CERTIFICATE OF COMPETENCY EXAMINATION

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF
MARITIME AND COASTGUARD AGENCY

SMALL VESSEL CHIEF ENGINEER <3000 GT, UNLIMITED

058-01 - APPLIED MARINE ENGINEERING

FRIDAY, 31 May 2024

1400-1600 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Candidates should note that 100 marks are allocated to this paper. To pass candidates must achieve 50 marks.
2. Non-programmable calculators may be used
3. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidate's examination workbook

APPLIED MARINE ENGINEERING

Attempt ALL questions
Marks for each part question are shown in brackets

1. With reference to carbon fibre:

(a) describe how the base raw material is turned into a useable carbon fibre; (2)

(b) describe how the fibres produced in part (a) are turned into a usable product; (2)

(c) explain how its internal structure gives it its unique strength properties; (2)

(d) list FOUR properties of carbon fibre that make it desirable for marine fabrication. (4)

2. With reference to the installation of copper pipes in engine cooling systems:

(a) describe THREE possible causes for their premature failure; (6)

(b) outline FOUR recommendations for the installation of copper pipes. (4)

3. With reference to fatigue failure of components:

(a) describe how material fatigue testing is carried out in the laboratory; (2)

(b) sketch the surface appearance of a fatigue fracture; (2)

(c) describe the THREE stages of the failure; (3)

(d) list the methods available on board to limit the possibility of fatigue failure to a propeller shaft. (3)

4. Describe, with the aid of sketches, FIVE defects that may be present on a weld produced using the covered electrode welding process. (10)

5. With reference to the cathodic protection of hull fittings:

(a) explain how sacrificial anodes achieve this; (2)

(b) state where sacrificial anodes would be fitted and why; (4)

(c) describe an impressed current system, stating the principle on which it works. (4)

6. With reference to in service defects found in glass reinforced plastic (GRP) hulls:

(a) state THREE possible causes of de-lamination; (3)

(b) describe TWO methods of detecting de-lamination in service; (2)

(c) describe TWO methods of repair to de-lamination on a sandwich construction hull; (2)

(d) list THREE design problems that can lead to stress cracking. (3)

7. (a) Describe, with the aid of a sketch, how a Bourdon Tube can be utilised to measure temperature. (8)

(b) State a typical application and location for this type of device. (2)

8. (a) State the reasons for fitting a pneumatic process valve with EACH of the following:

(i) a volume booster; (2)

(ii) a feedback positioner. (2)

(b) State, with reasons, the type of actuator fitted to the process valves for EACH of the following systems:

(i) a fuel supply system in which the valve must not move on loss of power to the control system; (3)

(ii) a lubrication oil cooling system in which the valve diverts the oil through a cooler. (3)

9. (a) State the relationship between *proportional band* and *gain*. (2)

(b) The figure shows the level in a water tank is being controlled by a float and lever proportional system.

(i) Describe how the gain of the control system can be increased and decreased. (2)

(ii) Describe what happens when the flow out is increased. (2)

(iii) Describe the effect of increasing the controller gain with respect to the steady state tank level when the outflow is increased. (2)

(iv) Describe how the introduction of Integral action would affect this system. (2)

