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Bengaluru

Mid Term Examinations - October 2026

Date: 05/10/2026 **Time:** 11:45 AM - 01:15 PM

Course Code: MEC3441 **Course Name:** Reliability and Maintenance in Oil and Gas Industry

Semester: Seventh Semester **Max. Marks:** 50 **Weightage:** 50%

CO - Levels	CO1	CO2	CO3
Marks	24	42	24

ANSWER KEY

PART A: Answer Following Questions. 10 M

Q.N.	Questions	M	CO	BT
1	• **Advantages:** (1) Highly portable, low equipment cost, and straightforward visual interpretation. (2) Applicable to non-ferromagnetic and non-conductive materials (e.g., austenitic stainless steel, aluminum alloys). • **Limitation:** Can only detect flaws that break the surface; ineffective on subsurface defects or porous materials, and requires rigorous surface cleaning.	2	CO1	BT2

2	• Model Answer / Key Points:
	  • **Working Principle:** An alternating current in an inspection coil generates an alternating magnetic field, inducing eddy currents in an adjacent conductive material. Surface/near-surface flaws disrupt current flow, altering the coil's electrical impedance.
	  • **Application:** Rapid in-service baseline inspection of thin-walled non-ferrous condenser and heat exchanger tubes to detect pitting and stress corrosion cracking.
		2	CO1	BT2

3	• **Definition:** The inability of an asset to fulfill its intended functions to the specified performance standard required by the user.
	• **Examples:**
	  • *Gas Compressor:* Inability to discharge gas at the required flow rate or pressure, or automated shutdown triggered by seal leakage.
	  • *Subsea Pipeline:* Loss of containment resulting in product loss, pressure drop, or hydrocarbon release into the sea.
		2	CO2	BT2

4	• **Formula:**
	$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{J}}$$
	• **Parameters:**
	  • K = Torsional stiffness of the shaft ($\mathrm{N \cdot m/rad}$)
	  • J = Mass polar moment of inertia of the rotating disc/rotor ($\mathrm{kg \cdot m^2}$)
	  • f_n = Torsional natural frequency (Hz)
		2	CO3	BT2

5	• **Equation:** $$C = I\omega\Omega$$ where I is mass moment of inertia, ω is spin angular velocity, and Ω is precession angular velocity. • **Right-Hand Screw Rule:** Rotate the spin vector by 90° in the direction of the precession axis; the advance of a right-hand screw indicates the vector direction of the gyroscopic couple.	2	CO3	BT2

PARTB: Answer Any 1 Following Questions. 20 M

Q.N.	Questions	M	CO	BT

PTO (Please Turn Over)

06.A	10	CO1	BT2

Component	Expected Damage Mechanism	Preferred NDE Method	Technical Justification
Boiler Tubes	Thinning, erosion, internal/ external pitting	UT Thickness Gauging / ECT	Accurate, direct measurement of residual wall thickness.
Pipeline Welds	Planar cracks, porosity, slag inclusion, lack of fusion	RT, PAUT / TOFD, MPT	RT identifies volumetric flaws; PAUT/TOFD accurately sizes planar crack depths.
Turbine Blades	Surface fatigue cracks, leading-edge erosion	DPT, Visual Testing (VT), IRT	Visual and penetrant methods detect tight surface-breaking fatigue micro-cracks.
Rotors & Shafts	Subsurface fatigue cracks, creep damage	Ultrasonic Testing (PAUT), MPT, AE	Deep acoustic penetration resolves internal volumetric and planar flaws.
Heat Exchanger Tubes	Localized pitting, Stress Corrosion Cracking (SCC)	Eddy Current Testing (ECT), Internal UT	High-speed sensitivity to fine flaws without couplant in conductive alloys.
Storage Tanks	Bottom plate corrosion, shell thinning, leakage	Acoustic Emission (AE), UT Crawlers, VT	AE detects active bottom plate corrosion; crawlers map thickness without

