APPLIED MARINE ENGINEERING

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

1. (a) Define the meaning of the term *alloy*, stating why they are used. (3)

   (b) Describe the changes in the mechanical properties of steel with increasing amounts of carbon. (4)

   (c) List SIX common alloying elements used in the production of steel. (3)

2. With reference to the case hardening of bearing journals:

   (a) explain why this process may be carried out; (2)

   (b) describe EACH of the following processes:

   (i) induction hardening; (3)

   (ii) nitriding; (3)

   (c) explain why the processes described in part (b) are best suited to this application. (2)

3. (a) State the TWO steps occurring in the fracture process of a material. (2)

   (b) Explain EACH of the following fracture failures:

   (i) highly ductile fracture; (2)

   (ii) moderately ductile fracture; (2)

   (iii) brittle fracture. (2)

   (c) Explain the process of *fatigue failure* and its significance in engineering design. (2)

4. List THREE advantages and TWO disadvantages for EACH of the following welding processes:

   (a) gas tungsten arc welding (TIG); (5)

   (b) covered electrode welding. (5)

5. With reference to the protection of aluminium from corrosion:

(a) explain the naturally occurring process and it's limitations; (4)

(b) explain the process of anodising, stating its advantages. (6)

6. A vessel has been laid up for a considerable time with shore power connected. Routine underwater hull inspections reveal an unusually high deterioration rate of the vessel's anodes. Assuming the dockside wiring, shore power connections and bonding systems are all in good condition and correctly connected:

(a) explain how this may occur; (8)

(b) state TWO devices that should be fitted to prevent this situation occurring. (2)

7. Describe, with the aid of a sketch, the principle and operation of a Bourdon tube gauge. (10)

8. Explain EACH of the following control terms:

(a) settling time; (2)

(b) repeatability; (2)

(c) dead zone; (2)

(d) hysteresis; (2)

(e) proportional bandwidth. (2)

9. (a) Describe, with the aid of a sketch, the principle and operation of a potentiometer. (6)

(b) Explain how a potentiometer can be used to measure rotary movement. (4)

10.

10. On passage at full sea speed, a high jacket water temperature alarm goes off. The header tank is full, there are no leaks in the systems, both the HT and SW pumps are running and in good condition, however the temperature is continuing to rise.

(a) State the immediate course of action that should be taken, explaining why. (2)

(b) From the information on the supplied system diagram, shown in the figure below, describe THREE possible actions that may bring the plant back to within normal operating parameters. (8)

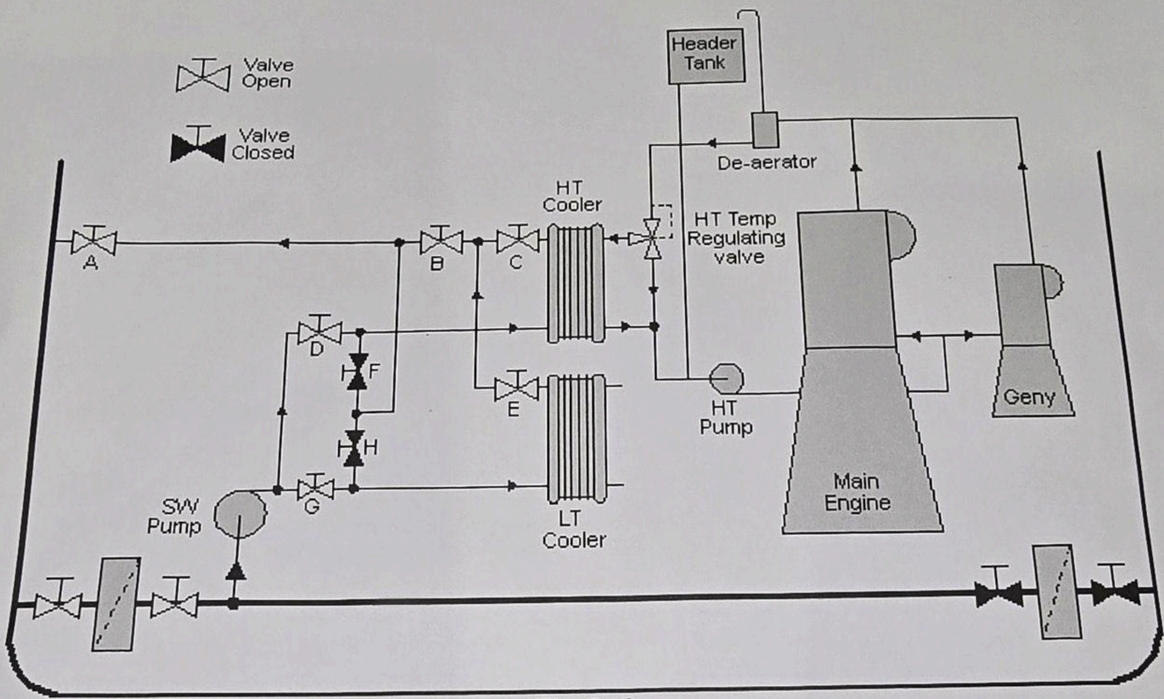

Fig Q10

1 (a) Define the meaning of the term *alloy*, stating why they are used. (3)

