058-01 - APPLIED MARINE ENGINEERING

FRIDAY, 19 November 2021

1400-1600 hrs

APPLIED MARINE ENGINEERING

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

1. State, with reasons, a different material suitable for EACH of the following applications:

   (a) a large motor vessel propeller; (2)

   (b) a centrifugal pump impeller; (2)

   (c) a sea water cooled heat exchanger tube; (2)

   (d) a 300mm diameter sea water cooling pipe; (2)

   (e) a cylinder head of a small auxiliary engine. (2)

2. With reference to aluminium:

   (a) explain what is meant by *work hardening*; (2)

   (b) describe the internal changes when it becomes work hardened; (2)

   (c) state the effect work hardening has on its properties; (2)

   (d) describe how it could be annealed on board a vessel. (4)

3. (a) List FOUR methods for non-destructive crack detection. (4)

   (b) Describe TWO procedures from the methods listed in part (a). (6)

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 osmosis in glass reinforced plastic (GRP) hulls:

   (a) explain how osmosis may be detected in service; (2)

   (b) explain why simply drying out the hull is not a cure for the effects of osmosis; (2)

   (c) describe the FULL process for the treatment of a hull suffering from the effects of osmosis. (6)

7. Describe, with the aid of a sketch, a floatation device that produces an output signal to remotely control the liquid level in a tank. (10)

8. (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)

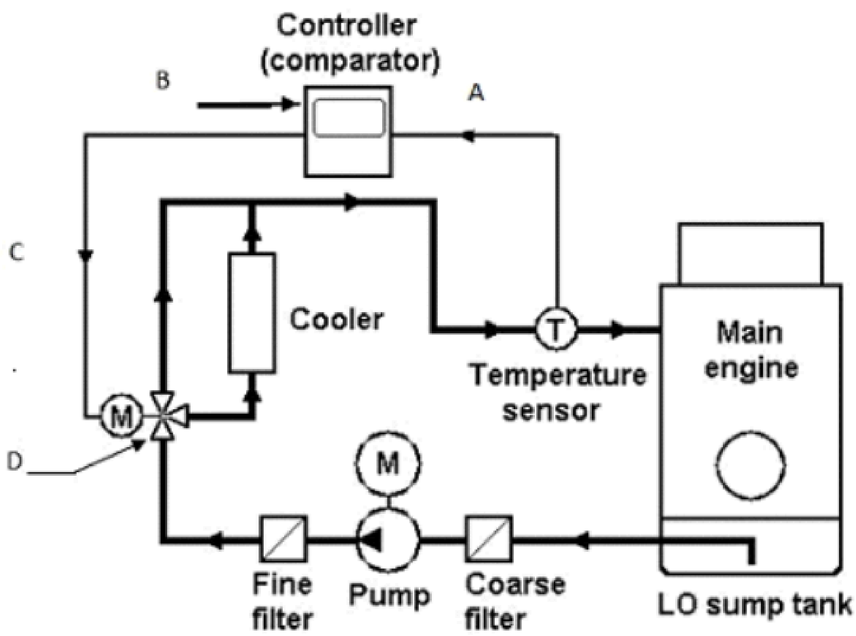
9. For the automatic closed loop engine cooling control system shown in the figure:

(a) identify the signal paths A, B, and C; (3)

(b) describe the function of the comparator; (2)

(c) name and describe the function of component D; (4)

(d) state a suitable device capable of producing a varying signal at T. (1)



Main engine LO temperature control system

Fig Q9

10. With reference to the elevations of a lever bracket and pin provided below, produce a three dimensional freehand sketch of the component.

Note: Marks will be awarded for dimensional accuracy and the quality of the sketch. (10)

