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, 13 June 2025

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 aluminium as a hull material:

   (a) explain how pure aluminium differs from marine grade aluminium; (4)

   (b) explain THREE significant problems associated with aluminium during construction and in service. (6)

   3

2. (a) Define the term *stainless steel,* making reference the percentage quantities of its TWO main constituents. (4)

   (b) With reference to EACH of the following grades of stainless steel, list ONE of its unique properties and a common use that utilises this property:

   (i) ferritic; – Soft, heat conductor, exhaust (kitchen wear) (2)

   (ii) austenitic; – hard (316) – Ship Side Valve. (corrosion resisted) (2)

   (iii) martensitic. – hard wearing (pumps, turbines) (2)

3. (a) Describe how a Brinell hardness test is carried out. (3)

   (b) With reference to a ball race bearing, explain EACH of the following terms:

   (i) brinelling; (2)

   (ii) false brinelling. (2)

   (c) Explain how false brinelling can be reduced in practice. (3)

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4. Describe FIVE different welding processes that could be utilised on board a vessel, to join TWO overlapping sections of mild steel. (10)

   5

5. With reference to Impressed Current Cathodic Protection of a vessel's hull:

   (a) explain why it may be required; (2)

   (b) describe, with the aid of a sketch, the key points of installation; (5)

   (c) describe its operating principle. (3)

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6. With reference to osmosis in glass reinforced plastic (GRP) hulls:

(a) explain the process of osmosis and the method by which osmotic blisters occur in service; (6)

(b) describe a procedure for the local treatment of a single blister. (4)

7. With reference to a PT100 probe (resistance thermometer):

(a) explain the principle of operation by which it is able to give a temperature measurement; (3)

(b) describe how the sensing element is constructed, explaining why it is called a PT100 probe; (4)

(c) explain why these probes typically have three or four wires to connect them to the temperature indicating device. (3)

8. With reference to a thermistor:

(a) state the materials used in their construction, the principle of operation and the reason for their use on vessels; (4)

(b) state the temperature range over which they are able to operate; (1)

(c) state, with reasons, FIVE applications where thermistors may be found on board a vessel. (5)

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)

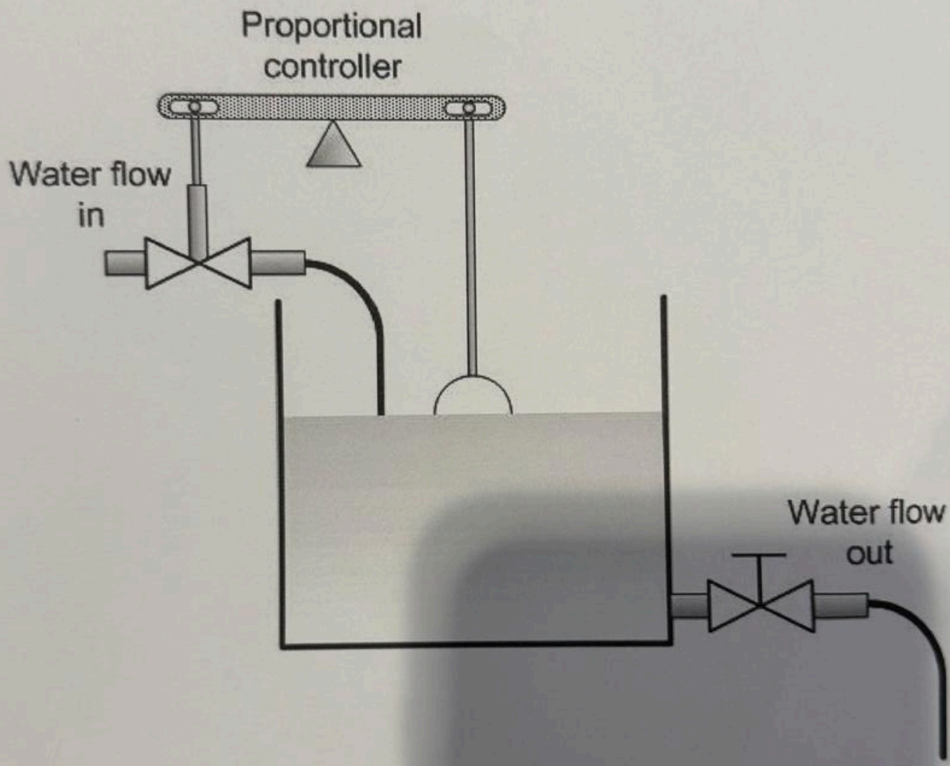

Fig Q9

10. (a) Explain the term *failsafe* in a control system, stating TWO examples where this term is applied. (4)