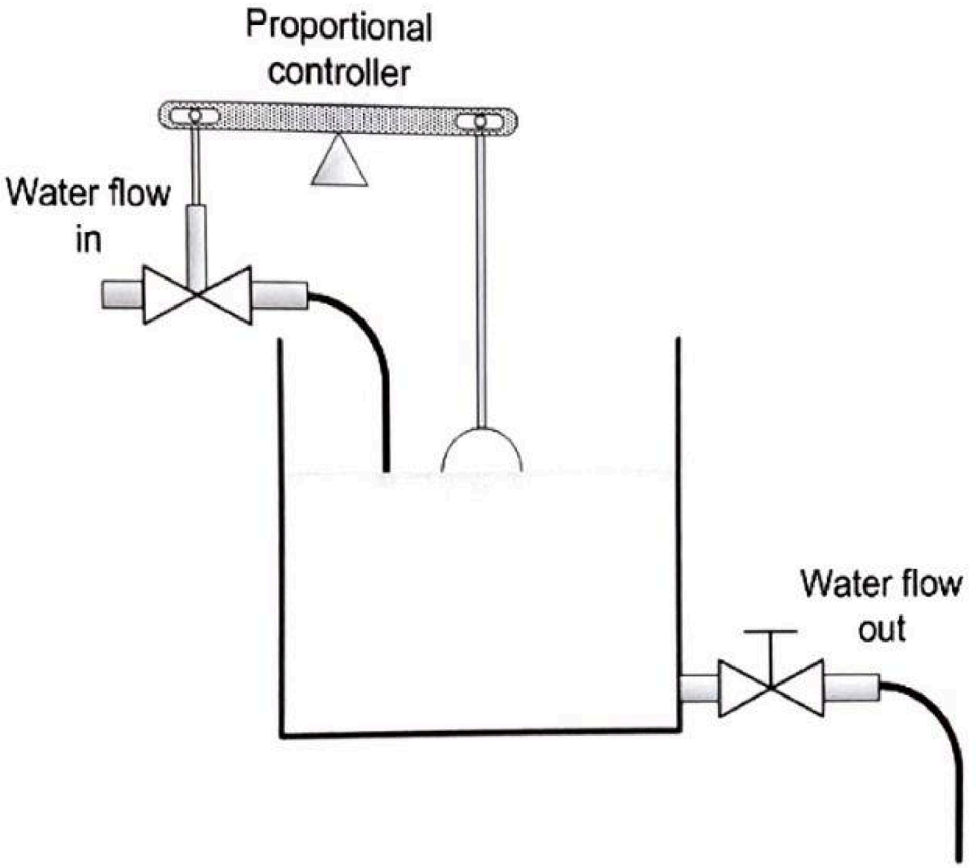

Fig Q9

10. In the Hydraulic Control System shown in the figure, identify components A, B, C, D, E, F, G, H, J and K from their symbols. (10)

