058-01 - APPLIED MARINE ENGINEERING

FRIDAY, 20 November 2020

1400-1600 hrs

APPLIED MARINE ENGINEERING

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

1. With reference to austenitic stainless steels:

   (a) list the THREE main constituents with approximate percentage composition; (3)

   (b) state the main difference between grades 304 & 316 and how this is achieved; (3)

   (c) list TWO typical applications for EACH grade stated in part (b) that would be found on a modern vessel. (4)

2. (a) Explain how the properties of steel are modified by its carbon content. (2)

   (b) Explain EACH of the following terms:

   (i) annealing; (3)

   (ii) normalising; (3)

   (iii) hardening. (2)

3. (a) Explain EACH of the following terms:

   (i) plasticity; (2)

   (ii) sheer stress; (2)

   (iii) Young's modulus; (2)

   (iv) safety coefficient (factor of safety). (2)

   (b) State TWO factors that may influence the safety coefficient in operation. (2)

4. State, with reasons, a different welding/brazing/soldering process that is best suited to effect EACH of the following situations:

   (a) joining two lengths of aluminium bronze seawater pipe, both pipes having the same diameter; (2)

   (b) attaching a stainless steel handrail to a steel hull; (2)

   (c) re-attach a section of broken flange on a cast iron pump casing; (2)

   (d) attaching a brass flange onto a stainless steel pipe; (2)

   (e) attaching a 1.0 mm steel section to 10 mm thick deckhead plate. (2)

5. Explain how corrosion and its effects can be minimised in seawater cooling systems. (10)

6. With reference to hot docking:

   (a) explain how this occurs, stating its effects; (6)

   (b) describe the operation of TWO devices that will prevent this occuring. (4)

7. With reference to capacitance probe sensors:

   (a) describe, with the aid of a sketch, how a capacitance probe produces an output which can be used to measure the liquid level in a tank. (7)

   (b) state TWO different uses of this device on a vessel; (2)

   (c) state ONE disadvantage of this type of probe. (1)

8. Describe, with the aid of a sketch, how a floatation device can produce an output signal that can be used to control the liquid level in a tank. (10)

9. (a) Define the term *Proportional Action*. (2)

   (b) Explain the purpose of *Integral Action*. (2)

   (c) Describe a possible effect of excessive Integral Action. (2)

   (d) Explain the purpose of *Derivitive Action*. (2)

   (e) Describe the effect of excessive Derivitive Action. (2)

10. 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)

Nov 2020

1. With reference to austenitic stainless steels:

(a) list the THREE main constituents with approximate percentage composition; (3)

(b) state the main difference between grades 304 & 316 and how this is achieved; (3)

(c) list TWO typical applications for EACH grade stated in part (b) that would be found on a modern vessel. (4)

a) The three main constituents of austenitic stainless steel are:

1. Iron: As the base metal, iron makes up the majority of the composition, typically ranging from 60% to 70%.
2. Chromium: This is the key element that gives austenitic stainless steel its corrosion resistance. It usually constitutes between 18% and 20% of the composition.
3. Nickel: This element contributes to the austenitic structure and enhances properties like ductility, toughness, and strength at low temperatures. The nickel content in austenitic stainless steel typically ranges from 8% to 10%.

While these three elements form the core of austenitic stainless steel, other elements can be added in smaller amounts to further enhance specific properties. These include:

- Carbon: Increases strength and hardness but decreases ductility and toughness.
- Manganese: Improves strength, workability, and hardenability.
- Nitrogen: Provides additional strength and enhances corrosion resistance.
- Molybdenum: Increases high-temperature strength and resistance to certain types of corrosion.

b) Both 304 and 316 are popular grades of austenitic stainless steel, but they do have some key differences:

Molybdenum content:

- 304: Does not contain molybdenum.
- 316: Contains 2-3% molybdenum, which significantly improves its corrosion resistance, especially in chloride-rich environments like saltwater.

Corrosion resistance:

- 304: Offers good corrosion resistance to mild environments, food acids, and freshwater.
- 316: Offers superior corrosion resistance to chlorides, acids, and saltwater, making it ideal for marine applications, chemical processing, and food processing equipment exposed to harsh cleaning solutions.

Applications:

- 304: Widely used in kitchen equipment, architectural trim, automotive parts, and other general applications where good corrosion resistance is needed but saltwater exposure is minimal.
- 316: Widely used in marine hardware, chemical processing equipment, medical implants, high-temperature applications, and food processing equipment requiring extra corrosion resistance.

Cost:

- 304: Less expensive due to the absence of molybdenum.
- 316: More expensive due to the addition of molybdenum.

