058-01 - APPLIED MARINE ENGINEERING

FRIDAY, 10 June 2022

1400-1600 hrs

APPLIED MARINE ENGINEERING

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

1. With reference to EACH of the following materials, list their percentage composition and a different application for EACH material on board, stating, with reasons, why they are suitable for this application:

   (a) cupro-nickel; (2)

   (b) aluminium bronze; (2)

   (c) admiralty brass; (2)

   (d) duralumin; (2)

   (e) solder. (2)

2. Describe the heat treatment process EACH of the following components would undergo, stating the reasons for EACH of the processes:

   (a) crankshaft; (4)

   (b) valve spring; (3)

   (c) used copper washer. (3)

3. With reference to stresses within engineering materials:

   (a) explain EACH of the following terms

      (i) tensile stress; (1)

      (ii) shear stress; (1)

      (iii) compressive stress; (1)

   (b) list TWO components within a diesel engine that are subject to the effects of EACH of the three stresses listed in part (a); (6)

   (c) state the component in a 4 stroke diesel engine that has a maximum recommended service life due to constant cyclic stress. (1)

4. Explain EACH of the following engineering terms, stating ONE material that exhibits EACH property:

   (a) brittleness; (2)

   (b) ductility; (2)

   (c) hardness; (2)

   (d) malleability; (2)

   (e) toughness. (2)

5. With reference to gas metal arc welding (MIG) of mild steel:

   (a) describe the process; (3)

   (b) explain, with reasons, the surface preparation required; (3)

   (c) list THREE advantages and ONE limitation. (4)

6. A drydock inspection of the stainless steel alloy propeller shafts has revealed serious pitting corrosion of the shafts in the region where the shafts pass through the stern tube. The stern tube arrangement consists of a shaft seal and a sea-water flooded stern tube with cutless bearing at the aft (sea) end.

   (a) Describe the possible reasons for this corrosion. (6)

   (b) Describe the modifications that could be made to the stern tube arrangement to reduce the likelihood of future shaft corrosion. (4)

7. With reference to the production of glass reinforced plastic (GRP) hulls:

(a) outline the properties of glass fibre and resin that make them suitable for the construction of a hull; (3)

(b) describe the traditional method for the layup of a GRP hull; (5)

(c) list FOUR disadvantages of GRP hulls in service. (2)

8. Describe, with the aid of a sketch, a method of measuring and remotely indicating EACH of the following:

(a) temperature; (4)

(b) rate of flow. (6)

9. (a) Describe, with the aid of a control block diagram, how a governor maintains the speed of a diesel engine driving a generator. (6)

(b) Describe the reasons for Integrating the error signal and the effect it has on the governor fuel rack. (4)

10. (a) Explain EACH of the following control terms:

(i) proportional bandwidth; (2)

(ii) integral action; (2)

(iii) derivative action. (2)

(b) Describe a 3-step method for tuning a PID controller. (4)

June 2022

1. With reference to EACH of the following materials, list their percentage composition and a different application for EACH material on board, stating, with reasons, why they are suitable for this application:

(a) cupro-nickel; (2)

(b) aluminium bronze; (2)

(c) admiralty brass; (2)

(d) duralumin; (2)

(e) solder. (2)

(a) Cupro-nickel

- Composition: 60-70% copper, 30-40% nickel, with small amounts of manganese and iron.
- Applications:
  - Piping systems, heat exchangers, and condensers in seawater systems, due to its excellent resistance to corrosion by saltwater.
  - Propellers, propeller shafts, and hulls of high-quality boats, for its strength and durability.

(b) Aluminum bronze

- Composition: 90-92% copper, 7-9% aluminum, with small amounts of iron, manganese, and other elements.
- Applications:
  - Marine hardware, such as propellers, shafts, and fittings, because of its resistance to corrosion and wear.
  - Bearings and gears, for its good strength and wear resistance.

(c) Admiralty brass

- Composition: 70% copper, 29% zinc, 1% tin.
- Applications:
  - Condenser tubes and plates in seawater systems, due to its good resistance to corrosion and erosion.
  - Heat exchanger tubes and marine hardware.

(d) Duralumin

- Composition: 90% aluminum, 4% copper, 1% magnesium, 0.5% manganese, with small amounts of silicon and iron.
- Applications:
  - Aircraft structures, because of its high strength-to-weight ratio and good fatigue resistance.