06.B	10	CO2	BT2

- **Criticality Factors:** Hydrocarbon containment, impact on continuous production, accessibility (subsea/offshore logistics), and safety/environmental hazards.
- **High Criticality:**
  - Characteristics: Direct containment of high-pressure hydrocarbons, unspared assets, high repair complexity, catastrophic consequence of failure.
  - Examples: Main export gas compressor, subsea export manifold, LNG cryogenic storage tanks.
  - Maintenance approach: Continuous online condition monitoring, strict risk-based inspection cycles.
- **Medium Criticality:**
  - Characteristics: Critical to sustained full capacity, but installed with standby redundancy or short-term operational buffer.
  - Examples: Crude booster pumps (with standby), closed-loop cooling water circulation pumps.
  - Maintenance approach: Periodic vibration analysis and preventive maintenance.
- **Low Criticality:**
  - Characteristics: Ancillary/utility systems; failure causes zero hydrocarbon release and does not stop oil/gas production.
  - Examples: Utility air compressor, potable water pumps, workshop ventilation fans.
  - Maintenance approach: Run-to-failure (corrective maintenance) is economically acceptable.

07.A	10	CO1	BT2

- **Level I (Stringent):** Applied to critical systems where failure is catastrophic (e.g., nuclear components, aerospace structures, high-pressure sour gas vessels). Micro-flaws and linear discontinuities are rejected.
- **Level II (Moderate):** Applied to standard industrial pipelines and petrochemical pressure vessels. Tolerates minor volumetric inclusions (gas pores) within defined size limits, but rejects active planar cracks.
- **Level III (Permissive):** Applied to non-critical, statically loaded general structures. Permits higher discontinuity allowances and surface irregularities.
- **Limitation of Traditional Code Criteria:** Standard design codes are often conservative, based on workmanship standards rather than remaining structural capacity.
- **Fracture Mechanics Integration:** Fracture mechanics establishes the relationship between applied operating stress (σ), flaw size (a), and material fracture toughness (K_{IC}):

$$K_I = Y\sigma\sqrt{\pi a} < K_{IC}$$

- **Fitness-for-Service (FFS):** Instead of immediately rejecting a component with an indication exceeding standard code criteria, quantitative NDE measures flaw height and orientation. An FFS engineering assessment evaluates whether the flaw will grow to critical size before the next inspection interval, avoiding unnecessary plant shutdowns.

ANSWER KEY

07.B	• **RCM Failure Logic Overview:** A structured decision tree that classifies every failure mode based on its operational evidence and impact. • **Failure Effects Documentation:** Identifies evidence showing the failure occurred, whether it causes physical damage to adjacent assets, or if it triggers emergency shutdowns. • **Consequence Categories:** 1. *Hidden vs. Evident Failures:* Distinguishes whether the failure becomes evident under normal conditions; hidden failures in protective devices (relief valves, trip circuits) present high risk. 2. *Safety & Environmental Consequences:* Failures risking personnel injury, fire/explosion, or environmental breaches mandate proactive maintenance or redesign. 3. *Operational / Economic Consequences:* Impacts production throughput and repair costs; maintenance is justified only if its cost is lower than the downtime loss. 4. *Non-Operational Consequences:* Involves direct cost of repair only; run-to-failure is selected if proactive maintenance cost exceeds replacement cost.	10	CO2	BT2

PARTC: Answer Any 1 Following Questions. 20 M				
Q.N.	**Questions**	**M**	**CO**	**BT**

08.A	• **Corrosion Under Insulation (CUI):**
	  • *Mechanism & Causes:* Ingress of moisture or chloride-laden atmospheric humidity through damaged insulation cladding; trapped water between insulation and outer pipe wall causes accelerated localized electrochemical corrosion.
	  • *Indicators:* Rust staining on insulation jackets, bulging insulation, and thermal anomalies detected by Infrared Thermography (IRT).
	• **Blade Fatigue in Gas Turbines:**
	  • *Mechanism & Causes:* Cyclic aerodynamic loading, thermal cycling, and high centrifugal stresses cause high-cycle fatigue (HCF) and thermal-mechanical fatigue micro-cracks on rotating blade roots and leading edges.
	  • *Indicators:* Elevated blade-pass vibration signatures, acoustic changes, and surface-breaking micro-cracks identified during borescope or dye penetrant inspections.
		10	CO2	BT2