(b) Explain the term *failset* in a control system, stating TWO examples where this term is applied. (4)

(c) State what is meant by a 4:3 control valve. (2)

7. With reference to aluminium as a hull material:

(a) explain how pure aluminium differs from marine grade aluminium; (4)

(b) explain THREE significant problems associated with aluminium during construction and in service. (6)

(a) Difference between pure aluminium and marine-grade aluminium (4 marks)

- **Pure aluminium**
  - Very soft and ductile.
  - Low strength, poor suitability for structural applications.
  - Excellent corrosion resistance in seawater due to a natural oxide film.
  - Not generally used for hull construction on its own.
- **Marine-grade aluminium**
  - An alloy of aluminium with elements such as **magnesium, manganese, silicon, or zinc**.
  - Much **stronger and tougher**, with higher yield and tensile strength.
  - Specifically formulated for **seawater corrosion resistance**.
  - Examples include **5083, 5754, and 6082 alloys**, widely used in marine hulls.

(b) Three significant problems with aluminium in construction and service (6 marks)

1. **Welding difficulties**
   - Aluminium conducts heat rapidly → difficult to weld consistently.
   - Requires special welding techniques (MIG/TIG) and skilled labour.
   - Risk of distortion and porosity in welds.
2. **Galvanic corrosion**
   - Aluminium is anodic relative to many other shipbuilding metals (e.g., steel, copper alloys).
   - Contact with dissimilar metals in seawater accelerates **pitting and wastage**.
   - Requires careful insulation, protective coatings, or sacrificial anodes.
3. **Fatigue and cracking**
   - Aluminium has a lower fatigue strength than steel.
   - More prone to crack initiation at welded joints or stress concentrations.
4. *(Alternative)* **Cost and availability**

- ○ Aluminium alloys are more expensive than mild steel.
- ○ Repair and replacement can be costlier and require specialist facilities.

✅ Full marks would usually come from **(a)** identifying strength/corrosion/ductility differences, and **(b)** correctly describing *three of the welding, galvanic corrosion, fatigue, or cost issues*.

2. (a) Define the term *stainless steel,* making reference the percentage quantities of its TWO main constituents. (4)

(b) With reference to EACH of the following grades of stainless steel, list ONE of its unique properties and a common use that utilises this property:

(i) ferritic; – Soft, heat Conductor, exhaust (Kitchen ware) (2)

(ii) austenitic; – hard (316) – Ship Side Valve. (Corrosion Resisted) (2)

(iii) martensitic. – hard Wearing (Pumps, Turbines) (2)

(a) Definition of stainless steel (4 marks)

- Stainless steel is an **iron–carbon alloy** with a minimum of **10.5–12% chromium** by mass.
- Carbon content is typically **less than 1.2%**.
- Chromium forms a thin, stable **passive oxide film** on the surface, giving resistance to rust and corrosion.
- Nickel or other alloying elements may also be present, but chromium and carbon are the two key constituents.

(b) Grades of stainless steel

(i) Ferritic stainless steel (2 marks)

- **Property:** Soft, magnetic, good resistance to stress corrosion cracking, lower cost.
- **Use:** Domestic and marine **exhaust systems**, kitchen equipment, or decorative trim.

(ii) Austenitic stainless steel (2 marks)

- **Property:** Excellent corrosion resistance, non-magnetic, good ductility (contains nickel, e.g., 316 grade).
- **Use: Ship side valves, pipelines, tanks** exposed to seawater (marine-grade 316).

(iii) Martensitic stainless steel (2 marks)

- **Property:** Can be heat-treated for **high hardness and wear resistance**, but less corrosion resistant.

- **Use: Propeller shafts, turbine blades, pumps**, and cutlery.

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3. (a) Describe how a Brinell hardness test is carried out. (3)

(b) With reference to a ball race bearing, explain EACH of the following terms:

(i) brinelling; (2)

(ii) false brinelling. (2)

(c) Explain how false brinelling can be reduced in practice. (3)

(a) How a Brinell hardness test is carried out (3 marks)

1. A **hardened steel or tungsten carbide ball** (usually 10 mm diameter) is pressed into the surface of the material under a **known load** (e.g., 500–3000 kg depending on specimen).
2. The load is applied for a **fixed time** (about 10–15 seconds).
3. The **diameter of the indentation** left in the material is measured with a microscope, and the **Brinell Hardness Number (BHN)** is calculated from:

$$BHN = \frac{\text{Load (kgf)}}{\text{Surface area of indentation (mm}^2\text{)}}$$

(b) With reference to a ball race bearing

(i) Brinelling (2 marks)

- Permanent **indentations** in the bearing race caused by **static overload** or impact when the bearing is not rotating.
- Named after the Brinell test because the marks resemble Brinell indents.

