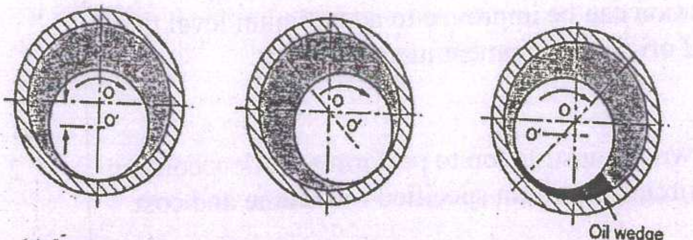
SCHEME OF EVALUATION

(Scoring Indicators)

REVISION: 2015 **COURSE CODE: 6026**

COURSE TITLE: Maintenance Engineering

Qst. No.	Scoring Indicator	Split up score	Sub Total	Total
	PART A			
I.1	Break down maintenance Planned maintenance Planned maintenance may further be categorized into the following types. a) Preventive maintenance b) Corrective maintenance c) Predictive maintenance d) Condition based maintenance (CBM) e) Reliability centered maintenance (RCM)	4X1/2	2	2
I.2	Failure density is the ratio of number of failures during a given unit interval of time to the total number of items at the very beginning of the test. Failure density $= \frac{n}{N}$	2	2	2
I.3	Vibration Condition Monitoring helps reduce the possibility of catastrophic failures, increasing safety and machine performance. Through Vibration Condition Monitoring machinery operation can be improved to an optimum level that can often exceed original equipment manufacturers specifications.	2	2	2
I.4	A job order is a written instruction to perform a work according to specified requirements within specified timeframe and cost estimates.	2	2	2
I.5	It is an analytical method of assessing machine condition by quantifying and examining wear particles suspended in the lubricant or hydraulic fluid.	2	2	2

	PART B			
II.1	1. Lower production unit cost 2. Reduced maintenance cost and reduced lifecycle cost 3. Better process stability 4. Extended equipment life and lesser asset replacement 5. Reduced maintenance part inventory 6. Reduced overtime and reduced out-sourcing 7. Improved employee safety 8. Reduced risk of environmental issues	6x1	6	6
II.2	**Hydrodynamic or fluid film lubrication:** In heavily loaded machineries which are thrust bearings and horizontal journal bearings higher fluid pressure is required to support the load. If the pressure is generated externally, it is called hydrostatic lubrication and if generated internally i.e. within the bearing by dynamic action and it is referred to as hydrodynamic lubrication. In hydrodynamic lubrication, a fluid wedge is formed by the relative surface motion of journals over their bearing surfaces. The operation of thrust bearing and operation of journal or sleeve bearing are examples of hydrodynamic lubrication. When the journal is at rest, its weight will squeeze the oil film so that the journal directly rests on the bearing surface. During operation, the journal has the tendency to roll up. So, the fluid adhering to the journal is drawn into contact area and when the speed increases an oil wedge is formed which is shown in the following figure.  *(a) Journal at rest* *(b) Journal starts to rotate* *(c) Journal at full speed* **Hydrodynamic Lubrication**	3+3	6	6
II.3	**Mean Time Between Failures (MTBF)** Mean Time Between Failures (MTBF) is the mean or average time between successive failures of a product.	3+3	6	6

	MTBF refers to the average time of breakdown until the device is beyond repair. $$MTBF = \frac{\sum(start\ of\ down\ time - start\ of\ up\ time)}{Number\ of\ failure}$$ $$MTBF = \frac{Total\ working\ of\ equipment}{Number\ of\ failure}$$ $$= \frac{1}{failure\ rate}$$ **Mean Time To Repair (MTTR)** Mean Time To Repair (MTTR) is the arithmetic mean of time required to perform maintenance action. MTTR is defined as the ratio of total maintenance time and number of maintenance action. $$MTBF = \frac{Total\ maintenance\ time}{Number\ of\ maintenance\ action}$$ MTTR consists of two separate time intervals: **passive repair time and active repair time.**			
II.4	1) Cost of maintenance from the recorded data (past experience) 2) Level and requirements of maintenance 3) Cost of spare parts and materials 4) Cost of replacement of components and assemblies subjected wear and tear 5) Accounting the number of breakdowns with their levels 6) Downtimes of the equipment for want of maintenance and repair 7) Penalty cost due to the loss of production 8) Cost of manpower involved 9) Cost of additional manpower requirements for emergency breakdown and maintenance. 10) Component of maintenance cost:	6x1	6	6
II.5	Wear Debris Analysis (WDA) is related to oil analysis in which particles to be studied are collected through drawing a sample	6	6	