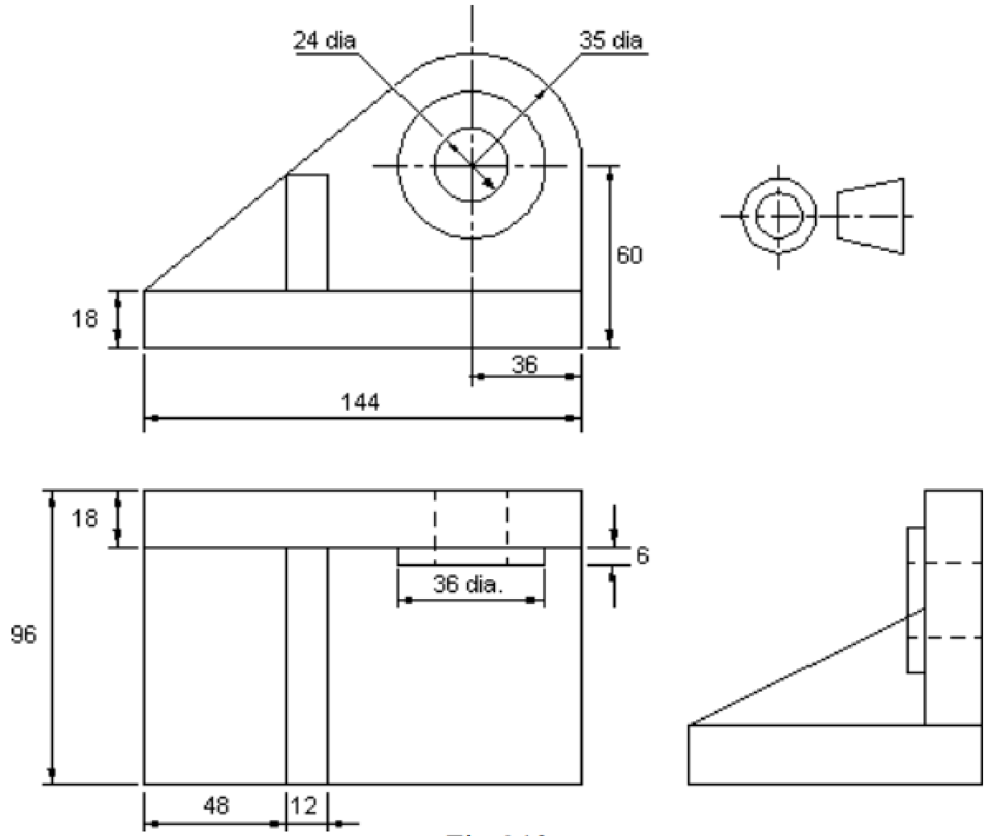


Fig Q10

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1. State, with reasons, a <u>different</u> material suitable for EACH of the following applications:

(a) a large motor vessel propeller; (2)

(b) a centrifugal pump impeller; (2)

(c) a sea water cooled heat exchanger tube; (2)

(d) a 300mm diameter sea water cooling pipe; (2)

(e) a cylinder head of a small auxiliary engine. (2)

(a) A large motor vessel propeller

- Material: Typically made of a bronze alloy, such as Ni-Al bronze or aluminum bronze. These alloys are chosen for their strength, toughness, and resistance to corrosion in seawater.

(b) A centrifugal pump impeller

- Material: Often made of stainless steel for its strength, corrosion resistance, and ability to handle abrasive fluids. In some cases, cast iron or nickel-aluminum bronze may be used depending on the specific application and cost considerations.

(c) A sea water cooled heat exchanger tube

- Material: Typically made of titanium or cupronickel. Titanium offers excellent corrosion resistance and strength, but is more expensive. Cupronickel is a more cost-effective option with good corrosion resistance and heat transfer properties.

(d) A 300mm diameter sea water cooling pipe

- Material: Often made of fiberglass reinforced plastic (FRP), which is lightweight, corrosion-resistant, and relatively inexpensive. In some cases, steel or high-density polyethylene (HDPE) may be used depending on the specific requirements and pressure rating.

(e) A cylinder head of a small auxiliary engine

- Material: Typically made of cast iron due to its good machinability, heat transfer properties, and affordability. In some high-performance engines, aluminum or aluminum alloys may be used for their weight saving benefits.

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2. With reference to aluminium:

(a) explain what is meant by *work hardening*; (2)

(b) describe the internal changes when it becomes work hardened; (2)

(c) state the effect work hardening has on its properties; (2)

(d) describe how it could be annealed on board a vessel. (4)

(a) Work Hardening Explained:

Work hardening, also known as strain hardening, is a phenomenon where the strength and hardness of aluminium increase as it is plastically deformed (bent, stretched, hammered, etc.). This doesn't involve any change in its chemical composition, but rather a rearrangement of its internal structure.