08.B	• **Consequence Analysis & Risk Evaluation:**
	  • Assess risk ranking by pairing Probability of Failure (PoF) from operating run hours with Consequence of Failure (CoF) across Health/Safety, Environmental, and Production disruption.
	  • Priority Tier 1: Toxic and high-pressure hydrocarbon-containing systems.
	• **Condition Monitoring Program:**
	  • *Vibration Analysis:* Continuous online accelerometers on main compressor and export pump bearings to detect unbalance, misalignment, and bearing wear.
	  • *Lube Oil Analysis:* Periodic spectrometry, particle counting, and viscosity analysis to identify metallic wear debris in gearboxes before catastrophic seizure occurs.
	  • *Thermography:* Routine IR scans on electrical motor drives, flare lines, and insulated pipes to catch insulation failures or loose terminals.
	• **Equipment Redesign & Hardening:**
	  • Upgrading hydrocarbon pumps to dual mechanical seals with pressurized barrier fluid to eliminate hazardous hydrocarbon release in the event of primary seal degradation.
	  • Material upgrades using corrosion-resistant alloys for sour gas piping.
	• **Redundancy Planning:**
	  • Implementing parallel pump configurations for critical duties and $N+1$ arrangement for power generation gas turbines to prevent unplanned shutdowns during maintenance.
		10	CO3	BT3

ANSWER KEY

09.A	• **RAM Analysis Requirements:**
	  • Standardizes RAM modeling procedures for petroleum, petrochemical, and natural gas systems.
	  • Uses equipment MTBF and MTTR data to simulate production availability and lifecycle maintenance costs.
	  • Identifies system bottlenecks and supports quantitative evaluation of redundant equipment configurations.
	• **Mechanical Seal Reliability Standards:**
	  • Establishes design, selection, and testing requirements for pump mechanical seals in hydrocarbon and chemical services.
	  • Specifies seal categories, arrangements (single, unpressurized dual, pressurized dual), and standardized piping flush plans.
	  • Objective: Ensure seals run continuously without unplanned maintenance for a minimum benchmark period (such as 25,000 hours), preventing loss of hydrocarbon containment.
		10	CO2	BT2

09.B	• **Torsional Resonance Phenomenon:**
	  • Occurs when alternating torque excitations match the system's torsional natural frequency:
	$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{J}}$$
	  • At resonance, angular oscillations multiply rapidly, producing high alternating shear stresses without noticeable lateral vibration, often leading to sudden fatigue shear failure of shafts or couplings.
	• **Parametric Influence on Reliability:**
	  • *Mass Polar Moment of Inertia (J):* Adding inertia (e.g., tuning flywheel or dampener inertia) lowers natural frequencies, shifting critical speeds below the operating envelope.
	  • *Torsional Stiffness (K):* Increasing shaft diameter or shortening length raises stiffness ($K = \frac{G \cdot I_p}{L}$), increasing natural frequency above operating speeds to maintain resonance-free operation.
	• **Marking Scheme:** 3.5 marks for torsional resonance analysis; 3.5 marks for evaluating the roles of J and K in reliability.
	(ii) Analyze the characteristics and equilibrium speed equations of a Watt Governor ($h = \frac{g}{\omega^2}$) versus a Porter Governor ($N = \frac{60}{2\pi}\sqrt{\frac{(w+W)g}{wh}}$), and demonstrate how gyroscopic couple ($C = I\omega\Omega$) influences vehicle and marine vessel stability. [6 Marks | CO3 | L3]
		10	CO3	BT3

ANSWER KEY