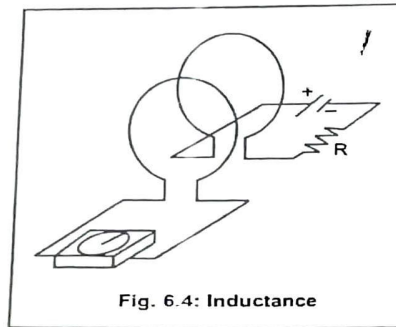
- ★ The frequency is the only parameter that can be varied by the inspector during inspection.
- ★ Eddy current testing is performed within a frequency range of approximate 50 Hz to 10 MHz.
- ★ As test frequency is increased, sensitivity to surface discontinuities increases permitting increasingly smaller surface discontinuities to be detected.
- ★ As frequency is decreased, eddy current penetration into the material increases.
- ★ In addition, as frequency is decreased, the speed of coil motion must be decreased in order to obtain full coverage. The optimum frequency is best determined by experimentation.

6.4.4. Resistivity:

Resistance is the opposition of a body or substance to the flow of electrical current through it, resulting in a change of electrical energy into heat, light, or other forms of energy.

6.4.5. Inductance:

When induction occurs in an electrical circuit and affects the flow of electricity it is called as inductance (L). An inductance is shown in Figure 6.4.



- ★ Self inductance, or simply inductance is the property of circuit where by a change in current causes a change in voltage in the same circuit.
- ★ When one circuit induces current flow in a second near by is known as mutual inductance.
- ★ It should be noted that since it is the changing magnetic field that is responsible for inductance, it is only present in AC circuits.

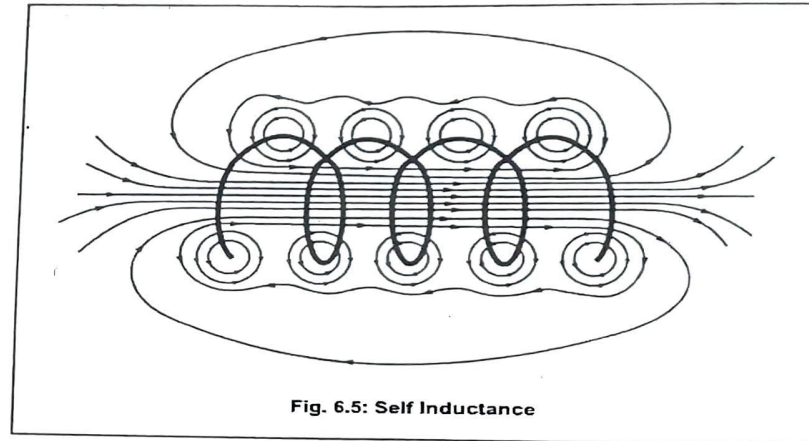
The common types of inductance

1. Self inductance.
2. Mutual inductance.

Self inductance:

- ★ Self inductance is defined as the induction of a voltage in a current carrying wire when the current in the wire itself is changing.
- ★ In case of self-inductance, the magnetic field created by a changing current in the circuit itself induces a voltage in same circuit.

- ★ Therefore, the voltage is self-induced, and the sketch of it is shown in Figure 6.5.



- ★ Increasing the number of turns or the rate of change of magnetic flux increases the amount of induced voltage.
- ★ Therefore Faraday's law must be modified for coil of wire and becomes the following.

$$V_L = \frac{L di}{dt}$$

where,

- V_L – The induced voltage in volts.
- L – The value of inductance in henries.
- di/dt – The rate of change of current in amperes per second.

Mutual Inductance:

The magnetic flux through a circuit can be related to the current in that circuit and the currents in other nearby circuits, assuming that there are no nearby permanent magnets. A schematic of mutual inductance is shown in Figure 6.6.

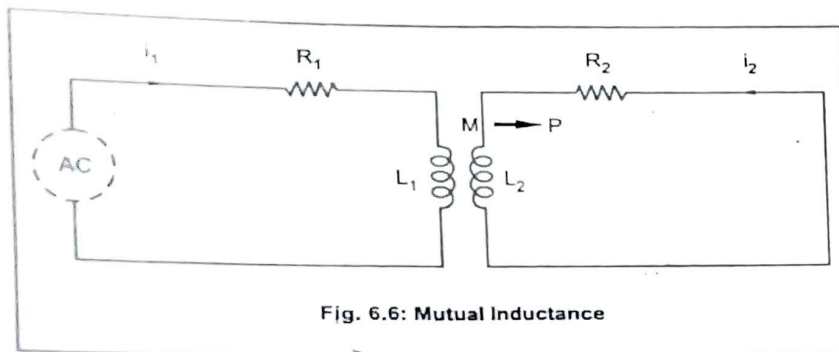


Fig. 6.6: Mutual Inductance

- ★ The magnetic field produced by circuit 1 will intersect the wire in circuit 2 and create current flow.
- ★ The induced current flow in circuit 2 will have its own magnetic field which will interact with the magnetic field of circuit 1.
- ★ At some point p, the magnetic field consists of a part due to i_1 and a part due to i_2 .
- ★ These fields are proportional to the current producing them.
- ★ The coils in the circuits are labeled as L_1 and L_2 and this term represents the self inductance of each of the coils.
- ★ The value of L_1 and L_2 depend on the geometrical arrangement of the circuit, and the conductivity of the material.
- ★ The constant M called the mutual inductance of the two circuits, is dependent on the geometrical arrangement of both circuits.