	of lubricating oil. By studying the particle shape, composition, size and quantity significant information about the wearing condition of the machine can be obtained. Optical methods, Filter blockage, Magnetic attraction, Ultrasound, Radioactivity, Electrical conductance, Image analysis			6
II.6	Three types of unbalance are: 1. Static unbalance 2. Dynamic unbalance 3. Couple unbalance Static unbalance: Occurred when the inertial axis of a rotating mass is displaced from and parallel to the axis of rotation. Static unbalance can occur more frequently in disk shaped rotors because the thin geometric profile of the disc allows for an uneven distribution of mass with an intertial axis that is nearly parallel to the axis of rotation. Dynamic unbalance: In rotation an unbalance when the mass/inertia axis does not intersect with shaft axis then it is call dynamic unbalance. Combination of static and couple unbalance is dynamic unbalance. Couple unbalance: A couple unbalance occurs when a rotating mass has two equal unbalance forces that are situated 180 degrees opposite each other. A system that is statically balanced may still hace a couple unbalance. Couple unbalance occurred frequently in elongated cylindrical rotors.	3X2	6	6
II.7	The liquid penetrant test is one of the oldest methods of non-destructive testing. It is based on the old oil and whiting process. LPT can be used to inspect almost any material such as Metals, Glass, ceramic, Rubber, plastics etc provided that its surface is not extremely rough or porous. Liquid penetrant inspection is used to inspect flaws like fatigue cracks, quench cracks, grinding cracks, overload and impact fractures, porosity, laps, seams, pin holes in welds, lack of fusion or braising along the edge of the bond line. The penetrant test procedure consists of following six basic processing steps. 1. Pre-cleaning and drying of test object surfaces to be inspected 2. Applying liquid penetrant to surface to be inspected and permitting it to seep into surface discontinuities. 3. Removing excess liquid penetrant from test surface 4. Applying developer to test surface to enhance indications formed by penetrant entrapments in discontinuities 5. Inspecting surface for penetrant indications 6. Post-cleaning to remove process residues (In some cases, a treatment to prevent corrosion may be required).	6	6	6

	PART C **UNIT I**			
III.(a)	1. It reduces friction between moving parts by separating them. 2. It reduces wear and tear of the moving parts. 3. It minimizes the power loss due to friction. 4. It provides the cooling effect: During circulation, it carries the heat from hot moving parts and delivers it to surrounding. 5. It provides the cushion effect. 6. It provides the cleaning action. 7. It provides a sealing action. It helps the piston rings to provide an effective seal against high pressure gases in the cylinder from leaking out. 8. It reduces noise.	8X1	8	8
III.(b)	It is a maintenance program which is committed to the prevention of break down maintenance. A comprehensive preventive maintenance program involves the periodical evaluation of critical equipment, machinery to detect problem and schedule maintenance task to avoid degradation in operating conditions. **Advantages of Preventive Maintenance** a) In general, the cost incurred towards breakdown maintenance is usually higher than the cost incurred on preventive maintenance. b) It keeps equipment in good condition to prevent large problems. c) It prolongs the effective life of the equipment. d) It detects the problem at earlier stages. e) It reduces the equipment or process failure. f) It reduces unplanned downtime g) It keeps equipment safer h) The parts stocking levels can be optimized **Disadvantages of Preventive Maintenance** a) Catastrophic failures still likely to occur. b) Performance of maintenance based on schedule is not required. c) Labour intensive. d) It includes performance of unneeded maintenance. e) Risk of damage when conducting unneeded maintenance. f) Saving not readily visible without a base line.	1+3+3	7	7