Think of aluminium as a pile of spaghetti strands. In its soft state, the strands are loosely tangled. When deformed, the strands get tangled and interlocked, making it harder to further deform them. This increased resistance to deformation translates to higher strength and hardness.

(b) Internal Changes during Work Hardening:

During work hardening, several internal changes occur within the aluminium:

- Dislocation Formation: Plastic deformation creates defects called dislocations in the crystal lattice of aluminium. These dislocations act as obstacles to further movement of atoms, hindering deformation and thus increasing strength.
- Grain Refinement: In some cases, severe deformation can break down larger aluminium grains into smaller ones. This also contributes to work hardening because smaller grains have more grain boundaries, which again act as obstacles to deformation.

(c) Effects of Work Hardening on Properties:

Work hardening has both positive and negative effects on aluminium:

- Positive:
  - Increased Strength and Hardness: As explained above, work hardening makes aluminium stronger and harder, making it suitable for applications requiring higher load-bearing capacity.
  - Improved Wear Resistance: The increased hardness also enhances the material's resistance to wear and tear.
- Negative:
  - Reduced Ductility and Malleability: The tangled grain structure makes the metal less ductile (stretchable) and malleable (formable). This can limit its usability in applications requiring bending or shaping.
  - Increased Brittleness: Severe work hardening can also make aluminium brittle, making it more prone to cracking and failure under high stress.

(d) Annealing Aluminium on a Vessel:

Annealing is a process that reverses the effects of work hardening, restoring the aluminium to its original soft and workable state. On a vessel, this can be achieved through:

- Flame Annealing: A handheld torch is used to locally heat the work-hardened area above a specific temperature (around 350°C). This softens the crystal structure and relieves internal stresses, restoring ductility and malleability.
- Induction Annealing: A portable induction heating coil is used to generate heat within the metal. This method offers precise control over the heating process and is suitable for areas with limited access.

These methods are chosen based on the specific application and size of the work-hardened part. Regardless of the method, it's essential to control the annealing temperature and duration to achieve the desired result without melting or weakening the aluminium.

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3. (a) List FOUR methods for non-destructive crack detection. (4)

(b) Describe TWO procedures from the methods listed in part (a). (6)

(a) Four Methods:

1. Visual Inspection: While seemingly simple, trained inspectors can often identify surface cracks and other defects under proper lighting and magnification. This method is quick and accessible but limited to surface flaws.
2. Dye Penetrant Testing (PT): A colored liquid is applied to the surface and allowed to seep into cracks. After wiping the surface, a developer draws the dye back out, highlighting crack locations. This is effective for surface and near-surface cracks but requires careful cleaning and interpretation.
3. Ultrasonic Testing (UT): High-frequency sound waves are transmitted through the material and reflected back. Cracks disrupt the wave path, generating signals detected by the receiver, indicating their presence and location. This works for internal and surface cracks but requires skilled operators and specialized equipment.
4. Eddy Current Testing (ET): Magnetic fields induced by a coil interact with the material, and cracks affect the resulting electrical currents. This method works best for surface and near-surface cracks in conductive materials like metals and can be automated for rapid inspection.

(b) Two Procedure Descriptions:

1. Ultrasonic Testing (UT):

- Process: A transducer sends short bursts of ultrasound waves into the material at specific angles. These waves propagate and reflect back from interfaces within the material, including cracks. The received signals are analyzed to determine the time and intensity of reflections.

- Strengths: Can detect internal and surface cracks, pinpoint crack location and depth, and evaluate crack severity. Works on various materials, including metals, composites, and ceramics.
- Limitations: Requires skilled operators and specialized equipment, interpretation of signals can be complex, and access to both sides of the material may be needed.

2. Eddy Current Testing (ET):

- Process: A coil generates an alternating magnetic field that induces eddy currents in the material. Cracks disrupt the flow of these currents, causing changes in the electromagnetic field detected by the coil. These changes are analyzed to identify crack locations and characteristics.
- Strengths: Fast and automated, suitable for surface and near-surface crack detection in conductive materials, can be used for continuous monitoring during operation.
- Limitations: Only works on conductive materials, less effective for deep cracks, and requires careful calibration and interpretation of readings.

These are just two examples, and the choice of method depends on the specific material, crack type, application, and desired level of detail.