6.4.6. Inductive Reactance:

- ★ The reduction of current flow in a circuit as a result of induction is called as inductive reactance.
- ★ At a coil of wire, applying Lenz's law, one can find, how inductance reduces the flow of current in the circuit.
- ★ An inductive reactance illustration is given in Figure 6.7.

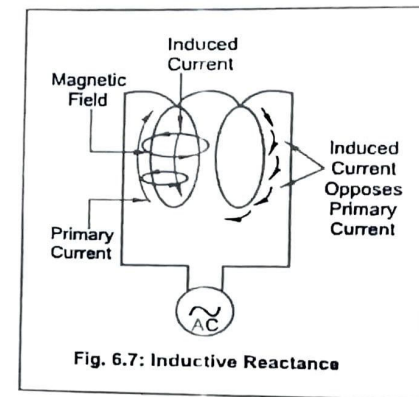


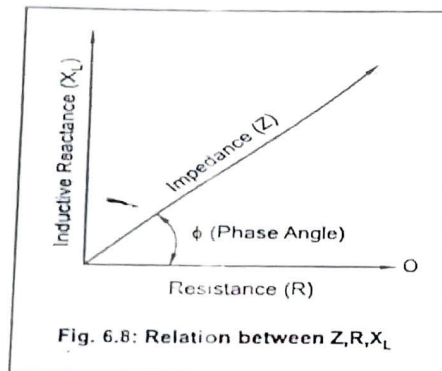
Fig. 6.7: Inductive Reactance

- ★ The direction of the magnetic field can be determined by Lenz's law.
- ★ According to Lenz's law, the induced current must flow in the opposite direction of the primary current.
- ★ The induced current working against the primary current results in a reduction of current flow in the circuit.

6.4.7. Impedance:

- ★ Impedance is the total opposition that a circuit presents to alternating current.
- ★ Impedance is measured in ohms, and may include resistance (R), inductive reactance (X_L) and capacitive reactance (X_C).

- ★ The impedance change is effected, mainly by electrical conductivity, magnetic permeability and geometry of the material, test frequency and the spacing between the coil and the material.
- ★ This impedance change can be measured and correlated with the change in the above mentioned parameter.
- ★ **Figure 6.8** shows the correlation between the inductive reactance and resistance.



- ★ The impedance in a circuit with resistance and inductive reactance can be calculated using the following equation

$$Z = \sqrt{(X_L^2 + R^2)}$$

- Z → Impedance.
- R → Resistance.
- X_L → Inductive Reactance.

6.4.8. Electricity:

- ★ Movement of electrons in a particular direction through a conductor is called as electricity.
- ★ The basic law of electricity is ohm's law.

$$V = I \times R$$

where,

V → Voltage in volts.

I → Electrical current in Ampere.

R → Resistance in ohm's.

6.4.9. Electromotive force:

- ★ The force that causes the electrons to move in an electrical circuit is called the electromotive force.
- ★ It is the force that makes electrons move in a certain direction within a conductor.
- ★ There are many sources of electromotive force, the most common being batteries and electrical generators.

6.4.10. Design or Geometry of coil:

- ★ The geometry of a component under test causes many difficulties in ECT.
- ★ A curved piece of metal will have a different 'lift off' response compared to a flat one, and the edge effect can distort the eddy current field and produces a signal lag.
- ★ Another feature of geometry is on the actual thickness of the material under test.

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- ★ If the eddy current penetrates the full thickness, there will be some effect when the thickness changes.
- ★ Signals from thickness changes are used to detect the loss of metal due to corrosion.

6.5. EQUIPMENT AND ACCESSORIES FOR EDDY CURRENT TESTING:

- ★ Special instruments have been developed in incorporating various methods of detecting and amplifying small impedance changes.
- ★ The functions of an eddy current instruments are given in block diagram of Figure 6.9.

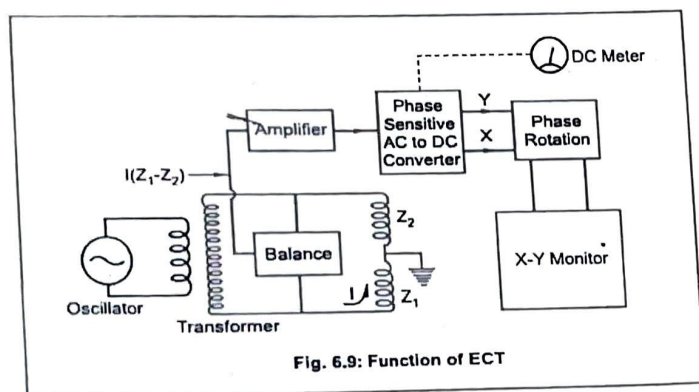


Fig. 6.9: Function of ECT

Explanation:

- ★ A sine wave oscillator generates sine current, at an specified frequency, that passes through a test coil.
- ★ Since the impedance of two coils is never exactly equal, balancing is required to eliminate the voltage difference between them.
- ★ Most eddy current instruments achieve this through an AC bridge or by subtracting a voltage equal to the unbalance voltage.

Eddy Current Testing

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- ★ Once balanced, the presence of a defect in one coil creates a small unbalanced signal which is then amplified, filtered and displayed on the storage oscilloscope after converting to DC signal.
- ★ The coil output may vary in both amplitude and phase and the relative variation of the parameters may be important for evaluation of the material under test.
- ★ Simple Eddy Current Testing (ECT) instruments usually operate at a fixed frequency and have an analog meter output, thus have limited applications.
- ★ Modern ECT instruments use both amplitude and phase information of the eddy currents.
- ★ These instruments permit test frequency to be varied over a wide range enabling selection of suitable skin depth.
- ★ The calibration and inspection results are normally recorded on dual channel chart recorders and on magnetic tapes.
- ★ The data stored on magnetic tapes can be played back at a later stage for further evaluation or documentation.