<table>
<tr><td>IV.(a)</td><td>1. Plant management in maintenance work
2. Production and maintenance objectives
3. Establishment of work order and recording system
4. Information based decision making
5. Adherence to planned maintenance strategy
6. Planning of maintenance functions
7. Manpower for maintenance
8. Workforce control
9. Role of spare parts
10. Training of the maintenance workforce</td><td>8X1</td><td>8</td><td></td><td>8</td></tr>
<tr><td>IV.(b)</td><td>Total Productive Maintenance (TPM) is a maintenance program which involves a newly defined concept of maintaining plants and equipment. The goal of TPM program is to, significantly increase the production at the same time increasing employee morale and job satisfaction. The preventive maintenance along with maintenance prevention and maintainability improvement gave birth to TPM. The aim of TPM was to maximize plant and equipment effectiveness to achieve the optimum life cycle cost of equipment.

TPM and TQM
<u>Similarities</u>
In many of the aspects, TPM is found to have similarity with the well-known Total Quality Management (TQM) program. The following are the similarities between them.
1. Empowerment of employees to initiate corrective action, bench marking and documentation.
2. Top level management committed to the program.
3. Long range outlook perspective.
<u>Dissimilarities</u>
<table>
<tr><th>Category</th><th>TQM</th><th>TPM</th></tr>
<tr><td>Objective</td><td>To have quality output.</td><td>To have reliable equipment.</td></tr>
<tr><td>Means of achieving</td><td>Thorough systematized management</td><td>Thorough active participation of employees.</td></tr>
<tr><td>Target</td><td>Minimized defective through planned preventive maintenance.</td><td>Elimination losses and wastes.</td></tr>
</table></td><td>1+3+3</td><td>7</td><td></td><td>7</td></tr>
<tr><td>

V.(a)</td><td><u>UNIT II</u>

Reliability engineering is engineering that emphasizes dependability in the lifecycle management of a product. The failure pattern of equipment over its whole lifecycle can be represented as bath-tub curve. This curve represents the pattern of failure for many products, especially complex products such as cars and washing machines. The bath-tub curve is divided into three regions such as infant mortality, useful life and wear- out.</td><td>4 +4</td><td>8</td><td></td><td>8</td></tr>
</table>

3) Operational availability

Inherent Availability

Inherent availability is the probability that a system or equipment shall operate satisfactorily when used under prescribed conditions in an ideal support environment without any scheduled or preventive maintenance at any given time.

$$\text{Inherent availability} = \frac{\text{MTBM}}{\text{MTBM} + \text{MTTR}}$$

Ideal support environment means the ready availability of tools, spare parts, manpower, manual, etc.

Achievable Availability

Achievable availability is the probability that a system or equipment shall operate satisfactorily when used under prescribed conditions in an ideal support environment with periodic preventive and corrective maintenance at any given time.

$$\text{Achievable availability} = \frac{\text{MTBM}}{\text{MTBM} + \text{M}'}$$

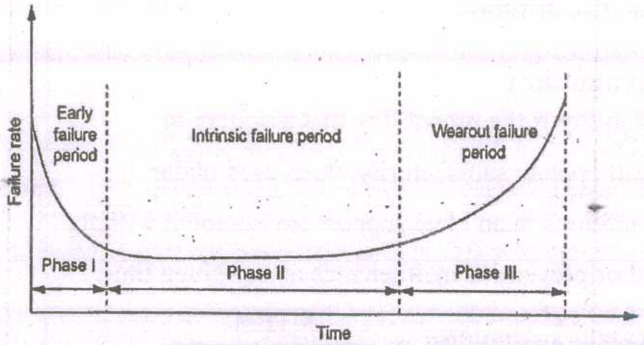
Where M' is the mean active maintenance downtime resulting from preventive and corrective maintenance.