- Marine applications, such as masts and booms, for its strength and corrosion resistance.

(e) Solder

- Composition: Varies depending on the type of solder, but typically a mixture of tin and lead, with or without other metals such as silver or copper.
- Applications:
  - Joining electrical components and stained glass panels.
  - Sealing metal cans and food containers.

June 2022

2. Describe the heat treatment process EACH of the following components would undergo, stating the reasons for EACH of the processes:

(a) crankshaft; (4)

(b) valve spring; (3)

(c) used copper washer. (3)

a) Crankshaft:

- Heat treatment: Nitriding or nitrocarburizing.
- Reasons:
  - Improved surface hardness: Enhances resistance to wear and tear from bearing contact and fatigue from cyclic loading, increasing crankshaft lifespan.
  - Reduced friction: Smoother surface minimizes friction and heat generation, improving engine efficiency and reducing operating temperature.
  - Fatigue resistance: Hardened surface resists subsurface cracks from repeated stress, enhancing fatigue strength and preventing shaft failure.
  - Corrosion resistance: Nitriding offers additional protection against corrosion, particularly beneficial for marine engines or harsh environments.

(b) Valve Spring:

- Heat treatment: Austempering or oil quenching and tempering.
- Reasons:
  - High strength and toughness: Enhanced tensile strength and fatigue resistance allow the spring to withstand high loads and repeated cycles without deformation or failure.
  - Heat resistance: The treatment maintains spring properties at elevated engine temperatures, ensuring consistent valve operation.
  - Dimensional stability: Minimizes spring relaxation and set loss over time, preventing valve clearance issues and maintaining engine performance.
  - Ductility: Austempering provides slightly better ductility for absorbing shock loads and preventing brittle fracture.

(c) Used Copper Washer:

- Heat treatment: None.
- Reasons:
  - Copper is malleable and soft: Its inherent properties allow it to conform to irregularities and create a tight seal even without heat treatment.
  - Heat exposure can weaken copper: Annealing or other heat treatments might reduce its strength and compromise its sealing function.
  - Used washers are typically discarded: Repetitive thermal cycling and mechanical stresses often render used washers unsuitable for reuse, regardless of heat treatment.

In summary, different engine components require specific heat treatment based on their function and desired properties. Crankshafts and valve springs benefit from hardening processes for strength, wear resistance, and fatigue resistance. Used copper washers, however, generally don't undergo any heat treatment due to their inherent properties and potential degradation from past use.

June 2022

3. With reference to stresses within engineering materials:

(a) explain EACH of the following terms

(i) tensile stress; (1)

(ii) shear stress; (1)

(iii) compressive stress; (1)

(b) list TWO components within a diesel engine that are subject to the effects of EACH of the three stresses listed in part (a); (6)

(c) state the component in a 4 stroke diesel engine that has a maximum recommended service life due to constant cyclic stress. (1)

a) Explaining Different Types of Stresses:

(i) Tensile Stress:

- Definition: A pulling force that acts to elongate a material, stretching it in the direction of the force.
- Imagine: Pulling a rope to extend it.

(ii) Shear Stress:

- Definition: A force that tends to slide or deform one part of a material relative to another along a parallel plane.
- Imagine: Sliding two bricks against each other, causing them to deform and potentially tear.

(iii) Compressive Stress:

- Definition: A pushing force that squeezes or compresses a material, shortening its length in the direction of the force.
- Imagine: Stacking heavy weights on top of a block, pushing it downwards and potentially crushing it.

(b) Components Experiencing Different Stresses in a Diesel Engine:

Tensile Stress:

- Connecting rod: The pull of the piston on the connecting rod creates tensile stress throughout its length.
- Cylinder head bolts: The pressure generated during combustion pushes outwards on the cylinder head, requiring the bolts to resist this tensile force.

Shear Stress:

- Crankshaft bearings: The connecting rod rotates on the crankshaft bearing, creating frictional shear stress between the two surfaces.
- Gear teeth: When gears mesh, their teeth slide against each other, generating shear stress at the contact points.

Compressive Stress:

- Piston: The combustion pressure pushes down on the piston, creating compressive stress throughout its crown.
- Cylinder walls: The pressure inside the cylinder also pushes outwards on the cylinder walls, subjecting them to compressive stress.