The common accessories are explained below:

Coils:

- ★ Coils are necessary in ECT to produce a sufficient magnetic field from limited current or a sufficient current from a limited magnetic field.
- ★ A field from adjacent wires in a nearby coil add to provide a total magnetic field depending on the number of turns in the coils.
- ★ This type of magnetic field from a coil is similar to that from a permanent magnet.

Eddy current generation:

- ★ When the coil is brought in close proximity with the conductive material, the alternating magnetic field will pass through the material.
- ★ The coil can be placed onto the material (or) encircle it (or) be inside a tube (or) sideways to the object as shown in Figure 6.10, and eddy currents will be induced into the material.

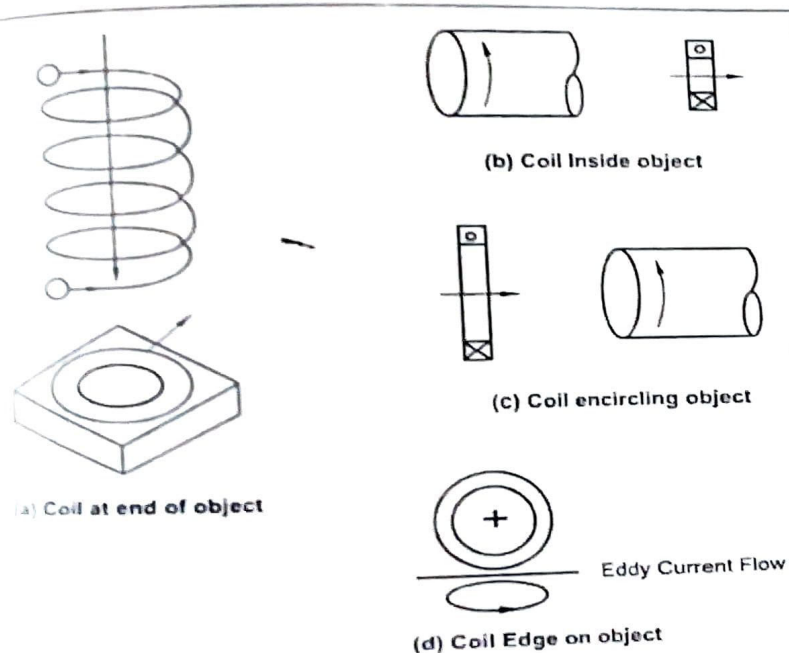


Fig. 6.10: Eddy Current with different coil arrangement

- ★ It can be shown that they normally have circular paths at right angles to the primary field parallel to the coil winding.

Eddy Current Testing**Eddy current detection:**

- ★ The eddy currents in the conducting material generate their own magnetic field which in fact opposes and modifies the primary field.
- ★ This in turn modifies the primary current usually in both phase and amplitude.
- ★ If the current flowing through the primary field is shown on a display, then variations in it can be seen in the presence of defects.
- ★ The coil which is used for both generating the primary field and detecting the secondary field is called an absolute coil as shown in Figure 6.11.

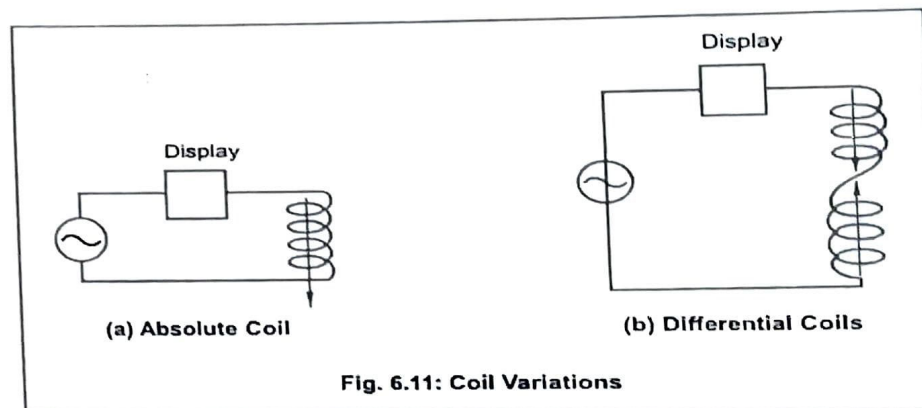


Fig. 6.11: Coil Variations

- ★ It is necessary to have two coils in close proximity which are electrically arranged to be in opposite i.e. wound in opposite directions.
- ★ This arrangement reduces the effects which can affect both coils for material variations and temperature.
- ★ Signals affect each coil differently, for example a crack sensed by one coil at a time is enhanced and this arrangement is called differential coil mode.

Probe Selection:

The selection of a test coil is influenced by a number of factors:

1. Shape of test specimen.
2. Likely distribution of variables affecting eddy currents and type of information required – crack detection, conductivity variation, permeability variation.
3. Accessibility.

Probe size requirements:

The probe size requirements for ECT of the tubes are determined by the fill factor,

where,

$$\text{Fill factor} = \frac{D_1^2}{D_2^2}$$

where,

$D_1 \rightarrow$ Diameter of the probe.