(b) Describe the changes in the mechanical properties of steel with increasing amounts of carbon. (4)

(c) List *SIX* common alloying elements used in the production of steel. (3)

(a) Define the meaning of alloy, stating why they are used (3 marks)

- **Alloy:** A metallic material made by combining two or more elements, at least one of which is a metal.
- **Purpose:** Alloys are used to improve **mechanical properties** (strength, hardness, toughness), **corrosion resistance**, **wear resistance**, or to reduce cost compared to pure metals.

(b) Changes in mechanical properties of steel with increasing carbon (4 marks)

- **Low carbon (≤0.25% C):** Soft, ductile, tough, easily welded (e.g., mild steel).
- **Medium carbon (0.25–0.6% C):** Higher strength and hardness, reduced ductility, can be heat-treated.
- **High carbon (0.6–1.4% C):** Very hard, wear resistant, but brittle and difficult to weld.
- **Trend:** As carbon content increases → **hardness and strength increase**, but **ductility, weldability, and toughness decrease**.

(c) Six common alloying elements in steel (3 marks)

1. **Chromium** – increases hardness and corrosion resistance.
2. **Nickel** – improves toughness and corrosion resistance.
3. **Molybdenum –** increases high-temperature strength and hardness.
4. **Vanadium –** improves wear resistance and strength.
5. **Manganese** – increases strength, wear resistance, and toughness.
6. **Silicon** – improves strength and oxidation resistance.

(Other acceptable: cobalt, tungsten, titanium, aluminium, copper.)

2 With reference to the case hardening of bearing journals:

(a) explain why this process may be carried out; (2)

(b) describe EACH of the following processes:

(i) induction hardening; (3)

(ii) nitriding; (3)

(c) explain why the processes described in part (b) are best suited to this application. (2)

(a) Why the process may be carried out (2 marks)

- *To produce a **hard, wear-resistant surface** on the journal that resists scuffing and fatigue.*
- *At the same time, to retain a **tough, ductile core** that can withstand impact and shock loads without cracking.*

(b) Processes

(i) Induction hardening *(3 marks)*

- *An alternating current is passed through a **copper induction coil** surrounding the journal surface.*
- *Rapidly heats the surface layer to austenitising temperature (~800–900 °C).*
- *The surface is then **quenched**, producing a hard martensitic case while leaving the core unchanged.*

(ii) Nitriding *(3 marks)*

- *The journal is heated (~500–550 °C) in an atmosphere of **ammonia gas (NH_3)**.*
- *Nitrogen diffuses into the surface and forms **hard nitrides** with alloying elements (e.g., Al, Cr, Mo, V).*
- *Produces a very hard, wear-resistant surface without requiring quenching, so distortion is minimal.*

(c) Why these processes are suited to bearing journals (2 marks)

- *Both methods produce a **hard, wear-resistant surface** while maintaining a **tough inner core**.*
- *Induction hardening gives **deep, localised hardness** for heavy-duty surfaces.*
- *Nitriding gives an **extremely hard, fatigue- and wear-resistant surface** with **good dimensional stability**, ideal for journals under rolling contact.*

3. (a) State the TWO steps occurring in the fracture process of a material. (2)

(b) Explain EACH of the following fracture failures:

(i) highly ductile fracture; (2)

(ii) moderately ductile fracture; (2)

(iii) brittle fracture. (2)

(c) Explain the process of *fatigue failure* and its significance in engineering design. (2)

(a) Two steps in the fracture process of a material (2 marks)

1. **Crack initiation** – formation of small cracks at points of stress concentration (e.g., defects, notches, grain boundaries).
2. **Crack propagation** – growth and spread of the crack until final fracture occurs.

(b) Types of fracture failures

(i) Highly ductile fracture (2 marks)

- Occurs with large plastic deformation before failure.
- Material undergoes significant necking, producing a **cup-and-cone fracture surface**.

(ii) Moderately ductile fracture (2 marks)

- Some plastic deformation, but less necking compared to highly ductile failure.
- Fracture surface shows a mix of shear lips and flat regions.