(c) Component with Maximum Cyclic Stress in a 4-Stroke Diesel Engine:

The component in a 4-stroke diesel engine with a maximum recommended service life due to constant cyclic stress is the piston and its rings. These components experience repeated cycles of high pressure during combustion, followed by release of pressure during exhaust and intake strokes. This constant cycling, along with high temperatures and friction, contributes to wear and tear, necessitating a recommended service life for their replacement.

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4. Explain EACH of the following engineering terms, stating ONE material that exhibits EACH property:

(a) brittleness; (2)

(b) ductility; (2)

(c) hardness; (2)

(d) malleability; (2)

(e) toughness. (2)

(a) Brittleness:

- Definition: A material that fractures with little or no plastic deformation under stress.
- Example: Cast iron: This type of iron is known for its brittleness, meaning it tends to crack or break easily even under moderate impact or bending.

(b) Ductility:

- Definition: The ability of a material to be drawn or stretched into a thin wire without breaking.
- Example: Copper: This metal is highly ductile, making it ideal for use in electrical wiring and plumbing applications where it needs to be bent and shaped easily.

(c) Hardness:

- Definition: Resistance to indentation or scratching.
- Example: Diamond: This gemstone is the hardest natural material known, making it virtually scratch-proof and extremely resistant to wear and tear.

(d) Malleability:

- Definition: The ability of a material to be hammered or rolled into thin sheets without cracking.
- Example: Gold: This precious metal is highly malleable, allowing it to be shaped into delicate jewelry and decorative objects.

(e) Toughness:

- Definition: The ability of a material to absorb energy before breaking. This combines both strength and ductility.
- Example: Bamboo: This natural material exhibits remarkable toughness due to its fibrous structure. It can bend without breaking and withstand considerable impact forces.

June 2022

5. With reference to gas metal arc welding (MIG) of mild steel:

(a) describe the process; (3)

(b) explain, with reasons, the surface preparation required; (3)

(c) list THREE advantages and ONE limitation. (4)

(a) MIG Welding Process:

MIG welding, also known as Metal Inert Gas welding, is a semi-automatic welding process that joins metals using a continuously fed consumable solid wire electrode and an inert shielding gas. Here's a breakdown of the steps:

1. Preparation: Clean the weld area thoroughly to remove dirt, grease, rust, paint, and any other contaminants that can weaken the weld and introduce impurities.
2. Setup: Choose the appropriate wire and inert gas (e.g., argon, argon-CO2 mix) based on the material and desired weld characteristics. Install the wire and gas cylinder, set the wire feed speed and welding current according to the material thickness.
3. Welding: Hold the welding torch at the appropriate angle and distance from the joint. As you trigger the welding gun, the wire feeds continuously and an arc forms between the wire tip and the metal, melting both materials. The shielding gas protects the molten metal from atmospheric contamination.
4. Travel Speed: Move the torch steadily along the joint seam at a controlled speed, melting and joining the metal while leaving a continuous weld bead.
5. Cleaning: Allow the weld to cool completely, then remove any slag (residue) with a chipping hammer or wire brush.

(b) Surface Preparation and its Importance:

Proper surface preparation is crucial for achieving strong and high-quality MIG welds in mild steel for several reasons:

- Contaminants: Dirt, grease, rust, and paint can all prevent the molten metal from properly bonding with the base metal, leading to weak welds and potential porosity (gas bubbles) within the weld.
- Oxidation: Rust and oxidation layers create impurities that can affect the weld strength and introduce slag inclusions.
- Smooth Melting: Clean surfaces offer a better contact surface for the molten metal, allowing for smoother melting and a more consistent weld bead profile.

Therefore, thorough cleaning with grinding, wire brushing, or other appropriate methods ensures optimal weld quality and performance.

(c) Advantages and Limitation of MIG Welding:

Advantages:

1. Versatility: Handles a wide range of materials and thicknesses with ease.
2. High Deposition Rate: Creates thick and strong welds quickly due to the continuous wire feed.
3. Cleanliness: Inert gas shielding minimizes spatter and fumes compared to other welding processes.

Limitation:

1. Wind Sensitivity: The shielding gas can be easily affected by wind, requiring shielding devices in outdoor environments for consistent weld quality.

MIG welding offers a balance of ease, speed, and quality for mild steel welding, making it a popular choice for various applications. However, its wind sensitivity needs to be considered for outdoor work.