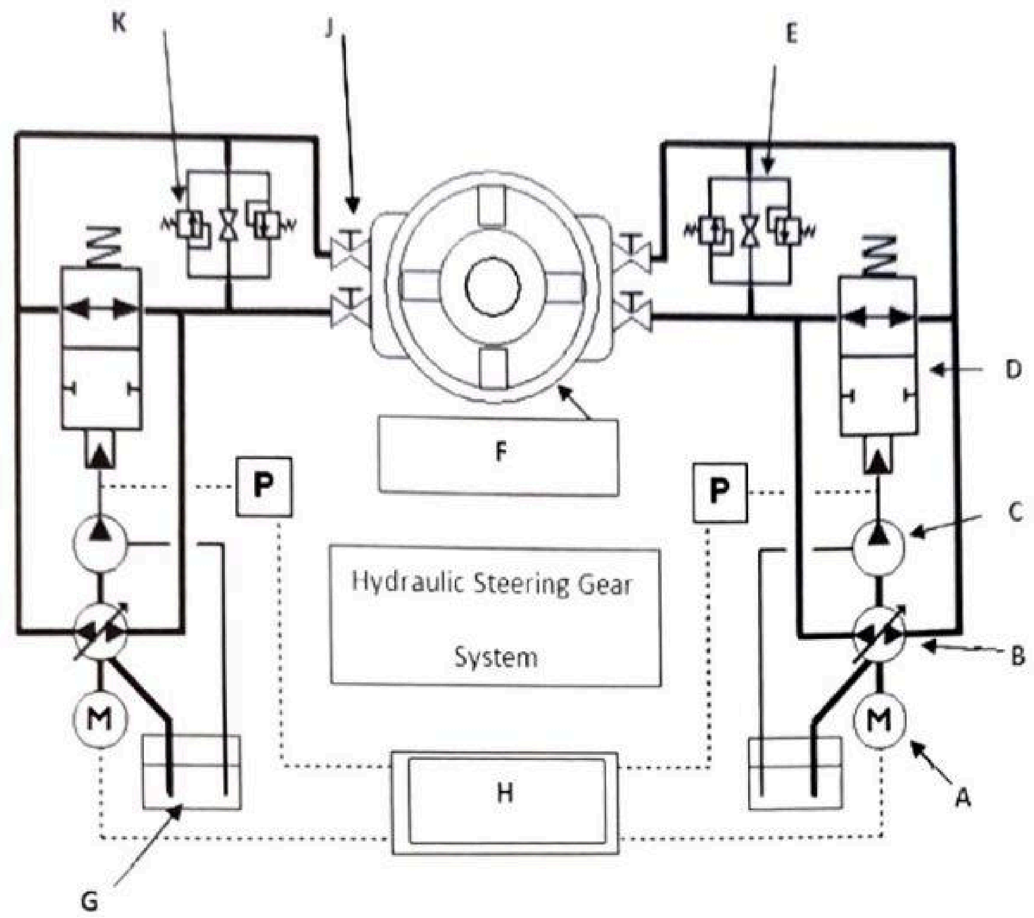

Fig Q10

1. With reference to carbon fibre:

(a) describe how the base raw material is turned into a useable carbon fibre; (2)

(b) describe how the fibres produced in part (a) are turned into a usable product; (2)

(c) explain how its internal structure gives it its unique strength properties; (2)

(d) list FOUR properties of carbon fibre that make it desirable for marine fabrication. (4)

(a) Turning base raw material into useable carbon fibre (2 marks)

- Base material (usually **polyacrylonitrile – PAN**, or pitch) is first **spun into filaments**.
- Fibres are then **stabilised and carbonised**: heated in inert atmosphere (1000–3000 °C) to drive off non-carbon atoms → leaving strong carbon fibres.

(b) Turning fibres into a usable product (2 marks)

- The carbon fibres are **woven or aligned into fabrics, mats, or tows**.
- They are then **impregnated with a resin (epoxy, polyester, vinyl ester)** and cured to form **composite laminates**.

(c) Unique strength from internal structure (2 marks)

- The carbon atoms are bonded in **hexagonal crystalline layers** (graphitic structure).
- These layers are aligned along the fibre axis → giving **very high tensile strength and stiffness** but low weight.

(d) Four desirable properties for marine fabrication (4 marks)

1. **High strength-to-weight ratio** → strong yet lightweight for hulls and superstructures.
2. **Corrosion resistance** → unaffected by seawater.
3. **Fatigue resistance** → withstands cyclic marine loads.
4. **Dimensional stability** → low thermal expansion, maintains shape under temperature changes.

(Other acceptable: ease of moulding into complex shapes, low maintenance, aesthetic finish.)

2. With reference to the installation of copper pipes in engine cooling systems:

   (a) describe THREE possible causes for their premature failure; (6)

   (b) outline FOUR recommendations for the installation of copper pipes. (4)

(a) Three possible causes of premature failure (6 marks)

1. **Erosion–corrosion** – high velocity seawater, turbulence at bends, or entrained air bubbles strip away protective oxide film, leading to rapid thinning.
2. **Galvanic corrosion** – when copper pipes are connected to dissimilar metals (e.g., steel, aluminium) without proper insulation, the copper may corrode preferentially.
3. **Dezincification** (if using brass alloys rather than pure copper) – zinc leaches out, leaving a porous and weak copper structure.
   (Other acceptable: stress cracking, improper water treatment leading to scaling/pitting.)

(b) Four recommendations for installation (4 marks)

1. Ensure **correct flow velocity** (generally < 2–3 m/s for seawater) to avoid erosion.
2. Use **electrical insulation or sacrificial anodes** to prevent galvanic action with dissimilar metals.
3. Provide **adequate support and alignment** of pipes to minimise vibration and stress.
4. Maintain **good water treatment** (filtration, oxygen removal, corrosion inhibitors) to reduce corrosion risk.

3. With reference to fatigue failure of components:

(a) describe how material fatigue testing is carried out in the laboratory; (2)

(b) sketch the surface appearance of a fatigue fracture; (2)

(c) describe the THREE stages of the failure; (3)

(d) list the methods available on board to limit the possibility of fatigue failure to a propeller shaft. (3)

(a) Material fatigue testing in the laboratory (2 marks)

- A specimen is subjected to **repeated cyclic loading** (e.g., bending, torsion, axial stress) at controlled stress levels.
- The **number of cycles to failure** is recorded, and results plotted on an **S–N curve** (stress vs. cycles) to determine fatigue life.

(b) Surface appearance of a fatigue fracture (2 marks)

- A fatigue fracture surface typically shows:
    - **Smooth concentric beach marks** or striations from progressive crack growth.
    - A final **rough crystalline zone** where sudden failure occurred.