(iii) Brittle fracture (2 marks)

- Occurs with little or no plastic deformation.
- Crack propagates suddenly and rapidly, producing a **flat, granular, crystalline surface** (often perpendicular to stress direction).

(c) Process of fatigue failure and significance (2 marks)

- **Fatigue failure** is the progressive cracking of a material under **repeated or cyclic loading**, even when stresses are below the static yield strength.
- Stages: crack initiation → gradual crack propagation (striations/beach marks) → sudden final fracture.
- **Significance in design:**

- Major cause of unexpected failures in machinery (e.g., shafts, propellers, crankshafts).
- Engineering design must account for fatigue life, using **S–N curves**, safety factors, and stress reduction methods.

4. List THREE advantages and TWO disadvantages for EACH of the following welding processes:

(a) gas tungsten arc welding (TIG); (5)

(b) covered electrode welding. (5)

(a) Gas Tungsten Arc Welding (TIG)

Advantages (3)

1. Produces **high-quality, clean welds** with excellent appearance.
2. Can weld **thin materials and non-ferrous metals** (aluminium, stainless steel, copper alloys).
3. No flux → **no slag inclusions**.

Disadvantages (2)

1. **Slow and less economical** for thick materials.
2. Requires **skilled operators** and precise control; equipment is expensive.

(b) Covered Electrode Welding (Manual Metal Arc, MMA)

Advantages (3)

1. **Portable and versatile** – suitable for site and shipboard repairs.
2. Can weld in **all positions**.
3. Equipment is **cheap and simple**.

Disadvantages (2)

1. **Slag must be chipped/cleaned** after welding.
2. **Electrode wastage and frequent replacement** make it less efficient for long welds.

5. With reference to the protection of aluminium from corrosion:

(a) explain the naturally occurring process and it's limitations; (4)

(b) explain the process of anodising, stating its advantages. (6)

(a) Naturally occurring process and its limitations (4 marks)

- When exposed to air, aluminium quickly forms a thin, tightly adherent layer of **aluminium oxide (Al_2O_3)**.
- This oxide film provides **natural corrosion resistance** by acting as a protective barrier against further oxidation.
- **Limitations:**
    1. The oxide layer is **very thin** (~2–10 nm) and can be **damaged mechanically**.
    2. It provides **limited protection in aggressive environments** (e.g., seawater, chloride attack).
    3. Localised corrosion (pitting, crevice corrosion, galvanic attack with dissimilar metals) can still occur.

(b) Process of anodising and its advantages (6 marks)

Process:

1. Aluminium component is made the **anode** in an electrolytic bath (typically sulphuric acid).
2. A **direct current** is passed, causing controlled oxidation of the aluminium surface.
3. This produces a **thicker, porous oxide layer** than natural oxidation.
4. The porous layer can be **sealed by boiling in water or nickel acetate**, closing pores for durability.
5. Optionally, pores can be **dyed** before sealing to give decorative coloured finishes.

Advantages:

1. Produces a **much thicker and harder oxide layer** than natural passivation.
2. Greatly improves **corrosion resistance** in marine and industrial environments.
3. Provides **wear resistance** (oxide is very hard).
4. Allows for **decorative finishes** (coloured anodising).
5. Improves **paint and adhesive bonding** due to porous structure.

6. A vessel has been laid up for a considerable time with shore power connected. Routine underwater hull inspections reveal an unusually high deterioration rate of the vessel's anodes. Assuming the dockside wiring, shore power connections and bonding systems are all in good condition and correctly connected:

(a) explain how this may occur; (8)

(b) state TWO devices that should be fitted to prevent this situation occurring. (2)

(a) Explain how this may occur (8 marks)

- The vessel is connected to **shore power**, and although the wiring and bonding are correct, a potential difference can exist between the **shore earth** and the vessel's **hull/earth system**.
- This allows **stray DC or low-level AC leakage currents** to flow through the hull and underwater fittings into the surrounding seawater.
- The hull becomes part of a **galvanic or electrolytic cell**, with the sacrificial anodes discharging at a much higher rate to protect the hull and fittings.
- Unlike normal galvanic corrosion, this deterioration is driven by the **continuous external electrical supply**.
- The result is **accelerated wastage of sacrificial anodes**, even though the vessel is laid up and not operating.
- This problem is known as **shore-side electrolytic corrosion** (sometimes called "stray current corrosion").

(b) Two devices to prevent this situation (2 marks)

1. **Galvanic isolator** – fitted in the shore earth connection; blocks low-voltage DC stray currents while allowing AC fault currents to pass for safety.
2. **Isolation transformer** – completely isolates ship's electrical system from shore supply, eliminating galvanic paths between vessel and shore earth.