$D_2 \rightarrow$ ID of the tube

6.5.1. Eddy Current Testing (ECT) probes types:

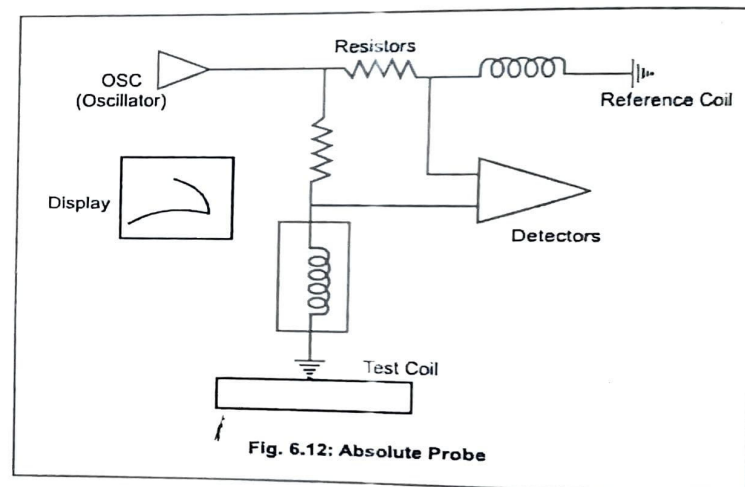
Eddy current probes are classified on the basis of model of operation.

The four general types of probes are:

1. Absolute probes.
2. Differential probes.
3. Reflection probes.
4. Hybrid probes.

Eddy Current Testing**6.5.1.1. Absolute Probes:**

- ★ Absolute probe is also called as single coil probe in which the change in material geometry can be detected by excitation coil as a change in coil impedance.
- ★ These probes are used for flaw detection, conductivity measurement, lift off measurement and thickness measurements.
- ★ Figure 6.12 shows the arrangement of sensing element of the eddy current testing.

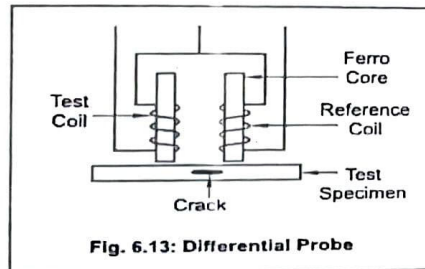


- ★ The simple coil consists of a ferrite rod with several turns of wire wound at one end which is positioned close to the surface of the product tested.
- ★ Primary functional element of the eddy current probe is the sensing coil. This is a coil of wire near the end of the probe.

- ★ Alternating current is passed through the coil which creates an alternating magnetic field and this field is used to sense the defect in the target.
- ★ The coil is encapsulated in plastic and epoxy installed in a stainless steel housing.

6.5.1.2. Differential Probe:

- ★ Differential probe consists of two active coils and are arranged in pairs, generally called a driven pair and this arrangement can be used with the coils connected differentially.
- ★ When a defectless test specimen is tested using this probe, no differential signal is developed between these two active coils.
- ★ When one coil is over a defect part of the test specimen and the other coil is over a defectless part of same specimen, differential signal is produced.
- ★ Figure 6.13 shows the construction of differential probe.

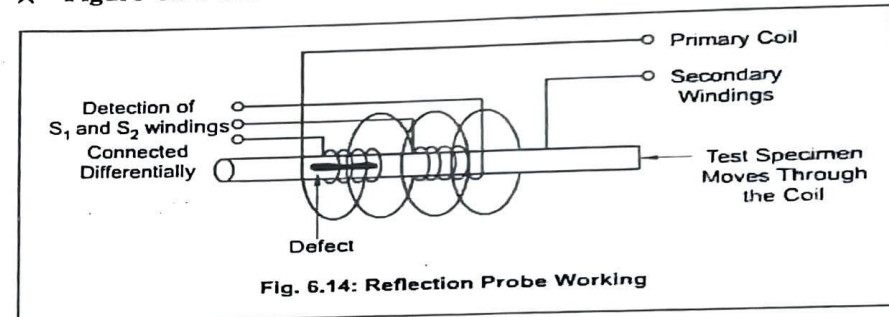


6.5.1.3. Reflection Probe:

- ★ Reflection probe combines the features of both absolute and differential probe.
- ★ In this probe, one coil is used to generate eddy current and other one is coupled to a reference standard, which evaluates the change in test specimen whenever indications from test specimen differs from the standard.

Eddy Current Testing

- ★ Figure 6.14 shows the working of reflection probe.



This type of probe has 3 windings.

- ★ One primary.
- ★ Two secondary windings.

It is also called as probe with transformer type coil.

6.5.1.4. Hybrid Probe:

- ★ It has a driver coil working on reflection mode and surrounded by two sensing coil working on differential mode.
- ★ Hybrid probes are very sensitive to surface defects only.

6.5.1.5. Comparison of Absolute and Differential Probe:

Absolute Probe	Differential Probe
• It can detect the entire length of defects. • Sensitive to probe wobble. • Interpretation of signals is simple • Prone to drift due to temperature changes. • Respond for abrupt and gradual change in properties and dimensions.	• Detects only the ends of long defects. • Less sensitive to probe wobble. • May yield signals difficult to interpret. • Immune to drift due to temperature changes. • More sensitive to abrupt localised changes.