(ii) False brinelling (2 marks)

- Appears similar to brinelling but caused by **vibration or oscillation** when the bearing is stationary.
- Leads to **fretting wear** due to small relative motions, removing lubricant and causing polished depressions.

(c) How false brinelling can be reduced (3 marks)

- Ensure adequate **lubrication** (grease or oil film to prevent metal-to-metal contact).

- Use **anti-vibration mounts** or damping to reduce transmission of vibration.
- Rotate the shaft periodically during long idle periods to redistribute lubricant.
- Use special lubricants with **anti-wear additives** for standby equipment.

4. Describe FIVE different welding processes that could be utilised on board a vessel, to join TWO overlapping sections of mild steel. (10)

Q: Describe FIVE different welding processes that could be utilised on board a vessel, to join TWO overlapping sections of mild steel. (10 marks)

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1. Shielded Metal Arc Welding (SMAW / Manual Metal Arc / Stick Welding)

- Uses a **flux-coated consumable electrode**.
- Arc is struck between electrode and workpiece, melting both.
- Flux coating produces shielding gases and slag to protect the weld pool.
- **Common on board ships** due to its portability and simplicity.

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2. Gas Metal Arc Welding (GMAW / MIG Welding)

- Uses a **continuous consumable wire electrode** fed through a welding gun.
- Shielding is provided by inert gas (e.g., CO_2 or argon mixtures).
- Produces clean welds with high deposition rates.
- Useful for **fabrication and repair work** in the shipyard.

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3. Flux-Cored Arc Welding (FCAW)

- Similar to MIG but the wire is **flux-cored**, allowing welding with or without external shielding gas.
- High deposition rate and good penetration.
- Effective in **outdoor or windy marine conditions** where gas shielding is difficult.

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4. Gas Tungsten Arc Welding (GTAW / TIG Welding)

- Uses a **non-consumable tungsten electrode**.
- Filler metal may be added separately.
- Shielding provided by inert gas (argon/helium).

- Produces very **high-quality, precise welds**, useful for thin mild steel sections or critical repairs.

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5. Oxy-Acetylene Welding (OAW / Gas Welding)

- Flame produced by burning **oxygen and acetylene gas**.
- Heat melts the edges of the steel and filler rod may be added.
- Portable and versatile, useful for **onboard repair and cutting operations**.

Alternative processes (if asked to expand):

- **Submerged Arc Welding (SAW)** – automatic process, not very common onboard but used in shipyards.
- **Spot Welding (Resistance Welding)** – joining overlapping thin plates, useful for non-structural mild steel sections.

5. With reference to Impressed Current Cathodic Protection of a vessel's hull:

(a) explain why it may be required; (2)

(b) describe, with the aid of a sketch, the key points of installation; (5)

(c) describe its operating principle. (3)

(a) Why it may be required (2 marks)

- The **steel hull of a vessel** is subject to **electrochemical corrosion** when in seawater, due to it acting as part of a galvanic cell.
- ICCP is required to **prevent or reduce corrosion**, extending hull life and reducing maintenance costs, especially for **large vessels where sacrificial anodes alone are insufficient**.

(b) Key points of installation (5 marks)

- **Anodes (usually inert, e.g., titanium with mixed metal oxide coating)** are mounted externally on the hull below the waterline.
- **Reference electrodes** (e.g., silver/silver chloride) are installed to continuously monitor hull potential.
- A **DC power source (rectifier)** is fitted onboard, converting AC supply to controlled DC current.
- Anodes are connected to the **positive terminal**, hull connected to the **negative terminal** of the rectifier.

- The system automatically adjusts the impressed current to maintain the hull at the desired **protective potential** (typically −0.85 V vs. Ag/AgCl).

(A sketch would show the hull, DC power source, anodes, reference electrodes, and current flow.)

(c) Operating principle (3 marks)

- The DC power supply forces current to flow from the **inert anodes into seawater**.
- Electrons are supplied to the **ship's hull (cathode)**, shifting its potential to a more negative value.
- This makes the hull act as a **cathode of the electrochemical cell**, thereby **suppressing anodic metal dissolution (corrosion)**.
- The system continuously regulates itself via reference electrodes.