7 Describe, with the aid of a sketch, the principle and operation of a Bourdon tube gauge. (10)

Principle (3 marks)

- The Bourdon tube gauge works on the principle that a **curved, flattened, hollow metallic tube** tends to **straighten** when subjected to **internal pressure**.
- This elastic deformation is proportional to the pressure applied inside the tube.

Construction (3 marks)

- Consists of a **curved, hollow, flattened tube** sealed at one end and connected to the pressure source at the other.
- The free (sealed) end of the tube is connected by a system of **linkages and gears** to a pointer.
- The pointer moves over a **calibrated dial** to display the pressure.

Operation (3 marks)

1. Pressure from the fluid enters the Bourdon tube.
2. The tube tends to straighten due to the internal pressure increase.

3. The small movement of the free end is transmitted through the **mechanical linkage** to rotate the pointer.

4. The pointer movement is proportional to the applied pressure and indicates it on the dial.

Applications (1 mark)

- Commonly used in **marine systems** to measure boiler pressure, hydraulic oil pressure, compressed air, fuel oil pressure, etc.

8. Explain EACH of the following control terms:

(a) settling time; (2)

(b) repeatability; (2)

(c) dead zone; (2)

(d) hysteresis; (2)

(e) proportional bandwidth. (2)

(a) Settling time (2 marks)

- The time taken for a system's output to reach and remain within a specified tolerance band (e.g., ±2%) of its final steady-state value after a disturbance or setpoint change.

(b) Repeatability (2 marks)

- The ability of a control system or instrument to give the same output under identical conditions when the same input is repeatedly applied.
- Indicates **consistency and precision** of performance.

(c) Dead zone (2 marks)

- A range of input change over which there is **no corresponding output response**.
- Example: a control valve may not move until the control signal changes by more than 2%.

(d) Hysteresis (2 marks)

- The difference in output for the same input depending on whether the input is **increasing or decreasing**.
- Caused by friction, backlash, or magnetic effects, leading to a lag in response.

(e) Proportional bandwidth (2 marks)

- The range of input error over which the **proportional controller output** moves from minimum to maximum.
- Expressed as a percentage of full-scale input range.

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

- Inversely related to gain:

9. (a) *Describe, with the aid of a sketch, the principle and operation of a potentiometer.* (6)

(b) *Explain how a potentiometer can be used to measure rotary movement.* (4)

(a) Principle and operation of a potentiometer (6 marks)

Principle:

- A potentiometer works on the principle of a **voltage divider**.
- A resistive element is connected across a supply voltage.
- A sliding contact (**wiper**) moves along the resistive track, tapping off a fraction of the total voltage proportional to its position.

Operation:

1. A DC supply is applied across the two fixed terminals of the resistive element.
2. As the wiper moves along the track, the resistance between the wiper and each end terminal changes.
3. This gives a **variable output voltage** at the wiper, which is proportional to the displacement.
4. Hence, the potentiometer converts **mechanical displacement (linear or rotary)** into a corresponding **electrical signal**.

(In an exam sketch: draw resistive track, supply across two ends, sliding wiper connected to output terminal.)

(b) Measuring rotary movement (4 marks)

- In a **rotary potentiometer**, the resistive element is circular (arc or full circle).
- The wiper is attached to a **rotating shaft** connected to the moving part.

- As the shaft rotates, the wiper moves around the resistive element.
- The output voltage varies in proportion to the **angular displacement**, allowing rotary position to be measured electrically.

10. On passage at full sea speed, a high jacket water temperature alarm goes off. The header tank is full, there are no leaks in the systems, both the HT and SW pumps are running and in good condition, however the temperature is continuing to rise.

(a) State the immediate course of action that should be taken, explaining why. (2)

(b) From the information on the supplied system diagram, shown in the figure below, describe THREE possible actions that may bring the plant back to within normal operating parameters. (8)