June 2022

6. A drydock inspection of the stainless steel alloy propeller shafts has revealed serious pitting corrosion of the shafts in the region where the shafts pass through the stern tube. The stern tube arrangement consists of a shaft seal and a sea-water flooded stern tube with cutless bearing at the aft (sea) end.

(a) Describe the possible reasons for this corrosion. (6)

(b) Describe the modifications that could be made to the stern tube arrangement to reduce the likelihood of future shaft corrosion. (4)

The pitting corrosion discovered on your stainless steel propeller shafts within the stern tube is a concerning finding. Let's explore the possible reasons and potential modifications to prevent future recurrence:

(a) Possible Reasons for Corrosion:

Several factors could be contributing to the localized pitting corrosion in this specific area:

- Crevice Corrosion: The tight space between the shaft and the stern tube can create a stagnant seawater environment, encouraging crevice corrosion. This occurs when oxygen levels get depleted in these confined areas, hindering the passive layer formation on stainless steel, making it vulnerable to pitting attacks.
- Galvanic Corrosion: If dissimilar metals are present in the vicinity, like a bronze cutless bearing in contact with the stainless steel shaft, galvanic corrosion can occur. The more active metal (in this case, the shaft) corrodes preferentially, accelerating pitting in the tight crevice formed by the bearing contact.
- Chlorides and Other Aggressive Ions: Seawater naturally contains chlorides and other aggressive ions that can break down the passive layer on stainless steel, leading to localized

pitting corrosion. The stagnant seawater within the stern tube can concentrate these ions, further intensifying the attack.

- Mechanical stress: Vibrations and minor movements experienced by the shaft during operation can create localized stress points on the surface, acting as initiation sites for pitting corrosion. These stresses can be amplified in the confined space of the stern tube.

(b) Modifications to Reduce Corrosion:

To combat these factors and prevent future corrosion, consider these modifications:

- Improve Ventilation & Reduce Stagnancy: Implementing a flushing system within the stern tube can introduce fresh seawater, replenishing oxygen levels and reducing crevice corrosion risks. Additionally, optimizing shaft seals to minimize trapped seawater within the crevice can be beneficial.
- Material Selection: Consider replacing the cutless bearing with a material compatible with the stainless steel shaft, minimizing galvanic interactions. Materials like composite bearings or elastomeric bearings offer alternatives.
- Protective Coatings: Applying specialized coatings like epoxy resins or silane-based coatings on the shaft within the stern tube can create a physical barrier against aggressive ions and enhance corrosion resistance.
- Cathodic Protection: In severe cases, employing a cathodic protection system with sacrificial anodes or impressed current can be implemented to actively protect the shaft from corrosion within the stern tube.
- Stress Reduction: Analyzing the shaft design and operational conditions to identify and address potential sources of stress on the shaft in the stern tube area can further minimize pitting initiation sites.

Remember, the most effective approach will depend on a thorough investigation of the specific factors contributing to the current corrosion issue. Consulting with experienced marine engineers and corrosion specialists is crucial to determine the optimal set of modifications for your vessel's stern tube arrangement.

By addressing the root causes and implementing preventative measures, you can effectively protect your propeller shafts from further corrosion and ensure their longevity and safe operation.

June 2022

7. With reference to the production of glass reinforced plastic (GRP) hulls:

(a) outline the properties of glass fibre and resin that make them suitable for the construction of a hull; (3)

(b) describe the traditional method for the layup of a GRP hull; (5)

(c) list FOUR disadvantages of GRP hulls in service. (2)

GRP Hulls: Material Properties, Production, and Disadvantages

(a) Material Properties:

Glass Fiber:

- High strength-to-weight ratio: Lightweight yet strong, providing good overall hull strength without excessive weight.
- Corrosion resistance: Resists saltwater and other harsh marine environments, ideal for boat hulls.
- Dimensional stability: Maintains shape well, minimizing warping or deformation.
- Electrical insulation: Non-conductive, preventing electrolysis issues between hull and electrical components.

Resin:

- Binds and protects fibers: Creates a strong composite material by holding fibers together and providing surface protection.
- Watertight: Forms a continuous barrier against water ingress, crucial for hull integrity.
- Curable: Transforms from liquid to solid, allowing for shaping and molding during construction.
- Variable properties: Different resin types offer varying flexibility, rigidity, and chemical resistance to suit specific hull needs.