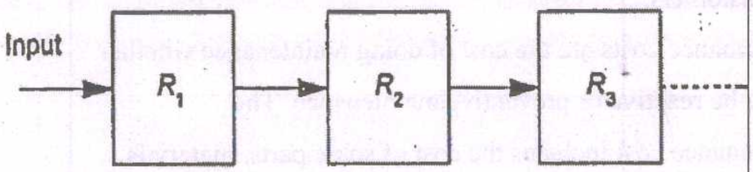
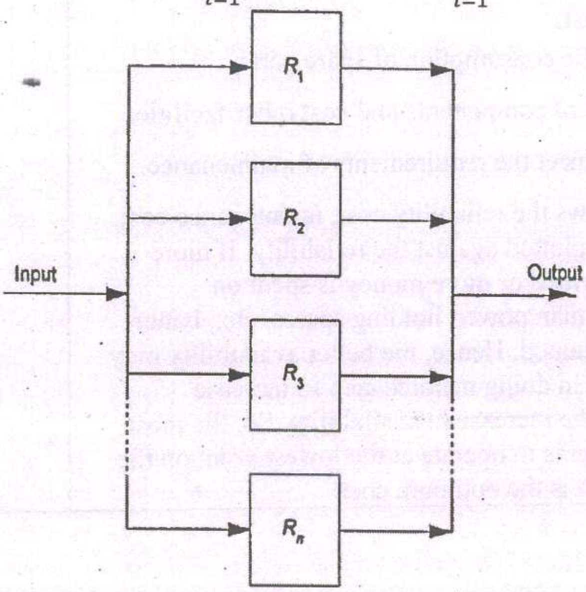
Operational Availability

In industrial system, a certain amount of delay will always be caused by time element such as supply downtime and administrative downtime. Operational availability is the probability that a system or equipment shall operate satisfactorily when used under prescribed conditions in an actual supply environment without any scheduled or preventive maintenance at any given time.

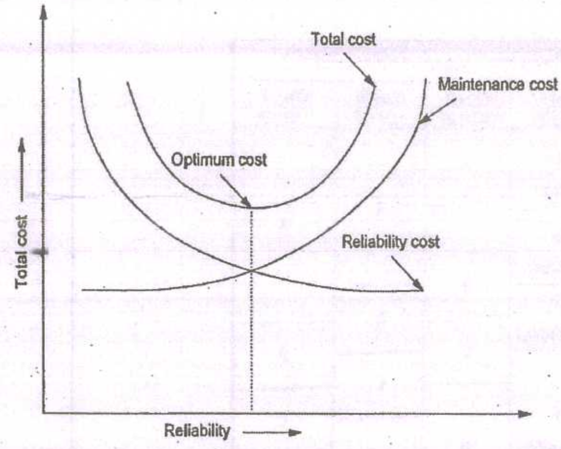
$$\text{Operational availability} = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}$$

In general, the availability of a system is a complex function of reliability, maintainability and supply effectiveness.

	 In Phase I, the failure is inherent in a new product because of manufacturing or design defects. Therefore, the failure rate at the beginning of infant mortality stage is high and then it decreases with time after early failures are removed by different methods. It is referred infant mortality period of equipment. Phase II shows the useful life period of an equipment where the failures rates are normally moderate as the equipment gets set to the working environment. This period is usually given the most consideration during design stage and it is the most significant period for reliability prediction and evaluation activities. In Phase III, the failures are occurring due to wear out failures which are caused due to aging of the equipment. The equipment life cycle is the essential requirement for the prediction of system reliability.			
V.(b)	Availability is the ratio of the time at which the equipment is available for the designated operation/service to the total time of operation and maintenance of the equipment. It is also defined as the ratio of equipment uptime to the equipment uptime and downtime over a specified period of time. $\text{Availability} = \frac{\text{System uptime}}{\text{System uptime} + \text{System downtime}}$ $Availability = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}}$ There are three types of availability are defined on the basis of time element. They are 1) Inherent availability 2) Achieved availability	1+6	7	7