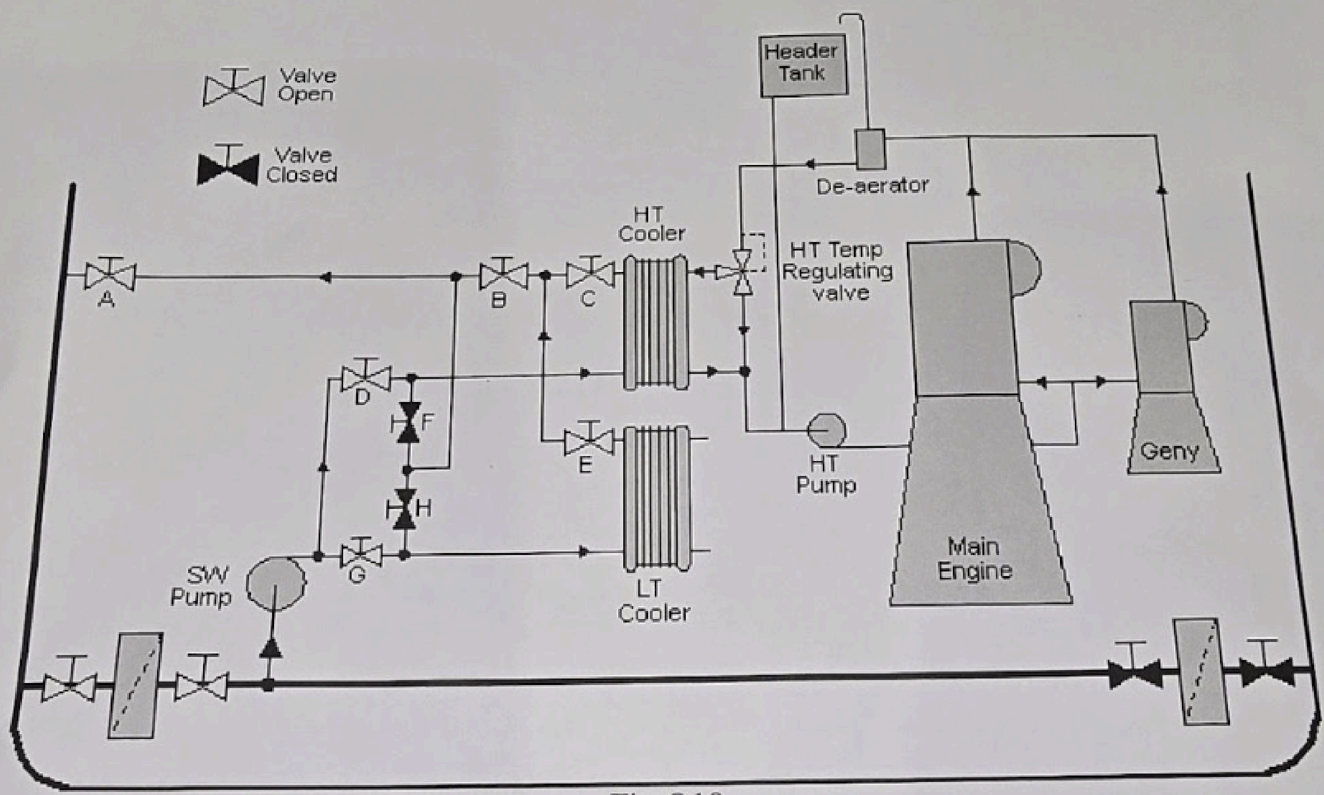

Fig Q10

(a) Immediate action (2)

Order an immediate reduction of engine load / ship's speed.
Reason: jacket-water temperature is rising and will continue to rise until heat input from the engine is cut; reducing load limits metal temperatures and prevents damage while you investigate.

(b) Three actions using the system shown to bring the temperature back down (8)

1. **Force more HT water through the HT cooler (fix the hot-water side).**
   - Put the **HT temperature-regulating valve** to **manual "full-cooling"** (bypass shut, flow directed through the HT cooler).
   - Make sure the **HT-cooler isolating valves** are **open** and the **bypass/isolation around the cooler is closed**; vent the cooler to clear any air pocket.
     Why it helps: maximises heat transfer area and restores proper HT flow through the cooler.
2. **Increase sea-water flow through the HT cooler (fix the cold-water side).**

- **Open** the SW valves feeding the **HT cooler** and **throttle/close** those feeding the **LT cooler** so the available SW is prioritised to the HT cooler.
- Check SW inlet/overboard valves are fully open and the **sea-water strainer is clean**; if fitted, start/bring on the standby SW pump.
  Why it helps: more SW through the HT cooler increases temperature difference and duty.

3. **Reduce other HT loads / check flow routing.**
   - If the **generator jacket** or other consumers are on the HT circuit, **isolate or reduce** their flow temporarily to free cooling capacity for the main engine.
   - Confirm the **HT pump** is delivering design flow and that all **non-return/isolating valves** on the HT loop are correctly set (no unintended bypass).
     Why it helps: lowers the total heat load and ensures the main engine gets full HT circulation.

Any combination of the above (full-cooling on the 3-way valve, maximise SW through the HT cooler, and prioritise HT cooling duty) will normally bring jacket-water temperature back within limits.