Other differences:

- Formability: Both are highly formable and weldable, but 304 may be slightly easier to work with.
- Strength: 316 may have slightly higher strength due to the molybdenum content.

Here's a table summarizing the key differences:

Feature	304	316
Molybdenum content	No	2-3%
Corrosion resistance	Good	Superior, especially to chlorides and salt

Applications	Kitchen equipment, architecture, automotive	Marine, chemical processing, medical, food processing with harsh cleaning
Cost	Less expensive	More expensive
Formability	Highly formable	Highly formable
Strength	Good	Slightly higher

Application 1: Food processing equipment (tanks, pipes, utensils)

- Possible grades: Austenitic stainless steels like AISI 304 (18/8) or 316 (18/10 Mo).
- Key features:
  - Corrosion resistance: Resists corrosion from food acids, cleaning chemicals, and saltwater.
  - Formability and weldability: Easy to shape and weld for complex equipment designs.
  - Hygiene: Smooth, non-porous surface prevents bacteria growth and is easy to clean.
  - Austenitic: Non-magnetic and has good low-temperature toughness.

Application 2: Chemical piping and tanks

- Possible grades: Depending on the specific chemicals, AISI 316L (16/10 Mo low carbon), 904L, or super austenitic grades like 254SMO.
- Key features:
  - High corrosion resistance: Resists strong acids, alkalis, and oxidizing environments.
  - Pitting resistance: Resists localized corrosion from chlorides and other aggressive ions.
  - Crevice corrosion resistance: Resists corrosion in tight spaces like under gaskets.
  - High strength and durability: Handles pressure and temperature extremes.

Application 3: Marine hardware (fasteners, fittings, shafts)

- Possible grades: AISI 316L (16/10 Mo low carbon), 17-4 PH, or duplex stainless steels like 2205.
- Key features:
  - Excellent saltwater corrosion resistance: Resists pitting and crevice corrosion from seawater.
  - High strength and toughness: Withstands mechanical loads and stresses.
  - Good machinability and weldability: Easy to fabricate and join for complex hardware.
  - 17-4 PH and duplex grades: Offer higher strength and hardness for demanding applications.

Application 4: Medical implants (surgical instruments, prosthetics)

- Possible grades: AISI 316LVM (16/10 Mo very low carbon) or 316L with electropolishing.
- Key features:
  - Biocompatibility: Non-toxic and does not reject human tissue.
  - High corrosion resistance: Resists body fluids and sterilization chemicals.
  - High strength and fatigue resistance: Withstands repeated stresses without breaking.
  - Smooth surface finish: Minimizes risk of infection and tissue irritation.

Application 5: Cryogenic tanks and vessels (storing extremely cold liquids)

- Possible grades: AISI 304L (18/8 low carbon) or 904L.
- Key features:
  - Excellent low-temperature toughness: Maintains strength and ductility at very cold temperatures.
  - Good weldability: Can be welded reliably for strong and leak-proof tanks.
  - Corrosion resistance: Resists contamination from cryogenic liquids and cleaning chemicals.
  - 304L: Offers a good balance of properties and affordability.

Nov 2020

2. (a) Explain how the properties of steel are modified by its carbon content. (2)

(b) Explain EACH of the following terms:

(i) annealing; (3)

(ii) normalising; (3)

(iii) hardening. (2)

(a) Steel Properties and Carbon Content:

The carbon content in steel significantly influences its properties in several ways:

- Strength and Hardness: As the carbon content increases, the strength and hardness of steel also increase. This is because carbon atoms form strong bonds with iron atoms, hindering dislocation movement and making the material more resistant to deformation.
- Ductility and Malleability: Conversely, higher carbon content reduces the ductility and malleability of steel. The tangled crystal structure caused by carbon atoms makes it more difficult to bend or shape the material without cracking.
- Weldability: High-carbon steel becomes less weldable due to increased susceptibility to cracking around the weld zone. Careful control of heat and filler materials is necessary during welding.
- Machinability: Low-carbon steel is easier to machine due to its softer nature. As carbon content increases, machining becomes more challenging and requires specialized tools.
- Corrosion Resistance: Generally, higher carbon content reduces the corrosion resistance of steel. However, certain high-chromium stainless steels with moderate carbon content offer excellent corrosion resistance.

Therefore, the optimal carbon content for steel depends on the desired properties for a specific application. A balance between strength, ductility, weldability, and other characteristics is often sought based on the intended use.

(b) Explaining Heat Treatment Terms:

(i) Annealing:

Annealing is a heat treatment process that softens a work-hardened or quenched steel by relieving internal stresses and promoting grain growth. This increases ductility and malleability while reducing strength and hardness. It typically involves heating the steel to a specific temperature above its recrystallization temperature and then slowly cooling it. Annealing is used to improve formability, relieve welding stresses, and prepare steel for further processing.