6.6. LIFT OFF EFFECT:

- ★ The distance between a surface coil and the test surface is called as proximity or lift off.
- ★ Since flux density decreases exponentially with distance from the test coil, the amount of lift off or separation between the coil and test specimen has a significant effect on sensitivity.
- ★ The closer the coupling between coil and test specimen, the denser the eddy current field that can be developed, and thus more sensitive to any material variable.
- ★ Similarly close coupling increases the sensitivity to lift off effect, noise due to probe nobbles, when encircling coils are used. Lift off is equivalent to fill factor.

6.7. EDGE EFFECT:

- ★ This refers to the effect that the component's edge or shape changes in geometry due to the eddy currents.
- ★ This can be neglected by placing a balancing probe near to the edge and scanning at that distance.
- ★ Edge effect is phenomenon that occurs when an inspection coil is at the end of the test piece.
- ★ At that instances, eddy current flow is distorted as currents cannot flow at the edge.
- ★ In order to avoid the confusion with flaws, inspection is limited near the edges.
- ★ The distance where the edge effect present is from approximately one to three times the diameter of the inspection coils in the case of encircling probes.
- ★ So, a reduction in coil size reduces the edge effect, although there is a limit as the diameter of external encircling coils must be higher than that of the inspected materials.

6.8. FILL FACTOR:

- ★ Fill factor is number which measures how well the test piece fills the coil in external encircling probes.

Fill factor is calculated by

$$\text{Fill factor} = \frac{(\text{Diameter}_{\text{test piece}})^2}{(\text{Diameter}_{\text{coil}})^2}$$

where,

$\text{Diameter}_{\text{test piece}} \rightarrow$ Test piece diameter

$\text{Diameter}_{\text{coil}} \rightarrow$ Diameter of the coil probe.

Note: Both the diameters are measured in same unit.

- ★ Fill factor is the ratio of the cross sectional area of the test piece and area of the coil section.
- ★ It is necessary that the coil wires be as close as possible to the test piece, in order to have a greater response potential to cracks.
- ★ Fill factor should be as near as unity.

6.9. END EFFECT:

- ★ In eddy current testing, end effect is defined as the disturbance of the magnetic field eddy current distribution, impedance due to proximity of the coil to an abrupt change in geometry.
- ★ The end effect is common for cylindrical parts being inspected with encircling or inside diameter bobbin coils.
- ★ Based on the specific coil construction, an uninspected region at the end of the cylindrical part is always unavoidable because the large end effect signals can mask signals originating from defects near the tube end zone.

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6.10. IMPEDANCE PLANE DIAGRAM: (in brief)

- ★ In an eddy current testing instrumentation, eddy current circuits usually have only resistance (R) and reactance (X_L) components.
- ★ For an eddy current circuit with resistance and inductive reactance components, the total impedance is calculated using the following equation.

$$Z = \sqrt{R^2 + X_L^2}$$

where,

Z → Total impedance.

R → Resistance.

 X_L → Inductive Reactance.

- ★ The resistance and reactance component are not in phase, so vector addition must be used to relate them with impedance.
- ★ Figure 6.8 shows a simple impedance plane diagram indicating the impedance with associated angle, called as phase angle.
- ★ During inspection, the eddy current signals generated during testing of components are displayed by impedance plane diagram.
- ★ The strength of the eddy currents and the magnetic permeability of the test material causes the eddy current signal on the impedance plane.

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6.10.1. Impedance plane diagram for magnetic material:

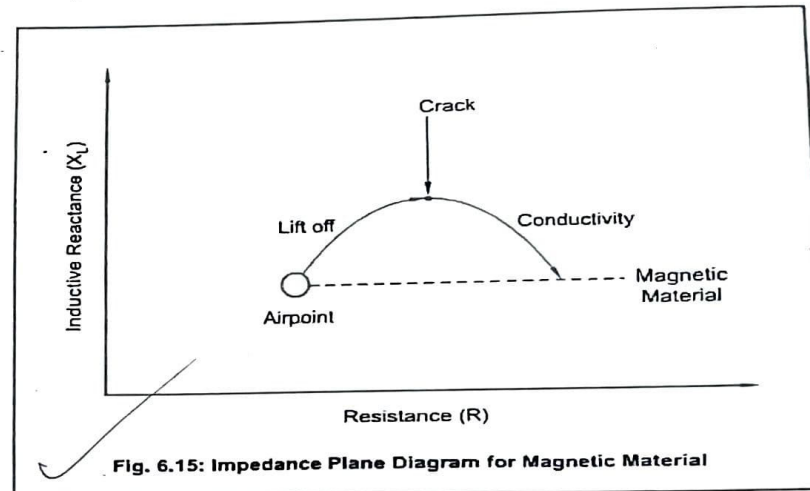


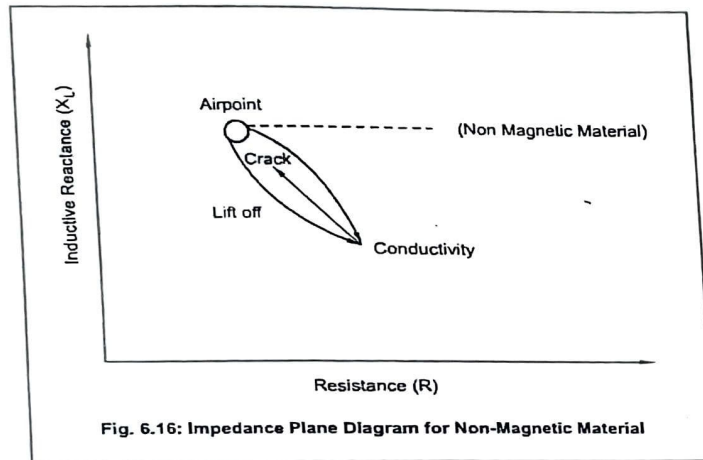
Fig. 6.15: Impedance Plane Diagram for Magnetic Material

- ★ Figure 6.15 shows the eddy current response on impedance plane for magnetic materials such as steel.
- ★ Table 6.1 shows the various display pattern and their reasons in eddy current testing for magnetic materials.