6. With reference to osmosis in glass reinforced plastic (GRP) hulls:

(a) explain the process of osmosis and the method by which osmotic blisters occur in service; (6)

(b) describe a procedure for the local treatment of a single blister. (4)

(a) Process of osmosis and formation of osmotic blisters (6 marks)

- **Osmosis process**
  - Osmosis is the movement of water molecules across a **semi-permeable membrane** from a region of low solute concentration to a region of high solute concentration.
  - In GRP hulls, the **gel coat layer** acts like a semi-permeable barrier.
- **Blister formation**
  - Small defects, voids, or pockets in the laminate contain **water-soluble residues** (e.g., uncured resin, salts, or contaminants).
  - Seawater penetrates through the gel coat and migrates into these voids.
  - The dissolved contaminants create a concentrated solution → water continues to be drawn in by osmosis.
  - Pressure builds up inside the void, causing **bulging or blistering** of the gel coat surface.
  - The blister may eventually rupture, releasing acidic liquid.

(b) Local treatment of a single blister (4 marks)

1. **Open the blister** by grinding or cutting away the raised area until sound laminate is exposed.

2. **Thoroughly clean and dry** the cavity (may require rinsing with fresh water and drying with hot air or allowing extended drying time).

3. **Fill the cavity** with an epoxy resin filler or GRP repair paste, ensuring good bonding.

4. **Fair and smooth the surface**, then re-apply protective coatings (epoxy primer, gel coat, or antifouling system) to restore integrity.

7. With reference to a PT100 probe (resistance thermometer):

(a) explain the principle of operation by which it is able to give a temperature measurement; (3)

(b) describe how the sensing element is constructed, explaining why it is called a PT100 probe; (4)

(c) explain why these probes typically have three or four wires to connect them to the temperature indicating device. (3)

(a) Principle of operation (3 marks)

- The PT100 operates on the principle that the **electrical resistance of platinum changes in a predictable way with temperature**.
- As temperature increases, the resistance of the platinum element **increases linearly**.
- By accurately measuring this resistance, the corresponding **temperature can be calculated**.

(b) Construction of the sensing element and why it is called PT100 (4 marks)

- The sensing element is made from a **thin coil or film of high-purity platinum** mounted on a ceramic or glass substrate.
- Platinum is chosen for its **stability, repeatability, and nearly linear resistance–temperature relationship**.
- It is called **PT100** because at **0 °C the resistance of the element is exactly 100 ohms** (Ω).
- Standardised by IEC 60751, the resistance increases by about **0.385 Ω per °C** (for the common industrial version).

(c) Why probes have 3 or 4 wires (3 marks)

- Lead wires between the probe and measuring device add extra resistance, which would cause **errors** in temperature readings.
- **Three-wire connection**: balances out the resistance of the leads using a bridge circuit, giving a more accurate reading.

- **Four-wire connection**: eliminates lead resistance entirely by using a separate current and voltage measurement pair, giving **highest accuracy**.
- These arrangements ensure the measured resistance truly reflects the **platinum element only**, not the wiring.

8. With reference to a thermistor:

(a) state the materials used in their construction, the principle of operation and the reason for their use on vessels; (4)

(b) state the temperature range over which they are able to operate; (1)

(c) state, with reasons, FIVE applications where thermistors may be found on board a vessel. (5)

(a) Materials, principle of operation, and reason for use on vessels (4 marks)

- **Materials:** Thermistors are made from **metal oxide semiconductors** such as manganese oxide, cobalt oxide, or nickel oxide, which are sintered and encapsulated.
- **Principle of operation:** Their **electrical resistance changes significantly with temperature**.
  - **NTC (Negative Temperature Coefficient):** resistance decreases as temperature increases.
  - **PTC (Positive Temperature Coefficient):** resistance increases as temperature increases.
- **Reason for use on vessels:**
  - They provide **high sensitivity and rapid response** to small temperature changes.
  - They are **compact, robust, and inexpensive**, making them ideal for marine monitoring and protection systems.

(b) Temperature range (1 mark)

- Typically operate between **–50 °C and +250 °C** (depending on design and encapsulation).

(c) Five applications on board a vessel (with reasons) (5 marks)

1. **Engine cooling water monitoring** – ensures jacket water is maintained within safe limits; protects against overheating.
2. **Lubricating oil temperature sensing –** prevents damage to bearings and moving parts by monitoring oil conditions.
3. **Refrigeration and air conditioning systems** – controls compressor cycling and protects against overtemperature.