VI.(a)	**Series Reliability Model** In this model, the components are arranged in series and the success of the system depends on the success of all of its components. Consider the reliability model as shown in following figure. Here n components having reliabilities as R_1, R_2 ...Rn are connected in series. In this system, the failure of any component puts the complete system in down position. The reliability of the complete system would be $$R_s = R_1 \times R_2 \times R_3 \times ... R_n = \prod_{i=1}^{n} R_i$$  **Parallel Reliability Model** In this model, the system can be partially operative even if some of its components are in the state of failure. Consider the reliability model as shown in following figure. Here n components having reliabilities as R_1, R_2 ...Rn are connected in parallel. The total system reliability can be calculated by the product law of unreliability of the system. $$R_s = 1 - \prod_{i=1}^{n}(1 - R_i) = 1 - \prod_{i=1}^{n}\left(1 - e^{-\lambda_i T}\right)$$  	4+4	8	8

VI.(b)	Reliability cost is the business cost of unreliable systems. If little or no maintenance is performed, the equipment becomes unreliable and they may produce defective parts. In such case, important orders may be missed or the equipment consumes more energy. They can also be other costs of unreliable systems such as environmental and occupational health and safety costs. The net result is poor customer satisfaction and lost customers. Maintenance costs are the cost of doing maintenance whether it may be reactive or preventive maintenance. The maintenance cost includes the cost of spare parts, materials, man power and expenditure involved on services such as electricity, water, gas etc. The maintenance cost also involves the cost of downtime of the equipment. The maintenance cost is comprised of two factors. 1. **Fixed cost:** It includes the cost of support facilities including the maintenance staff. 2. **Variable cost:** It includes the consumption of spare parts, replacement of components and cost other facilities required to meet the requirements of maintenance. Following figure shows the reliability cost, maintenance cost and total cost curves plotted against the reliability. If more maintenance is performed or more money is spent on maintenance such as man power, holding spares, etc., better reliability may be obtained. Hence, the better availability may be obtained but costs in doing maintenance so increase disproportionally to the increase in availability. So, the most cost effective situation is to operate at the lowest point on the total cost curve which is the optimum cost.	Fig 3 2+2	7	7

				
	UNIT III			
VII.(a)	• Temperature crayons, tapes • Thermometer and optical pyrometer • Thermocouple and fusible plug • Infrared meter • Thermography • Bimetallic strip. • Vapour pressure in bulbs • Mercury in glass.	Short Explanations on any 4 4X2	8	8
VII.(b)	Machinery vibration standards are intended for the following purposes 1. To set up criteria for rating or classifying the performance of equipment or material 2. To provide a basis for comparison of the maintenance qualities of pieces of equipment of the same type 3. To test equipment whose continuous operation in necessary for industrial or public safety 4. To provide a basis for the selection of equipment or material 5. To setup a procedure for the calibration of equipment. ISO 2372 Standards provide guidance for evaluating vibration severity in machines operating in the 10 to 200Hz (600 to 12,000 RPM) frequency range. Examples of these types of machines are small, direct coupled, electric motors and pumps, production motors, medium motors, generators, steam and gas turbines, turbo compressors, turbo-pumps and fans. Some of these machines can be coupled rigidly or flexibly, or connected though shaft may be horizontal, vertical or inclined at any angle. The Table can be used to judge the overall Vibration severity of the equipment.	7	7	7

Vibration velocity in mm/sec RMS	Vibration severity ranges for machines belonging to: Class I < 20 HP	Class II 20-100 HP	Class III >100 HP	Class IV >100 HP
0.28				
0.45	A			
0.71	(Good)	A	A	
1.12	B			A
1.80	(Satisfactory)			
2.80	C	B		
4.50	(Unsatisfactory)		B	
7.10		C		B
11.2	D		C	
18.0	(Unacceptable)	D		C
28.0			D	
45.0				D

For conventional vibration overall measurements, there exist a number of general machinery vibration severity charts developed through years. However, it is almost impossible to develop a universal overall level spike energy severity chart for general machinery applications. This is due to the fact that too many variables involved such as different machine types, operating conditions, accelerometers, mounting methods and ambient conditions. On the other hand, it is possible to develop an overall spike energy severity chart based upon empirical data for certain type of machines. General machinery vibration severity chart is used by vibration analyst for setting alarm level at different points of machine.