Table 6.1: Display Pattern

Display pattern	Reason
1. Decrease in the coil resistance.	Formed eddy currents taking energy away from the coil.
2. Increase in reactance	Due to magnetic permeability of the steel concentrating the coil's magnetic field.
3. Decrease in resistance and increase in inductive reactance.	Presence of crack causes fewer eddy current to form.

6.10.2. Impedance plane diagram for non-magnetic material:



- ★ Figure 6.16 shows the eddy current response on impedance plane for non-magnetic materials such as aluminium.
- ★ Table 6.2 shows the variation in display patterns and their reasons in eddy current testing for non-magnetic material.

Table 6.2

Display pattern	Reason
1. Increase in coil resistance	Eddy currents are being generated in the Aluminium and this takes energy away from the coil, which shows up increase in resistance..
2. Decrease in inductive reactance	The magnetic field created by the eddy currents opposes the coil magnetic field and the net effect is weaker magnetic field.
3. Reversal of both resistance and inductive reactance.	Presence of crack causes fewer eddy current signals.

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6.11. DEPTH OF PENETRATION:

- ★ Eddy current concentrates near to the surface adjacent to an excitation coil and their strength decreases with distance from the coil. (i.e.) Eddy current density decreases exponentially with depth. This phenomenon is known as the **skin effect**.
- ★ Skin effect arises when the eddy current flowing in the test object at any depth produces magnetic fields which oppose the primary field, thus reducing the net magnetic flux and causing a decrease in eddy current flow as the depth increases.
- ★ Alternatively eddy current near the surface can be viewed as shielding the coil's magnetic field, thereby weakening the magnetic field at greater depths and reducing induced currents.
- ★ It is mathematically convenient to define the "standard depth of penetration" where the eddy current is 37% of its surface value.

6.12. RELATION BETWEEN FREQUENCY AND DEPTH OF PENETRATION:

- ★ The depth of penetration of eddy currents in a material is a critical factor.
- ★ For example, in the case of tube inspection, if the eddy currents do not penetrate the wall thickness of the tube, then it is possible to miss the defects.
- ★ The depth of penetration of eddy current can be found by the relation.

$$\delta = \frac{500}{\sqrt{\sigma \mu f}} \quad \dots (1)$$

where,

$\delta \rightarrow$ Standard depth of penetration (mm)

$\sigma \rightarrow$ Conductivity (mhos/m)

$\mu \rightarrow$ Relative permeability.

$f \rightarrow$ Inspection frequency (Hz).

- ★ The standard depth of penetration is generally taken to be the depth of which the eddy current field intensity drops to 37% of the intensity at the surface of the conductor.
- ★ Higher the frequency, lower the depth of penetration.
- ★ Thus a frequency must be chosen which permits penetration to the depth upto which defects are to be found.
- ★ For general tube inspection, the frequency used is often the frequency at which the standard depth of penetration is equal to the wall thickness of the tube. This given by the equation,

$$f = \frac{250}{\sigma t^2} \text{ kHz} \quad \dots (2)$$

$t \rightarrow$ wall thickness of the tube in mm.

Equation (1) shows that higher the permeability, lower is the depth of penetration.

- ★ Since relative permeabilities of ferromagnetic materials are of 500 to 2000, eddy currents in these materials are concentrated at the surface.
- ★ Subsurface defects are not detectable in ferromagnetic materials.
- ★ Small variations in permeability gives rise to relatively high impedance change.
- ★ Conventional ECT fails to inspect ferromagnetic materials.

13 APPLICATIONS OF EDDY CURRENT TESTING:

1. Detection of Discontinuities / surface breaking cracks.
2. Conductivity measurement.
3. Inspection of tube.
4. Thickness measurement.

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6.13.1 Detection of Discontinuities: (defect detection)

- ★ Eddy current testing is an excellent method for detecting surface and near surface defects.
- ★ Defects such as cracks are detected when they disrupt the path of eddy currents and weaken their strength.
- ★ The sensitivity of eddy current inspection to detect surface discontinuities depends on the factors such as type of material, surface finish and condition of the material, the design of the probe.
- ★ For surface flaws, the frequency should be as high as possible for maximum resolution and high sensitivity.
- ★ For subsurface flaws, lower frequencies are preferred to set the required depth of penetration and this results in less sensitivity.
- ★ High conductive or ferromagnetic materials require the use of an even lower frequency to arrive at some level of penetration.

The steps involved in identification are listed below:

1. Selection of Instrument and Probe:

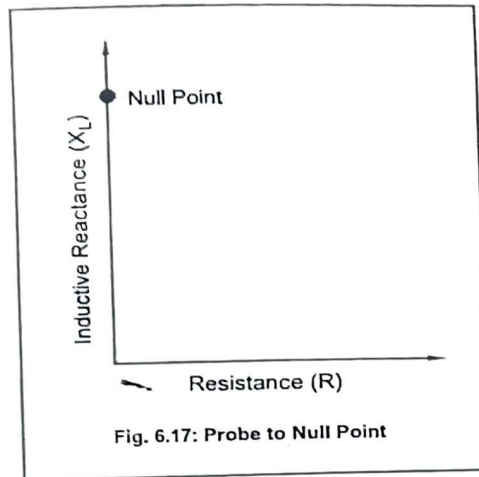
- ★ The instrument includes the basic devices such as oscillator, probe/coil, signal processing and display.
- ★ To test surface cracks, pancake probe or surface probe is preferred.