4. **Electrical machine protection (generators, motors, transformers)** – embedded thermistors monitor winding temperatures to prevent insulation failure.

5. **Cargo monitoring (perishables or refrigerated goods)** – ensures cargo is kept within safe temperature limits.

(Other acceptable answers: boiler monitoring, exhaust gas detection, alarm systems, etc.)

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)

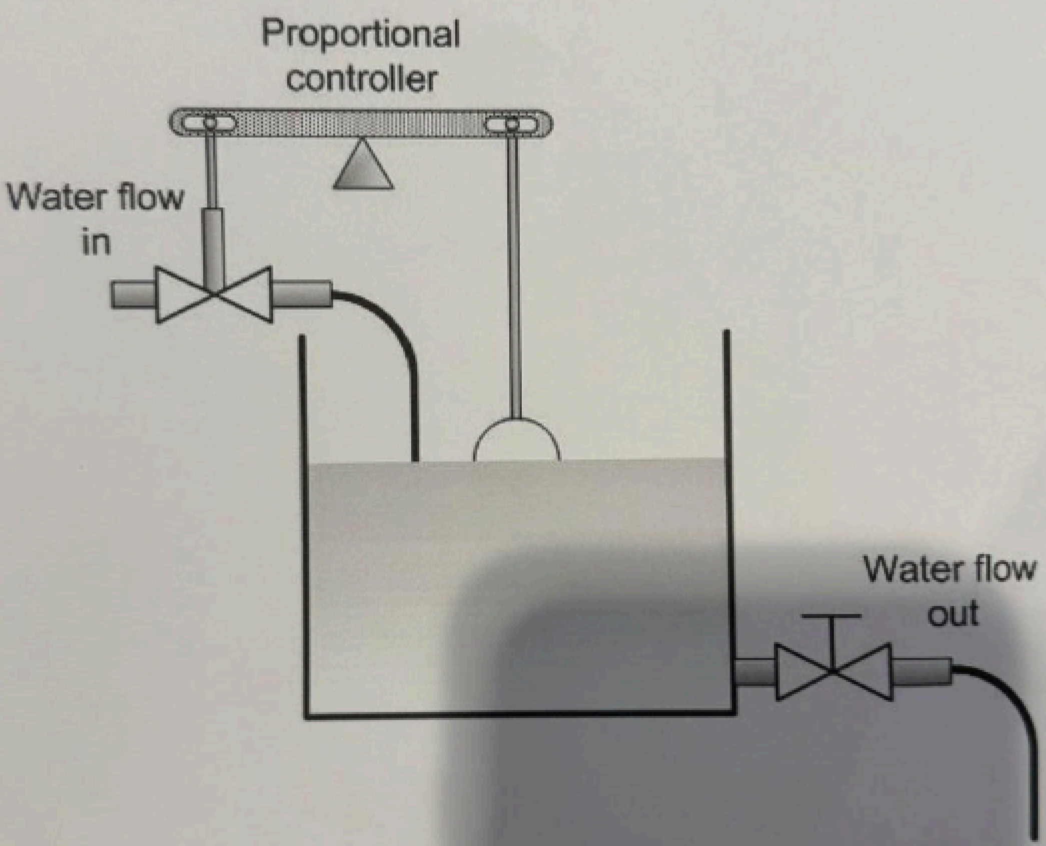

Fig Q9

(a) Relationship between proportional band and gain (2)

They're **inversely related**.
For a proportional controller:

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

So a **narrower PB** ⇒ **higher gain**, and vice-versa.

(b) Float/lever proportional level control

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

- Increasing the **lever ratio** (shorter float arm / longer valve arm; move fulcrum towards float),
- Using a **larger float** (more buoyant force),
- Using a **softer/less preload spring** on the valve.
  Decrease gain by the opposite adjustments.

(ii) What happens when flow out is increased (2)
Load ↑ ⇒ level **falls** until the controller opens the inlet valve more. With proportional-only control a **steady-state offset ("droop")** remains: the level settles **below setpoint** so that inflow equals the new outflow.

(iii) Effect of increasing controller gain when outflow is increased (2)
Higher KpK_pKp **reduces the offset**, so the new steady level is **closer to setpoint**. If KpK_pKp is too high, expect **hunting/oscillation**.

(iv) Effect of adding integral action (2)
Integral removes the proportional **offset** by integrating error and driving the valve until **level = setpoint**. Response is slower and may introduce **overshoot/wind-up** unless tuned/limited.