(ii) Normalising:

Normalizing is a heat treatment process similar to annealing but involves heating the steel to a higher temperature (above its critical temperature) and then cooling it in air. This refines the grain structure, resulting in a balance between strength and ductility compared to annealing. Normalizing is often used for forging and casting processes to improve mechanical properties and machinability.

(iii) Hardening:

Hardening is a heat treatment process that involves austenitizing (heating above the critical temperature) a steel followed by rapid quenching (cooling). This rapid cooling traps carbon atoms in the austenitic lattice structure, forming a metastable phase called martensite. Martensite is very hard and brittle, significantly increasing the steel's strength and hardness. However, it also becomes more brittle and susceptible to cracking. Hardening is often followed by tempering to improve toughness and reduce internal stresses without significantly sacrificing strength.

Nov 2020

3. (a) Explain EACH of the following terms:

(i) plasticity; (2)

(ii) sheer stress; (2)

(iii) Young's modulus; (2)

(iv) safety coefficient (factor of safety). (2)

(b) State TWO factors that may influence the safety coefficient in operation. (2)

(a) Definitions:

(i) Plasticity:

The property of a material to undergo permanent deformation under stress. Unlike elastic materials that return to their original shape after stress is removed, plastic materials retain a portion of the deformation. Imagine bending a paperclip - it retains the bend after you let go.

(ii) Shear Stress:

The stress that tends to slide or distort one part of a material relative to another along a parallel plane. Picture sliding two books against each other, causing them to shear and potentially tear.

(iii) Young's Modulus:

Also known as the elastic modulus, it measures the stiffness of a material. It quantifies the relationship between stress and strain within the elastic range (where deformation is temporary). A higher Young's modulus indicates a stiffer material that requires more force to deform a given amount. Think of a stiff beam compared to a limp noodle.

(iv) Safety Coefficient (Factor of Safety):

A factor applied to the design load of a component to ensure it has sufficient strength to handle actual operating conditions with a buffer against unexpected stresses or material imperfections. It acts as a safeguard against component failure and associated risks. Imagine adding extra bricks to a bridge design to ensure it can safely support cars and trucks.

(b) Factors Influencing Safety Coefficient:

(i) Operating Conditions: Unexpected loads or environmental factors like extreme temperatures, corrosive environments, or sudden shocks can necessitate a higher safety coefficient to account for these additional stresses.

(ii) Material Properties: Variations in material properties due to manufacturing processes, aging, or inherent inconsistencies can require adjusting the safety coefficient to ensure reliable performance despite these uncertainties.

March 2022

4. State, with reasons, a different welding/brazing/soldering process that is best suited to effect EACH of the following situations:

(a) joining two lengths of aluminium bronze seawater pipe, both pipes having the same diameter; (2)

(b) attaching a stainless steel handrail to a steel hull; (2)

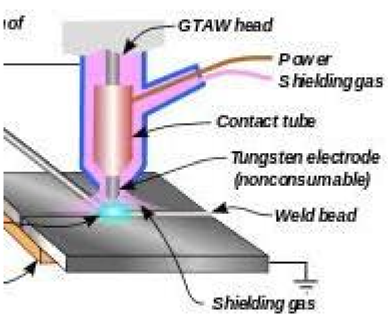
(c) re-attach a section of broken flange on a cast iron pump casing; (2)

(d) attaching a brass flange onto a stainless steel pipe; (2)

(e) attaching a 1.0 mm steel section to 10 mm thick deckhead plate. (2)

(a) Joining two lengths of aluminum bronze seawater pipe, both pipes having the same diameter.

The best process for this situation is gas tungsten arc welding (GTAW), also known as TIG welding. TIG welding is a precise and controlled process that is well-suited for joining thin materials, such as aluminum bronze. It is also resistant to corrosion, which is important for seawater pipes.



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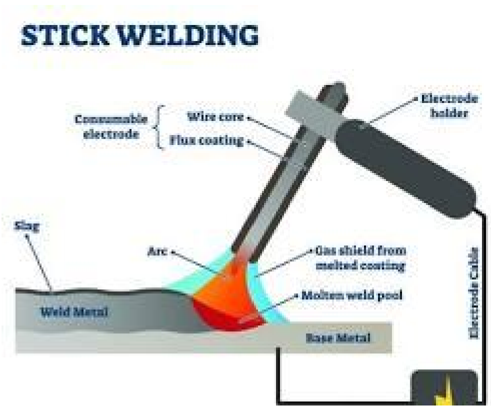
Gas tungsten arc welding (GTAW)

(b) Attaching a stainless steel handrail to a steel hull.