(In exam, a sketch should show concentric semicircles spreading from a crack initiation point, then a rough final fracture zone.)

(c) Three stages of fatigue failure (3 marks)

1. **Crack initiation** – at surface defects, stress raisers, or corrosion pits.

2. **Progressive crack propagation** – crack slowly extends under cyclic stress (beach marks form).
3. **Final sudden fracture** – once the remaining section can no longer sustain the load.

(d) Methods on board to limit fatigue failure of a propeller shaft (3 marks)

- Ensure **accurate alignment** of the shaft and couplings.
- Use **flexible or rubber couplings** to absorb vibration and misalignment.
- Maintain **proper bearing support and lubrication** to avoid uneven stresses.
- Inspect regularly for **cracks, wear, or corrosion pits** and rectify early.

4. Describe, with the aid of sketches, FIVE defects that may be present on a weld produced using the covered electrode welding process. (10)

Five common weld defects (with description)

1. **Porosity**
   - Small cavities or holes in the weld caused by trapped gas.
   - Causes: damp electrodes, contamination, poor shielding.
   - Effect: reduces strength of the weld.
2. **Slag inclusions**
   - Non-metallic material (flux/slag) trapped in the weld metal.
   - Causes: inadequate cleaning between passes, poor electrode angle.
   - Effect: weakens weld, potential crack initiation sites.
3. **Lack of fusion**
   - Weld metal does not properly fuse with base metal or previous pass.
   - Causes: low heat input, incorrect technique.
   - Effect: reduces load-carrying capacity, hidden defects possible.
4. **Undercut**
   - A groove melted into the base metal along the weld toe that is not filled with weld metal.
   - Causes: excessive current, incorrect electrode angle or travel speed.
   - Effect: acts as a stress raiser, leading to cracking.
5. **Cracking**

  - May be hot cracks (during solidification) or cold cracks (after cooling).
  - Causes: high restraint, hydrogen in weld, improper cooling.
  - Effect: serious defect – can lead to sudden failure.

Exam tip:

- In the answer booklet, **add sketches** beside each defect:
  - Porosity → scattered round holes in weld.
  - Slag inclusion → dark trapped line inside weld bead.
  - Lack of fusion → gap between weld metal and parent plate.
  - Undercut → groove along weld toe.
  - Cracking → sharp line across bead or through HAZ.

5. With reference to the cathodic protection of hull fittings:

(a) explain how sacrificial anodes achieve this; (2)

(b) state where sacrificial anodes would be fitted and why; (4)

(c) describe an impressed current system, stating the principle on which it works. (4)

(a) How sacrificial anodes achieve protection (2 marks)

- Sacrificial anodes are made from a **more reactive metal** (e.g., zinc, aluminium, magnesium).
- When electrically connected to the steel hull, they corrode preferentially, making the hull act as a **cathode** → preventing its corrosion.

(b) Where sacrificial anodes are fitted and why (4 marks)

- **Locations:** Hull plating (especially stern), rudders, bilge keels, sea chests, propeller shafts, stern gear.
- **Reasons:**
  - These areas are most exposed to seawater and turbulence.
  - Vulnerable to galvanic action with dissimilar metals (e.g., bronze propellers, stainless shafts).
  - Ensure uniform protection of high-risk areas.

(c) Impressed current system (ICCP) and principle (4 marks)

- Uses **inert anodes** (titanium with mixed metal oxide) attached to the hull.
- Connected to a **DC power source**: hull = negative terminal, anodes = positive terminal.
- Current is “impressed” onto the hull, keeping its potential at a protective level (around −0.85 V vs. Ag/AgCl).
- Reference electrodes continuously monitor hull potential and adjust current flow.
- **Principle:** By supplying external DC current, the hull is forced to remain **cathodic**, eliminating corrosion.

6. With reference to in service defects found in glass reinforced plastic (GRP) hulls:

(a) state THREE possible causes of de-lamination; (3)

(b) describe TWO methods of detecting de-lamination in service; (2)

(c) describe TWO methods of repair to de-lamination on a sandwich construction hull; (2)

(d) list THREE design problems that can lead to stress cracking. (3)

(a) Three possible causes of de-lamination (3 marks)

1. **Poor bonding during manufacture** – contamination, inadequate curing, or trapped air pockets.
2. **Mechanical damage or impact** – grounding, collision, or vibration stresses separating laminate layers.
3. **Water ingress** – moisture penetration weakens the resin–glass bond over time.