VIII.(a)

1. Imbalance of rotating parts
2. Eccentric components
3. Misalignment of couplings and bearings
4. Bent shafts
5. Component looseness
6. Worn or damaged gears
7. Bad drive belts and drive chains
8. Bad antifriction bearings
9. Torque variations
10. Aerodynamic forces
11. Hydraulic forces
12. Resonance
13. Rubbing

8X1 | 8 | 8

VIII.(b)

SPM used to analyse the vibration of bearing. SPM Method detects development of a mechanical shock wave caused by the impact between two masses. At the instantaneous moment of impact, molecular contact occurs and a compression (shock) wave develops in each mass. The SPM Method is based on the events occurring in the mass during the extremely short time period after the first particles of the colliding bodies come in

7 | 7 | 7

	contact. This time period is so short that no detectable deformation of the material has yet occurred. The molecular contact produces vastly increased particle acceleration at the impact point. SPM Instrument uses a piezo-electric accelerometer to measure the mechanical impact or shock pulse, without being influenced by other factors such as background vibration and noise.			
IX.(a)	**UNIT IV** There are many types of equipment records available in industry catering to various needs. They are as follows. 1. Equipment history cards and records 2. Planned work and percentage of planned work achieved 3. Ratio of planned to performed work 4. Production delays and downtime 5. Ratio of preventive work to corrective work 6. Failure patterns 7. Repetitive breakdown 8. Manuals including operating manual, instruction manual, maintenance manual, job manual and drawing 9. Spare cards 10. Maintenance requirement records 11. Performance details 12. Cost reports 13. Condition monitoring reports Advantages of Equipment Records 1. Clear picture about the details of maintenance programmes is obtained 2. Information about completed, pending and regular jobs carried out to the equipment is available. 3. Records can be retrieved easily and quickly 4. Records can be distributed to various units of the industry easily 5. It helps in standardisation of procedures 6. It helps in evaluation of performance of maintenance tasks 7. It provides the details of frequency of maintenance requirements for each job manual and drawings equipment 8. It helps in comparison of time taken for completing the maintenance job with the past records. 9. It provides the strategies for better maintenance management	4+4	8	8

IX.(b)	Ultrasonic testing is a NDT method that uses sound waves having frequencies in the mega cycle range. Sound waves can pass through solids without any absorption. It can also be reflected from a surface. Hence, ultrasonic waves are used in this test. These ultrasonic Waves are produced by a transducer. The transducer can change the high frequency electrical energy into ultrasonic sound waves and vice versa. The transducer which converts high frequency electrical energy into ultrasonic sound waves is called transmitter. There are two transducers placed on the surface to be inspected. One transducer acts as a transmitter probe. The other one act a receiver probe. The receiver probe is connected to a monitor. In recent days, only one transducer is used for both transmission and reception to scan the entire volume of components. The direction of scanning is changed suitably to detect defects oriented in different directions. Ultrasonic testing is widely used for the detection of internal defects in materials. Audible sound waves have frequencies ranging from about 20Hz to 20Hz. The waves used in ultrasonic are way beyond the audible region having frequencies ranging from about 0.5 MHz to 20MHz. **Testing procedure** Following shows the basic principles of the ultrasonic method for detecting internal defects. The probe contains a piezoelectric crystal which transmits ultrasonic waves into the material when an alternating potential difference is applied across it. When high frequency AC power is supplied to the transmitter probe, it will pass the ultrasonic waves through the work. If the work is defect free, the wave	4+Fig 3	7	7

will strike the bottom of the work and return to the receiver. The striking of waves at the bottom surface and top surface are indicated in the form of normal pip in the monitor. If there is any defect in between the top and bottom surfaces, the wave is reflected back from that spot, and it is indicated as a short pip in the monitor.