The best process for this situation is shielded metal arc welding (SMAW), also known as stick welding. SMAW is a versatile process that can be used to join a variety of metals, including steel and stainless steel. It is also a relatively inexpensive and portable process, which makes it a good choice for shipboard repairs.



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Shielded metal arc welding (SMAW)

(c) Re-attaching a section of broken flange on a cast iron pump casing.

The best process for this situation is brazing. Brazing uses a filler metal that has a lower melting point than the base metals. This allows the filler metal to melt and flow into the joint, without melting the base metals. Brazing is a good choice for cast iron because it is less likely to cause cracking.

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brighton-science.com

Brazing

(d) Attaching a brass flange onto a stainless steel pipe.

The best process for this situation is silver soldering. Silver solder is a type of solder that has a high melting point and is very strong. It is a good choice for joining dissimilar metals, such as brass and stainless steel.

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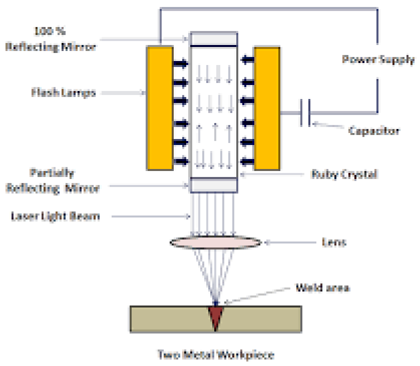
Silver soldering

(e) Attaching a 1.0 mm steel section to 10 mm thick deckhead plate.

The best process for this situation is laser beam welding. Laser beam welding is a high-energy process that can create very strong and narrow welds. It is a good choice for this situation because it can weld the thin steel section to the thicker deckhead plate without melting too much of either metal.



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Laser beam welding

Nov 2020

5. Explain how corrosion and its effects can be minimised in seawater cooling systems. (10)

Minimizing corrosion and its effects in seawater cooling systems is crucial for maintaining system integrity, efficiency, and longevity. Here are some key strategies:

Preventing Corrosion:

- Material Selection: Choosing corrosion-resistant materials like stainless steel, copper-nickel alloys, or titanium can significantly reduce corrosion rates. While initially more expensive, their long-term cost-effectiveness outweighs frequent maintenance and replacements.
- Seawater Treatment: Pre-treating seawater before it enters the system can remove harmful elements like dissolved oxygen, chlorides, and sulfates, reducing their corrosive potential. Techniques like deaeration, filtration, and chemical dosing can be employed.
- Protective Coatings: Applying specialized coatings like epoxy resins, polyurethanes, or zinc primers can create a physical barrier between the metal and the seawater, further diminishing corrosion. However, regular inspection and reapplication may be necessary.
- Cathodic Protection: Impressing a small current on the metal surface can shift its potential, making it cathodic and preventing oxidation. This can be achieved through sacrificial anodes (e.g., zinc) that corrode instead of the system components, or impressed current systems.

Monitoring and Mitigation:

- Regular Inspections: Regularly inspecting the system for signs of corrosion, such as pitting, scaling, or cracks, allows for early detection and intervention. Visual inspections can be supplemented with ultrasonic testing, eddy current testing, or other non-destructive techniques.
- Cleaning and Maintenance: Periodically cleaning and removing corrosion products like barnacles and biofilms can prevent them from accelerating corrosion and improve heat transfer efficiency. Chemical or mechanical cleaning methods can be utilized depending on the severity of the buildup.
- Flow Optimization: Maintaining proper flow rate through the system ensures continuous removal of corrosion products and prevents stagnant zones where corrosion can become concentrated. Optimize pump operation and pipe configurations to achieve ideal flow patterns.

Additional Measures:

- Galvanic Isolation: Avoid direct contact between dissimilar metals within the system, as it can lead to galvanic corrosion. Use insulating materials or design modifications to prevent electrical connections between incompatible metals.
- Biofouling Control: Implement biofouling control measures like chlorination or ultraviolet treatment to prevent marine organisms from colonizing the system and contributing to localized corrosion.
- Operational Adjustments: Optimizing operating parameters like temperature, pH, and pressure can further minimize corrosion rates. Consult material specifications and corrosion charts for appropriate operating ranges.