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

Covered electrode welding is a versatile and widely used process, but even the most skilled welder can encounter imperfections. Here are five common defects you might find on a weld, along with simple sketches to visualize them:

1. Slag Inclusion:

- Sketch: Imagine a dark, irregular line embedded within the weld bead.
- Description: Small pieces of molten slag (residue from the electrode coating) become trapped within the weld metal as it solidifies.
- Causes: Improper cleaning of the joint, incorrect welding angle, excessive current.
- Effects: Weakened weld strength, potential cracking, corrosion risk.

2. Undercut:

- Sketch: Picture a groove at the toe of the weld, where the base metal dips below the level of the weld bead.
- Description: Excessive melting of the base metal at the edge of the weld, creating a groove or undercut.
- Causes: High welding current, excessive travel speed, incorrect electrode angle.
- Effects: Reduced weld cross-sectional area, weakened joint, increased stress concentration.

3. Porosity:

- Sketch: Imagine small, round voids or gas pockets scattered throughout the weld bead.

- Description: Gas bubbles entrapped within the molten metal during solidification.
- Causes: Moisture on the base metal or electrode, improper shielding gas flow, contamination.
- Effects: Weakened weld strength, potential leakage paths, reduced fatigue life.

4. Incomplete Fusion:

- Sketch: Picture a gap or lack of bonding between the weld metal and the base metal.
- Description: The weld metal doesn't fully penetrate and bond with the base metal, leaving unfilled areas.
- Causes: Low welding current, improper electrode manipulation, inadequate joint preparation.
- Effects: Weak joint, potential cracking, structural failure risk.

5. Spatter:

- Sketch: Imagine small, solidified droplets of metal scattered around the weld area.
- Description: Molten metal droplets ejected from the arc during welding, sticking to the surrounding surface.
- Causes: Incorrect electrode angle, excessive current, worn-out electrode.
- Effects: Aesthetically undesirable, potential surface damage, cleaning challenges.

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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)

Protecting the Underwater Warriors: Unveiling Cathodic Protection of Hull Fittings

(a) Sacrificial Anodes: Guardians of the Hull:

Imagine these gallant knights, made of zinc or aluminum, standing guard on the hull, sacrificing themselves to protect the nobler metals around them. These are sacrificial anodes, the champions of cathodic protection for hull fittings. They work by creating a galvanic cell with the steel hull:

1. Potential Difference: Sacrificial anodes have a lower electrochemical potential than the steel hull. This creates a voltage difference between them.
2. Anode & Cathode Formation: The anode becomes the anode, readily releasing electrons and dissolving into ions. The steel hull becomes the cathode, attracting electrons.
3. Electron Flow: Electrons flow from the anode through the conductive seawater to the cathode (hull).
4. Cathodic Reaction: Electrons at the cathode react with oxygen and water to form harmless compounds like hydroxide ions.

This cycle essentially shifts the corrosion away from the hull onto the sacrificial anode. As the anode corrodes, it gradually shrinks, eventually needing replacement. But during its noble sacrifice, it protects the vital hull from the ravages of corrosion.

(b) Strategic Positioning: Protecting the Vulnerable:

Like wise generals placing their troops, sacrificial anodes are strategically positioned on the hull, focusing on areas most susceptible to corrosion:

- Propeller: The spinning propeller creates turbulence, accelerating corrosion. Anodes near the propeller ensure its protection.
- Rudder and Stern: These areas experience high water flow and stress, making them vulnerable. Strategically placed anodes shield them.
- Seawater Inlets and Outlets: Where water enters and exits the hull, corrosion risk is high. Anodes protect these crucial points.
- Bilge keels: These protrusions on the hull bottom are prone to corrosion, and anodes strategically placed underneath offer protection.

By placing anodes in these vulnerable areas, we ensure the vital parts of the hull remain shielded from corrosion, extending their lifespan and safeguarding the vessel's integrity.

(c) Impressed Current Systems: Engineered Protection:

For situations where sacrificial anodes aren't sufficient, or for more precise control, an impressed current system can be employed. This system operates based on the same principle of cathodic protection but uses an external power source:

1. Reference Electrode: A reference electrode measures the hull's potential against seawater.
2. Control Unit: The control unit analyzes the potential and adjusts the current output from a DC power source.
3. Anode: A specially designed anode, often made of platinum or graphite, releases current into the seawater.
4. Electron Flow: The current flows from the anode through the seawater to the hull, making it the cathode.
5. Cathodic Reaction: Similar to sacrificial anodes, electrons on the hull react with oxygen and water to form harmless compounds.