(b) Two methods of detecting de-lamination in service (2 marks)

1. **Percussion (tap) test** – tapping with a small hammer or coin; a dull sound indicates voids or delamination.
2. **Ultrasonic or infrared testing** – non-destructive methods to detect hidden separation between layers.

(c) Two methods of repair on a sandwich construction hull (2 marks)

1. **Local grinding out** of delaminated area, drying, then rebuilding with fresh resin and laminate.
2. **Injection of resin/adhesive** into voids under pressure to re-bond separated layers.

(d) Three design problems that can lead to stress cracking (3 marks)

1. **Sharp corners or abrupt changes in thickness** – create stress concentration points.
2. **Insufficient reinforcement** in high-load areas (e.g., near bulkheads, stiffeners).
3. **Poor laminate orientation** – fibres not aligned with primary stress directions, leading to weakness.

7. (a) Describe, with the aid of a sketch, how a Bourdon Tube can be utilised to measure temperature. (8)

(b) State a typical application and location for this type of device. (2)

(a) How a Bourdon Tube can be used to measure temperature (8 marks)

- **Principle:** A Bourdon tube is a curved, flattened, hollow metallic tube that tends to straighten when internal pressure increases.
- To measure **temperature**, the Bourdon tube is connected to a sealed system containing a **volatile fluid or gas** (thermometric fluid).
- When the bulb (temperature sensor) is placed in the medium (e.g., cooling water), the fluid inside expands or contracts with temperature changes.
- This causes a change in **pressure inside the Bourdon tube**.
- The tube flexes slightly in response, and its tip movement is transmitted through a linkage and gearing mechanism to a **pointer on a dial**.
- The dial is calibrated in **temperature units (°C or °F)** rather than pressure.

(If sketching in exam: draw a bulb in liquid, capillary tube leading to Bourdon tube, linkage to pointer on dial.)

(b) Typical application and location (2 marks)

- **Application:** Measurement of cooling water temperature, lubricating oil temperature, or refrigerant temperature.
- **Location:** Engine cooling system outlet, lube oil system, or refrigeration compressor discharge line.

8. (a) State the reasons for fitting a pneumatic process valve with EACH of the following:

(i) a volume booster; (2)

(ii) a feedback positioner. (2)

(b) State, with reasons, the type of actuator fitted to the process valves for EACH of the following systems:

(i) a fuel supply system in which the valve must not move on loss of power to the control system; (3)

(ii) a lubrication oil cooling system in which the valve diverts the oil through a cooler. (3)

(a) Reasons for fitting auxiliaries to pneumatic process valves

(i) Volume booster (2 marks)

- Increases the **rate of air flow** into or out of a large actuator.
- Ensures **faster valve response** when rapid movement is required (e.g., emergency shut-down).

(ii) Feedback positioner (2 marks)

- Provides **accurate valve positioning** by feeding back actual valve stem position to the controller.
- Overcomes problems of **friction, hysteresis, and varying supply pressure**, ensuring the valve reaches and stays at the demanded position.

(b) Type of actuator for different systems

(i) Fuel supply system (valve must not move on loss of control power) (3 marks)

- Use a **double-acting actuator with fail-in-place (fail-set) positioner**.
- Ensures the valve remains in its **last commanded position** if power or air is lost.
- Prevents unplanned fuel shut-off or flooding, maintaining safe and stable operation.

(ii) Lubrication oil cooling system (valve diverts oil through cooler – fail-safe) (3 marks)

- Use a **spring-return actuator** designed to move to the **safe position** (oil through cooler) on loss of control power.
- Protects bearings and machinery from overheating by ensuring cooling is always maintained.

9. (a) State the relationship between *proportional band* and *gain*. (2)

(b) The figure shows the level in a water tank is being controlled by a float and lever proportional system.