2. Selection of frequency to produce the desired Depth of Penetration:

- ★ Depth of penetration depends on frequency, conductivity and permeability.
- ★ High frequency is used for surface cracks and low frequency is used to locate deeper cracks.

3. Placing the coil probe and setting the instrument to Null point:

- ★ Place the coil (probe) on the surface of the component to be tested and set the instrument to null point as shown in **Figure 6.17**.

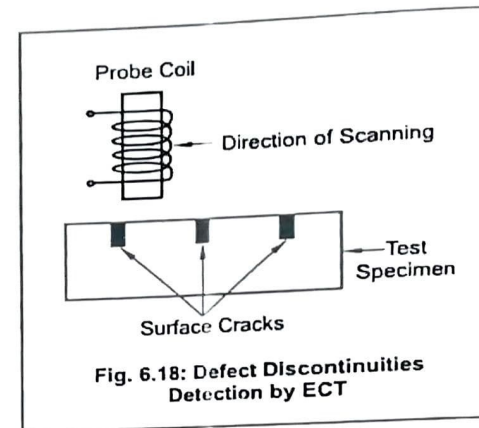


4. Scanning the surface by moving the probe in a pattern:

- ★ When the probe is moved over the surface of the specimen, eddy current strength is altered due to presence of crack.
- ★ Depending on the density and phase lag of interrupted eddy current circulation, signal response is displayed through impedance plane.
- ★ Since a discontinuity of any size will possess some degree of thickness, it will interrupt eddy currents over a range of current densities and phase lag depending on the dimension, shape and orientation of the discontinuity.

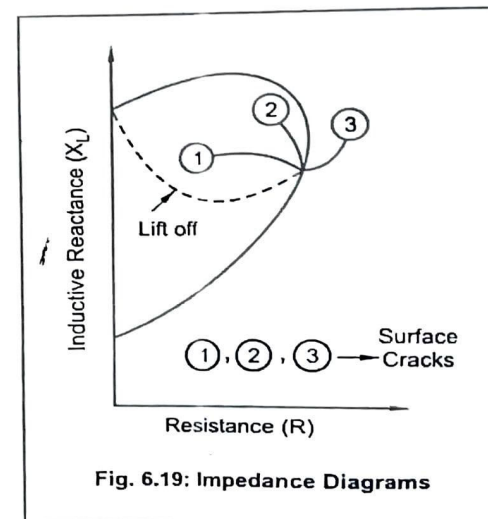
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- ★ **Figure 6.18** shows inspection of surface crack on the given plate.



5. Monitoring the signal for a change in Impedance:

- ★ The effect of crack depth from the surface is shown in impedance diagram of **Figure 6.19**.



- ★ With increasing depth of crack from the test surface, the impedance locations are:

(1) – Nearer to the surface.

(3) – Crack at greater depth

- ★ Figure 6.19 shows that a change in impedance includes a change in magnitude as well as phase.

- ★ The direction of movement of the signal curve reveals the possible discontinuity in the material.

6.13.2. Conductivity Measurements for the Verification of Heat Treatment:

- ★ One of the uses of eddy current instruments is for the measurement of electrical conductivity.
- ★ The value of the electrical conductivity of a material depends on several factors such as its chemical composition and the stress state of its crystalline structure.
- ★ Electrical conductivity information can be used for sorting metals, checking for proper heat treatment, and inspecting for heat damage.
- ★ The technique usually involves nullifying an absolute probe in air and placing the probe in contact with the sample surface.
- ★ For non magnetic materials, the change in impedance of the coil can be correlated directly to the conductivity of the material.
- ★ The technique can be used to easily sort magnetic materials from non-magnetic materials but it is difficult to separate the conductivity effects from the magnetic permeability effects, so conductivity measurements are limited to non-magnetic materials.

- ★ When the probe is brought near a conductive but non-magnetic material, the coil's inductive reactance goes down since the magnetic field from the eddy current opposes the magnetic field of the coil.
- ★ The resistance in the coil increases since it takes some of the coil's energy to generate the eddy currents and this appears as additional resistance in the circuit.
- ★ As the conductivity of the materials being tested increases, the resistance losses will be less and the inductive reactance changes will be greater.
- ★ With some materials like aluminium alloys, conductivity measurements are often made verifying that parts and materials have received the proper heat treatment.
- ★ High purity aluminium is soft and ductile and gains strength and hardness with the addition of alloying elements.

6.13.3. Inspection on tube:

- ★ Eddy current inspection is often used to detect corrosion, erosion, cracking and other changes in tubing.
- ★ Heat exchanger and steam generators, which are used in power plants, have many tubes which must be prevented from leaking.
- ★ For the nuclear power plants where reused contaminated water must be prevented from mixing with fresh water that will be returned to the environment.
- ★ The contaminated water flows on one side of the tube and the fresh water flows on the other side.
- ★ The heat is transferred from the contaminated water to the fresh water and the fresh water is then returned back to its source, usually a lake or river.