By adjusting the current output, the system can precisely control the cathodic protection over the entire hull surface. This offers advantages like:

- Tailored Protection: Adjusting the current allows for customized protection for different hull areas and materials.
- Longer Anode Life: Impressed current systems can use non-sacrificial anodes, which last much longer than sacrificial ones.
- Remote Monitoring: The system can be monitored and controlled remotely, simplifying maintenance and adjustments.

However, impressed current systems are more complex and require additional maintenance compared to sacrificial anodes. Choosing the right approach depends on the size and complexity of the vessel, specific corrosion risks, and operational requirements.

Remember, both sacrificial anodes and impressed current systems play crucial roles in protecting hull fittings from corrosion, ensuring the safety and longevity of vessels navigating the watery depths.

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

(a) explain how osmosis may be detected in service; (2)

(b) explain why simply drying out the hull is not a cure for the effects of osmosis; (2)

(c) describe the FULL process for the treatment of a hull suffering from the effects of osmosis. (6)

Part (a): How osmosis may be detected in service

Osmosis is a process where water diffuses through a semipermeable membrane from a less concentrated solution to a more concentrated one. In the case of GRP hulls, the semipermeable membrane is the gelcoat, and the more concentrated solution is the seawater outside the hull. This can cause the gelcoat to blister and delaminate.

Here are some ways to detect osmosis in service:

- Visual inspection: Look for blisters, cracks, or changes in the color or texture of the gelcoat.
- Tapping: Gently tap on the hull with a mallet or other blunt object. A hollow sound may indicate delamination beneath the surface.
- Moisture meter: Use a moisture meter to measure the moisture content of the hull. This can be a more quantitative way to detect osmosis.

Part (b): Why simply drying out the hull is not a cure for the effects of osmosis

Simply drying out the hull will not cure the effects of osmosis because it does not address the underlying cause of the problem, which is the presence of water trapped within the laminate. Once water has entered the laminate, it can react with the resin and cause it to break down. Even if the hull is dried out, the damage has already been done and the blisters and delamination will likely reappear.

Part (c): The FULL process for the treatment of a hull suffering from the effects of osmosis

The full process for treating a hull suffering from osmosis is a complex one and can vary depending on the severity of the damage. However, here are the general steps involved:

1. Cleaning and drying the hull: The hull must be thoroughly cleaned to remove any dirt, grime, or salt deposits. It should then be dried out completely, ideally using a combination of heat and ventilation.
2. Grinding: The blisters and any delaminated areas must be ground out to remove the damaged material.
3. Neutralizing the acids: The exposed laminate must be neutralized to remove any acidic salts that can cause further damage.
4. Filling and fairing: The ground-out areas must be filled with a suitable epoxy filler and faired smooth.
5. Re-laminating: A new layer of gelcoat or epoxy resin must be applied to the repaired areas.
6. Painting: The hull may need to be repainted to restore its appearance and protect it from further damage.

Part (d): The chemical reaction that occurs during osmosis

The chemical reaction that occurs during osmosis is complex, but it essentially involves the diffusion of water molecules through the gelcoat and into the laminate. The water molecules react with the resin in the laminate, causing it to break down and lose its strength. This can lead to the formation of blisters and delamination.

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7. Describe, with the aid of a sketch, a floatation device that produces an output signal to remotely control the liquid level in a tank. (10)

Here's an example of a floatation device that produces an output signal for remotely controlling the liquid level in a tank, along with a sketch:

Device: Magnetic Float Level Switch with Integrated Transmitter

Sketch:

1. Tank: Depicts the storage tank containing the liquid being monitored.
2. Float: A hollow, buoyant cylinder (shown in red) floats atop the liquid surface.
3. Guide Rod: A vertical rod attached to the tank's top guides the float movement vertically.
4. Magnet: A permanent magnet is mounted inside the float, facing downwards.
5. Reed Switch: One or more reed switches (magnetically sensitive switches) are positioned alongside the guide rod at predetermined levels within the tank.
6. Wiring: Each reed switch connects to a dedicated wire running to the control unit.