(i) Describe how the gain of the control system can be increased and decreased. (2)

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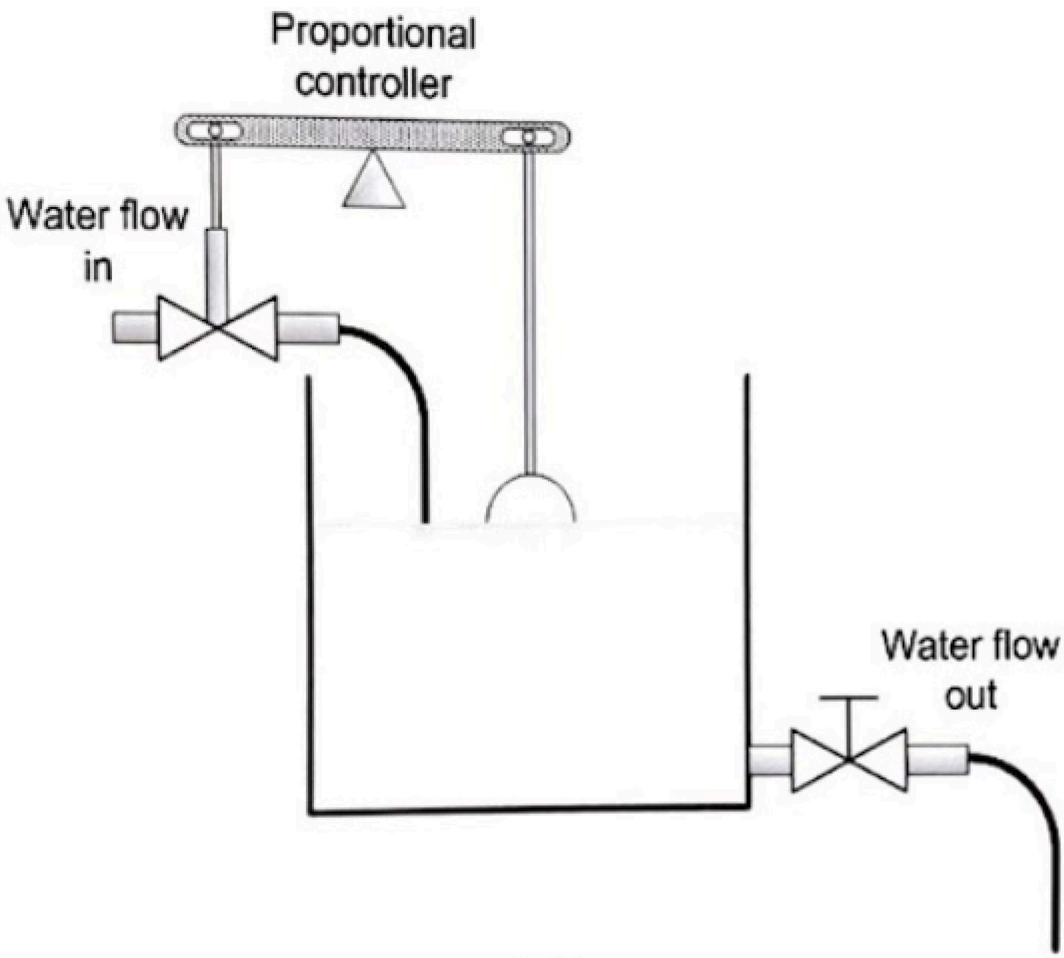

Fig Q9

(a)

Relationship between proportional band and gain (2)

They are **inversely related**:

$$K_p = \frac{100\%}{\text{Proportional Band (\%)}}$$

So a **narrow PB ⇒ high gain** and a **wide PB ⇒ low gain**.

(b) Float–lever proportional level control

(i) How to increase/decrease gain (2)
Gain ≈ valve travel per unit level error.

- **Increase**: move fulcrum toward the float (larger lever ratio to valve), use a larger/more buoyant float, reduce return spring stiffness/friction.
- **Decrease**: opposite adjustments.

(ii) What happens when flow out is increased (2)
Level **falls**, inlet valve opens more via the lever, and a new steady level is reached **below setpoint** (proportional **offset/droop**) where inflow equals higher outflow.

(iii) Effect of increasing controller gain when outflow is increased (2)
Higher KpK_pKp gives a **bigger corrective valve movement**, so the new steady level is **closer to setpoint**; too much gain can cause **hunting/oscillation**.

(iv) Effect of adding integral action (2)
Integral accumulates error and drives the valve until **offset is eliminated** (level → setpoint). It improves accuracy but can slow response and risks **overshoot/wind-up** if not tuned.