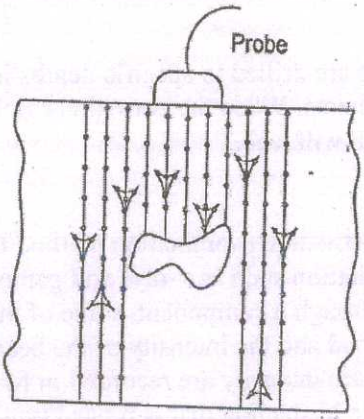
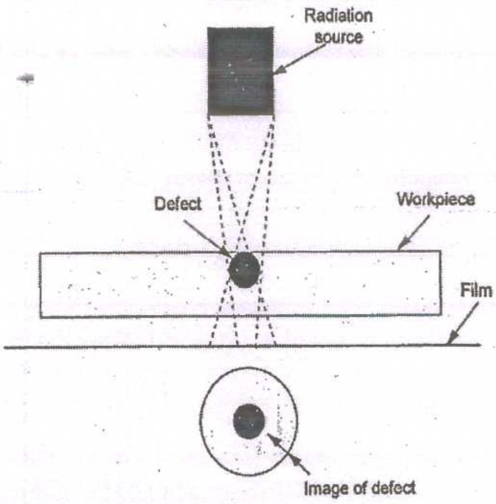


Figure 1 – Ultrasonic Testing

X.(a)	1.Weight loss method This technique is most commonly used for general and localized corrosion. The weight loss of the material of known surface area is determined in the specific environment for a known time period. From this, the corrosion rate can be calculated. 2. Electrical resistance method A probe which consists of a thin wire is inserted into the process fluid. As the wire corrodes it's cross-sectional area reduces and the electrical resistance increases. It can be measured with a suitable bridge circuit to give a continuous signal related to the rate of corrosion. 3. Linear Polarization method Corrosion is an electrochemical reaction and the slope of the current curve is inversely proportional to the reaction rate on the electrode surface. It can be related to the rate of corrosion. This technique is used for finding out the rate of corrosion in electrically conductive corrosion fluid. 4. Corrosion potential measurement The electrical potential between plant being maintained and a	4X2	8	8

	reference electrode can be related to the rate of corrosion. This technique is useful where the material shows both active and passive corrosion behaviour in the process and it can be used to indicate the development of active corrosion. 5. Ultrasonic Testing An ultrasonic pulse is sent from one side of the component and the time is measured to reflect from the other side and return. It indicates the thickness of the material and it is a valuable method for monitoring pipe wall thickness and pressure vessel wall thickness. 6. Sentinel hole method In this method, small holes are drilled to specific depths in a pipewall or similar components. When the corrosion reaches the bottom of the hole, the wall will leak.			
X.(b)	Radiography is a non- destructive examination method that uses a beam of penetrating radiation such as x-rays and gamma rays. When the beam passes through a component, some of the radiation energy is absorbed and the intensity of the beam is reduced. Variations in beam intensity are recorded in film and they are seen as difference in shading that is typical types and sizes of any flaws present. Three basic elements of radiograph are a radiation source or probing medium, the test piece or object being evaluated and a recording medium which (usually film). Variations in the intensity of x-rays or gamma rays that pass through a material can be presented as a (a) visible permanent image, (b) visible real time image and (c) meter reading. A permanent image is recorded in an X-ray film, radiographic paper etc. X-ray film is used more extensively than all other recording mediums. Radiography can be used with most materials for the detection of both internal and surface defects.	7	7	7

	 **Figure 2 – Radiography Test** **Applications:** 1. Radiography can be used to inspect most types of solid material, both ferrous and non-ferrous alloys as also non-metallic materials and composites. 2. It can be used to inspect the condition and proper placement of components for proper liquid fill level in sealed components, etc. 3. The method is used extensively on castings, weldments, forgings and parts when there is a critical need to ensure freedom from internal flaws. 4. Radiography is well suited to the inspection of semiconductor device for cracks, broken wires, unsoldered connections, foreign material and misplaced components, whereas other methods are limited in ability to inspect semiconductor devices.				