Operation:

- As the liquid level rises, the float moves up along the guide rod.
- The magnet inside the float triggers the reed switch positioned at the corresponding level as it passes by.
- The activated reed switch completes the circuit for its associated wire, sending an electrical signal to the control unit.

- The control unit interprets the signal based on which reed switch was activated, indicating the liquid level reaching that specific point.
- Depending on the system configuration, the control unit can then activate pumps, valves, or other devices to maintain the desired liquid level in the tank.

Benefits:

- Non-invasive: No contact with the liquid, minimizing contamination or maintenance needs.
- Reliable: Simple and robust design with minimal moving parts.
- Customizable: Multiple reed switches can be used to create multi-level control.

Limitations:

- Accuracy: Limited to discrete level readings at the positions of the reed switches.
- Sensitivity: May not be suitable for highly precise level control requirements.

Alternative Options:

- Float Switch with Mechanical Lever: Instead of reed switches, the lever attached to the float can directly activate switches or valves mechanically.
- Hydrostatic Pressure Transmitter: Measures the pressure exerted by the liquid column, providing a continuous and more accurate level reading.

Choosing the right type of floatation device depends on factors like desired level control precision, system complexity, and cost considerations.

8. (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)

(a) Fail-Safe:

In a control system, "fail-safe" refers to the design and operation of the system in a way that minimizes damage or risk when a component failure occurs. This ensures the system transitions to a known safe state even when unexpected malfunctions happen.

Examples:

1. Emergency Shutdown in Chemical Plants: If a sensor detects a hazardous gas leak, the system immediately activates the emergency shutdown sequence, safely isolating the leak and preventing further danger.
2. Aircraft Engine Thrust Reduction: If an engine failure is detected, the system automatically reduces thrust on the affected engine, maintaining flight stability and minimizing the risk of a crash.

(b) Failset:

"Failset" refers to the behavior of a system where, upon component failure, the system remains in its current state. While not actively transitioning to a safe state, this approach may be acceptable in specific situations where maintaining the current state is preferable to an uncontrolled change.

Examples:

1. Room Temperature Control: If the thermostat fails, the heating or cooling system might remain in its last active state (on or off), maintaining the room temperature until manual intervention.
2. Traffic Light Signals: If a power outage occurs, the traffic lights might stay in their last illuminated state (red, green, or yellow) until power is restored, providing static information to drivers.

Important Note: Failset is generally less desirable than fail-safe, as it doesn't guarantee a safe outcome in all failure scenarios. Its use should be carefully considered and only implemented if a fail-safe approach is impractical or poses additional risks.

(c) 4:3 Control Valve:

This refers to a control valve whose stroke or travel distance relates to its flow area change according to a 4:3 ratio. Mathematically, the flow area (A) varies with the valve stem position (x) as follows:

$A \propto x^4 / 3$

This characteristic leads to two key features:

1. High flow sensitivity at low openings: Small changes in stem position near the closed position result in significant changes in flow, making the valve suitable for precise control at low flow rates.
2. Limited flow gain at high openings: As the valve approaches its fully open position, further stem movement has a reduced impact on flow rate, providing a degree of "self-regulation" and preventing excessive flow overshoot.

Applications:

- High-precision flow control in chemical processes
- Throttle control in engine fuel systems
- Dosage control in medical equipment

Remember, the specific advantages and drawbacks of a 4:3 control valve depend on the intended application and its control requirements.

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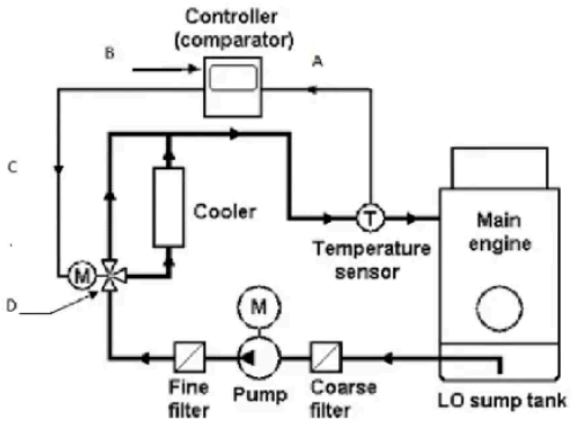
9. For the automatic closed loop engine cooling control system shown in the figure:

(a) identify the signal paths A, B, and C; (3)

(b) describe the function of the comparator; (2)

(c) name and describe the function of component D; (4)

(d) state a suitable device capable of producing a varying signal at T. (1)



Main engine LO temperature control system

Fig Q9

- Path A: This path carries the coolant temperature signal from the temperature sensor to the comparator.
- Path B: This path carries the control signal from the comparator to the cooler (fan).
- Path C: This path represents the coolant flow through the engine, cooler, and back to the engine.