10. In the Hydraulic Control System shown in the figure, identify components A, B, C, D, E, F, G, H, J and K from their symbols. (10)

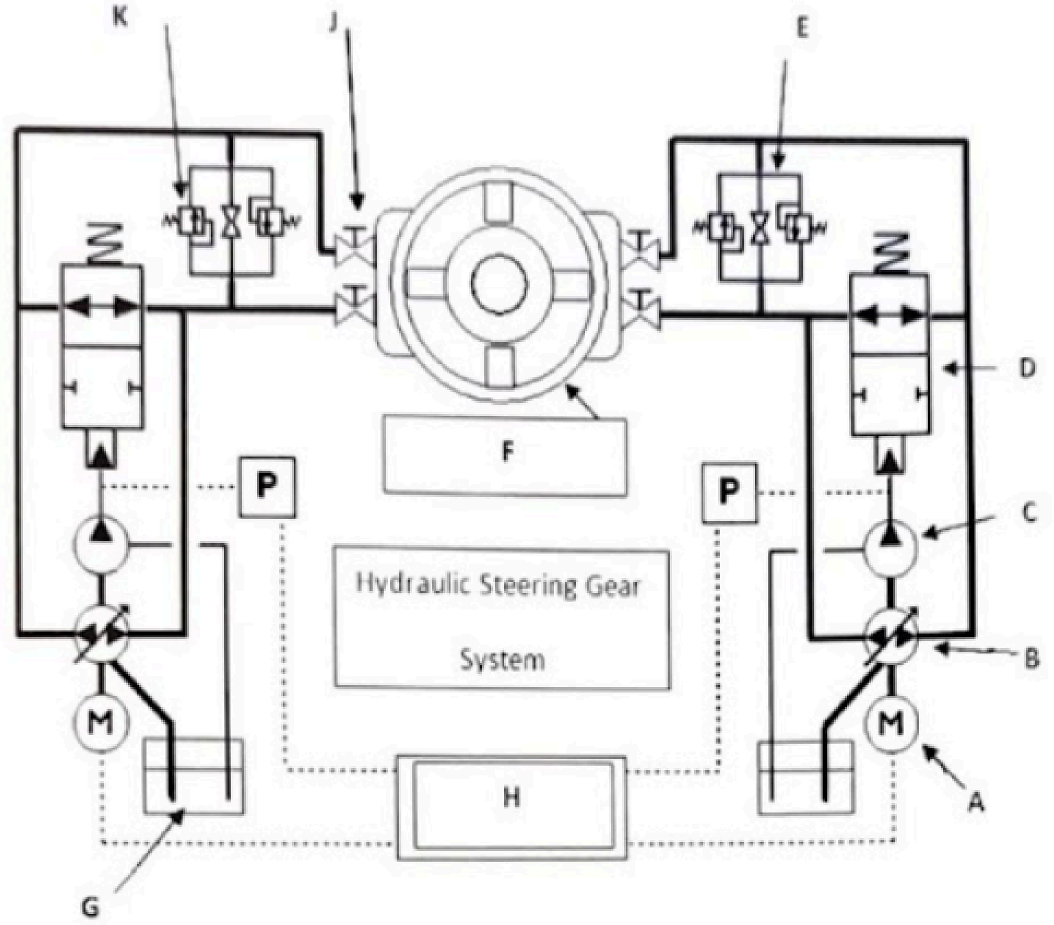

Fig Q10

Component Identification

- **A – Electric Motor (M)**
  Drives the hydraulic pump.
- **B – Flexible Coupling / Drive Shaft**
  Connects motor to pump, allowing slight misalignment.
- **C – Hydraulic Pump (P)**
  Supplies pressurised hydraulic oil to the system.
- **D – Non-return Valve (Check Valve)**
  Prevents reverse flow of hydraulic oil.
- **E – Relief Valve (Spring-loaded)**
  Protects the system by relieving excess pressure.
- **F – Hydraulic Ram / Actuator**
  Moves the rudder stock by converting hydraulic pressure into linear motion.
- **G – Manual Hand Pump**
  Backup for steering in case of power failure.

- **H – Hydraulic Oil Reservoir (Tank)**
  Stores hydraulic fluid for circulation.

- **J – Change-over Valve**
  Directs oil flow into either side of the steering ram for port/starboard movement.

- **K – Filter Unit**
  Removes contaminants from hydraulic oil before entering the system.