(b) Traditional Layup Method:

1. Mold preparation: A polished mold with the desired hull shape is prepared.
2. Gelcoat application: A thin layer of pigmented gelcoat is sprayed onto the mold for a smooth, protective outer surface.
3. Reinforcement layer: Chopped strand mat (CSM) or woven roving fiberglass fabrics are applied and saturated with resin, building initial thickness and strength.
4. Additional layers: Further layers of different fabric types and resin are added based on design requirements, varying thickness and stiffness in different areas.
5. Consolidation: Techniques like rollers, vacuum bagging, or hand pressure ensure proper resin distribution and eliminate air pockets.
6. Curing: The resin is allowed to cure and harden, typically at room temperature or with controlled heat.
7. Mold release: The cured hull is carefully removed from the mold for finishing and fitting.

(c) Disadvantages of GRP Hulls:

1. Osmosis susceptibility: Can be prone to osmotic blisters if water permeates through the laminate and encounters salts, leading to structural damage.
2. Stress cracking: Susceptible to cracking under high loads or stresses, especially if design or construction isn't robust enough.
3. Fire resistance: Not inherently fire-resistant, requiring additional fireproofing measures for safety.
4. Repair challenges: Complex repairs require skilled technicians and specific materials, sometimes needing professional intervention.

While GRP offers advantages in cost, versatility, and weight savings, these disadvantages in service need to be considered and mitigated through proper maintenance, design, and construction practices.

June 2022

8. Describe, with the aid of a sketch, a method of measuring and remotely indicating EACH of the following:

(a) temperature; (4)

(b) rate of flow. (6)

(a) Temperature Measurement and Remote Indication (Sketch):

Imagine a probe inserted into the object or environment you want to monitor. Let's call it a thermocouple, made of two dissimilar metals joined at the tip. Here's how it works:

Sketch:

- Hot Junction: The tip of the thermocouple experiences the temperature you want to measure.
- Dissimilar Metals: Each metal in the thermocouple has a unique relationship between temperature and voltage.
- Voltage Difference: When the hot junction experiences a temperature change, the voltage difference between the two metals at the junction also changes.
- Connecting Wires: Two or four wires connect the thermocouple to a measuring device.
- Measuring Device: This device detects the voltage change and converts it into a temperature reading based on pre-programmed equations specific to the chosen metal pair.
- Remote Indicator: The temperature reading is then displayed on a remote panel or transmitted wirelessly for monitoring.

Key Points:

- Thermocouples are simple, robust, and widely used for temperature measurement.
- The choice of metal pair influences the temperature range and sensitivity of the thermocouple.

(b) Flow Rate Measurement and Remote Indication (Sketch):

Now, imagine a device installed in a pipe carrying the fluid you want to measure. Let's call it a magnetic flow meter. Here's how it works:

Sketch:

- Magnetic Field: The meter generates a magnetic field across the flowing liquid within the pipe.
- Moving Conductors: The moving fluid particles act as conductors within the magnetic field.
- Induced Voltage: The interaction between the moving conductors and the magnetic field induces a voltage proportional to the flow velocity.
- Electrodes: Sensors within the meter pick up this induced voltage.
- Flow Calculation: The electronic unit within the meter converts the voltage to a flow rate value based on the pipe cross-section and calibration factors.
- Remote Indicator: The flow rate reading is then displayed on a remote panel or transmitted wirelessly for monitoring.

Key Points:

- Magnetic flow meters are non-invasive and accurate for measuring flow rates.
- They work with various conductive fluids and are not affected by pressure or temperature changes.

Remember, these are just two examples, and various other technologies can be used for temperature and flow rate measurement and remote indication. Choosing the right method depends on factors like accuracy requirements, fluid properties, budget, and environmental conditions.

June 2022

9. (a) Describe, with the aid of a control block diagram, how a governor maintains the speed of a diesel engine driving a generator. (6)

(b) Describe the reasons for Integrating the error signal and the effect it has on the governor fuel rack. (4)

Governor in Diesel Engine Speed Control:

(a) Control Block Diagram:

The governor in a diesel engine driving a generator maintains the engine speed by regulating the fuel supply based on sensed deviations from the desired speed. Here's the control block diagram:

```
+--------------------+          +------------------+
| Speed Sensor       |          | Fuel Injector      |
| (Engine Speed)     |          +------------------+
+--------------------+                    |
                     |                    v
+--------------------+          +------------------+
| Governor           |          | Fuel Rack        |
| (Controller)       |          +------------------+
+--------------------+                    |
                     |                    v
           +-------+           +-------+
           | Error |           | Gain  |
           +-------+           +-------+
                   |                   |
                   v                   v
            +-----------------+     +-----------------+
            | Setpoint      | |     | Engine Load     |
            | (Desired Speed) |     | (External Disturbance)|
            +-----------------+     +-----------------+
```