- ★ A technique that is often used involves feeding a differential bobbin probe into the individual tube of the heat exchanger.
- ★ With the differential probe, no signal will be seen on the eddy current instrument as long as no metal thinning is present.
- ★ When metal thinning is present, a loop will be seen on the impedance plane as one coil of the differential probe passes over the flawed (damaged) area and a second loop will be produced when the second coil passes over the damage.
- ★ When the corrosion is on the outside surface of the tube, the depth of corrosion is indicated by a shift in the phase lag.
- ★ The size of the indication provides an indication of the total extent of the corrosion damage.

✓ *coating* 6.13.4. Thickness Measurement:

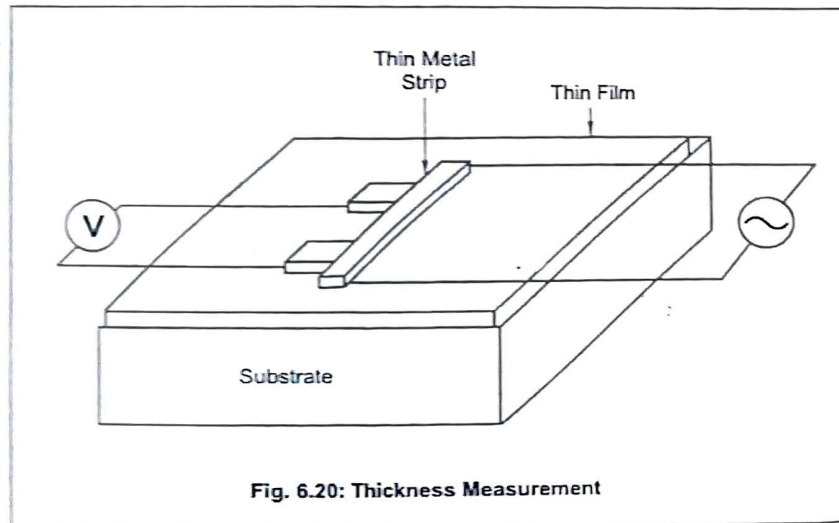


Fig. 6.20: Thickness Measurement

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- ★ Eddy current techniques are used to measure the thickness of hot sheet, strip and foil in rolling mills and to measure the amount of metal thinning that has occurred over time due to corrosion on skins of aircraft.

For thin material:

- ★ When making this measurement, it is important to keep in mind that the depth of penetration of the eddy current must cover the entire range of thicknesses being measured.
- ★ A frequency is selected that produces about one standard depth of penetration at the maximum thickness.
- ★ At lower frequencies, which are often needed to get the necessary penetration, the probe impedance is more sensitive to changes in electrical conductivity.
- ★ The effect of electrical conductivity cannot be phased out and it is important to verify that any variations of conductivity over the region of interest are at a sufficiently low level.

Thickness measurements of Non-conducting Coating:

- ★ The thickness of non-metallic coatings on metal substrates can be determined simply from the effect of lift off on impedance.
- ★ The coating serves as a spacer between the probe and the conductive surface.

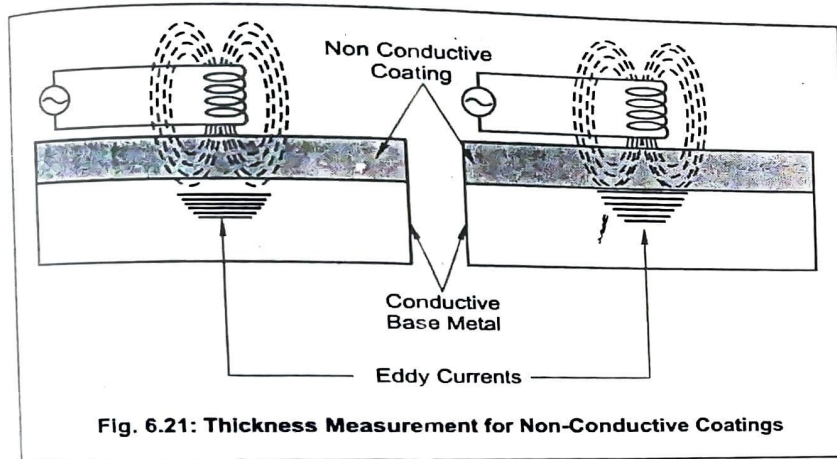


Fig. 6.21: Thickness Measurement for Non-Conductive Coatings

- ★ As the distance between the probe and the conductive base metal increases, the eddy current field strength decreases because less of the probe's magnetic field can interact with the base metal.
- ★ Thickness between 0.5 and 25 μm can be measured to an accuracy between 10% for lower values and 4% for higher values.
- ★ Contribution to impedance changes due to conductivity variations should be phased out, unless it is known that conductivity variations are negligible, as normally found at higher frequency.

6.14. ADVANTAGES OF EDDY CURRENT TESTING:

1. High speed testing.
2. Accurate measuring of conductivity.
3. Discontinuities at or near surface can be reliably detected.
4. This technique can be automated.

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5. It can detect flaws through surface coatings.
6. No physical contact required.
7. It provides immediate results of inspection.
8. Low costs.
9. Portable.
10. Complex shape can be inspected.

6.15. DISADVANTAGES OF EDDY CURRENT TESTING:

1. Limited penetration into test piece.
2. Only suitable for testing conductive materials.
3. Discontinuities are qualitative not quantitative indications.
4. Not suitable for large areas
5. Highly skilled persons are required to perform inspection.
6. False indications can result from edge effects and parts geometry.

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7. Maintaining distance between the probe and test specimen is essential.
8. No permanent record is possible.
9. Interpretation of signal is required.