(b) Comparator function:

The comparator compares the coolant temperature signal (Path A) with a reference voltage (setpoint temperature). If the coolant temperature is higher than the setpoint, the comparator outputs a high signal to Path B. This high signal activates the cooler (fan) to start cooling the engine. When the coolant temperature reaches the setpoint, the comparator outputs a low signal, turning off the cooler (fan).

(c) Component D and its function:

Component D is a fine filter. Its function is to remove fine particles from the coolant to protect the engine and other components from wear and tear.

(d) Device at T for varying signal:

A suitable device capable of producing a varying signal at T would be a temperature sensor. This sensor would convert the engine oil temperature into an electrical signal. This signal could then be used to adjust the setpoint temperature of the comparator based on the engine's operating conditions. This would allow for more dynamic and efficient cooling control.

Nov 2021

10. With reference to the elevations of a lever bracket and pin provided below, produce a three dimensional freehand sketch of the component.

Note: Marks will be awarded for dimensional accuracy and the quality of the sketch. (10)

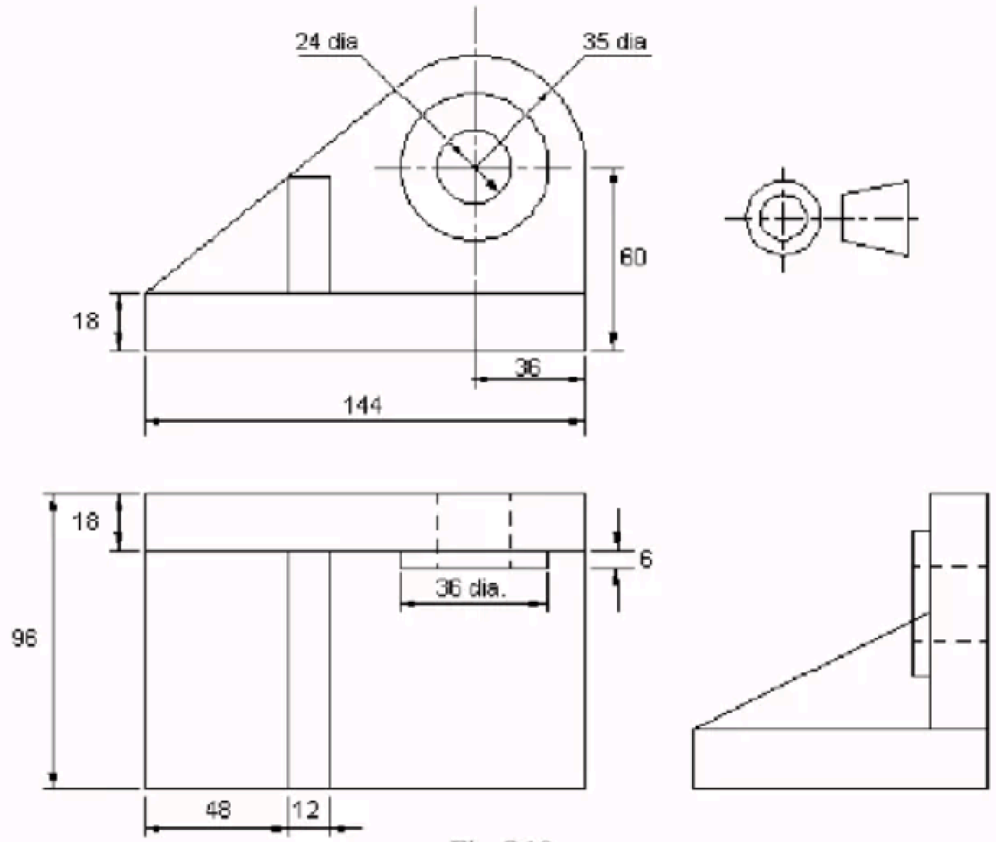


Fig Q10