Components and Functions:

- Speed Sensor: Measures the actual engine speed (feedback signal).
- Governor (Controller): Compares the measured speed with the desired speed (setpoint) and calculates the error.
- Error: Difference between actual and desired speed.
- Gain: Amplifies the error signal to adjust the fuel rack position effectively.
- Fuel Rack: Regulates the amount of fuel delivered to the engine cylinders.
- Fuel Injector: Injects fuel into the cylinders based on the rack position.
- Setpoint: Represents the desired engine speed, often adjustable based on generator load.
- Engine Load: External disturbance affecting the engine speed (e.g., increased electrical demand).

(b) Integrating the Error Signal:

Governors often incorporate integral action to improve speed regulation:

- Reason: Constant speed deviations (steady-state errors) can occur with proportional (gain) control alone. The governor might react to the initial error but may not reach the setpoint perfectly, especially under varying loads.

- Effect: Integrating the error signal accumulates the error over time, providing a larger correction signal until the error is eliminated. This helps the governor "remember" past deviations and adjust the fuel rack further to reach the exact setpoint, even with external disturbances.
- Impact on Fuel Rack: Integrating the error results in a gradual, sustained adjustment of the fuel rack towards the required position. This ensures the engine speed converges to and maintains the desired value, overcoming steady-state errors.

Summary:

The governor uses a feedback loop with error correction and amplification to regulate the fuel supply and maintain the engine speed despite load changes. Integration improves the system's ability to eliminate steady-state errors and achieve precise speed control.

June 2022

10. (a) Explain EACH of the following control terms:

(i) proportional bandwidth; (2)

(ii) integral action; (2)

(iii) derivative action. (2)

(b) Describe a 3-step method for tuning a PID controller. (4)

(a) Control Terms:

(i) Proportional Bandwidth (PB):

Proportional bandwidth (PB) refers to the range of input values around the setpoint that will cause the proportional controller's output to span its entire range. It can be expressed as a percentage of the setpoint and is calculated as the inverse of the proportional gain (K_p):

PB = 100 / K_p

A higher PB corresponds to a smaller gain, meaning the controller reacts less aggressively to input changes, leading to slower but more stable behavior. Conversely, a lower PB signifies a higher gain, resulting in faster response but potentially causing oscillations if not tuned properly.

(ii) Integral Action:

Integral action, also known as "reset" or "I action," accumulates the error over time and contributes an additional term to the controller output based on the integral of the error signal. This helps eliminate steady-state errors that proportional control alone might not address.

The integral term gradually increases the output as long as the error persists, eventually bringing the output to a value that cancels out the error. The integral gain (K_i) determines how quickly this adjustment occurs. Too high a value can lead to overshoot and instability, while too low a value might leave steady-state errors uncorrected.

(iii) Derivative Action:

Derivative action, also known as "rate" or "D action," considers the rate of change of the error signal and adjusts the controller output accordingly. This helps to anticipate future changes and provides faster response to transient disturbances.

The derivative term adds a component to the output proportional to the rate of change of the error. The derivative gain (K_d) determines the sensitivity to error rate. High values can lead to excessive control action and instability, while low values might cause sluggish response.

(b) 3-Step PID Tuning Method:

1. Start with Proportional control only (set Ki and Kd to zero):
    - Increase the proportional gain (K_p) gradually until the system starts to oscillate.
    - Note the value of K_p at which oscillations begin (P_osc).
    - Reduce K_p to approximately 50% of P_osc to achieve a stable but oscillatory response.
2. Introduce Integral action:
    - Increase the integral gain (K_i) slowly while observing the system response.
    - The integral term will gradually eliminate the steady-state error introduced by the proportional control alone.
    - Stop increasing K_i when the response becomes sluggish or overshoots significantly.
3.
4. Fine-tune with Derivative action (optional):
    - If further response improvement is desired, introduce derivative action cautiously.
    - Increase the derivative gain (K_d) slightly while monitoring the system's stability.
    - The derivative term can help dampen oscillations and improve transient response, but avoid excessive values that might cause instability.