Nov 2020

6. With reference to hot docking:

(a) explain how this occurs, stating its effects; (6)

(b) describe the operation of TWO devices that will prevent this occuring. (4)

(a) Marine Hot Docking Explained and its Effects:

Marine hot docking occurs when a boat approaches and connects to a dock while its engine is still running. While seemingly convenient, this practice can have several detrimental effects:

- Safety Risks: The running engine and propellers pose significant safety hazards for passengers, crew, and anyone near the dock. Uncontrolled prop wash can cause injuries, lines can snap, and sudden movements can lead to collisions.
- Dock and Boat Damage: The boat might strike the dock due to lack of precise control, causing damage to both structures. Running props can suck in debris or lines, damaging propellers and shafts.
- Environmental Impact: Exhaust fumes and fuel spills increase pollution in the vicinity of the dock, harming the marine environment.
- Increased Wear and Tear: Engaging gears and clutches while hot puts unnecessary stress on engine components, accelerating wear and tear.

In short, marine hot docking is generally discouraged due to safety risks, potential damage, and environmental concerns.

(b) Two Devices to Prevent Hot Docking:

Thankfully, several devices can assist in preventing marine hot docking, promoting safe and controlled docking maneuvers:

1. Auto-Shift Interruptor: This device is connected to the boat's engine and transmission. When the boat gets close to the dock and senses a predetermined proximity through sensors, it automatically disengages the gears, forcing the engine into neutral. This eliminates the risk of accidental engagement of gears while approaching the dock, preventing uncontrolled acceleration or prop wash.

2. Automatic Docking System: This advanced system utilizes GPS, cameras, and sensors to guide the boat autonomously towards and into the docking position. Pre-programmed docking plans account for wind, current, and other factors, ensuring a smooth and precise approach. The system disengages the gears automatically at the appropriate moment, further preventing inadvertent engine engagement.

Both devices offer different levels of automation and can be tailored to specific needs and budgets. While auto-shift interruptors provide a simple and cost-effective solution, automatic docking systems offer superior precision and convenience.

Remember, regardless of the device used, responsible boatmanship and awareness are crucial during docking procedures. Always be mindful of safety, adjust your speed accordingly, and communicate clearly with anyone assisting you on the dock.

Nov 2020

7. With reference to capacitance probe sensors:

(a) describe, with the aid of a sketch, how a capacitance probe produces an output which can be used to measure the liquid level in a tank. (7)

(b) state TWO different uses of this device on a vessel; (2)

(c) state ONE disadvantage of this type of probe. (1)

Demystifying Capacitance Probes: Sensing the Secrets of Your Vessel's Tanks

(a) Capacitance Probe Operation and Sketch:

Imagine a tank filled with liquid, and within it, a slender probe like a metal rod inserted. This is the essence of a capacitance probe sensor, and here's how it works:

Sketch:

- Electrodes: The probe itself acts as one electrode, and the tank wall or another immersed conductor serves as the other.
- Dielectric Constant: The space between the electrodes is filled with the liquid, which acts as a dielectric material with a specific dielectric constant (epsilon). This constant influences the capacitance formed between the electrodes.
- Capacitance Change: As the liquid level rises or falls in the tank, the volume of the dielectric (liquid) changes. This, in turn, affects the overall capacitance between the electrodes.
- Measuring the Change: An external device connected to the probe measures this change in capacitance.
- Level Conversion: Using pre-programmed equations and calibration data, the device converts the capacitance value into a corresponding liquid level reading.

Key Points:

- The dielectric constant of the liquid significantly impacts the sensor's sensitivity.
- Capacitance probes are contactless, offering non-invasive level measurement.

(b) Applications on a Vessel:

These versatile sensors find multiple uses on board:

1. Fuel Tank Monitoring: Accurately tracking fuel levels in tanks is crucial for fuel management and voyage planning. Capacitance probes provide reliable and continuous level readings, ensuring optimal fuel utilization.
2. Bilge Water Management: Monitoring bilge water levels is essential for ensuring the vessel's seaworthiness and preventing flooding. Capacitance probes offer accurate level data, triggering alarms or pump activation in case of excessive accumulation.

(c) Disadvantage:

One potential drawback of capacitance probes is their susceptibility to changes in the dielectric constant of the liquid. Materials like oil or seawater with varying conductivities or contaminants can affect the capacitance readings and require careful calibration or compensation techniques for accurate performance.

Remember, capacitance probes offer a valuable tool for liquid level measurement on vessels, but understanding their operating principles and potential limitations is crucial for their effective implementation. Choosing the right probe type and considering the liquid properties are essential for reliable and accurate level monitoring.

Nov 2020

8. Describe, with the aid of a sketch, how a floatation device can produce an output signal that can be used to 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.

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9. (a) Define the term *Proportional Action.* (2)

(b) Explain the purpose of *Integral Action.* (2)

(c) Describe a possible effect of excessive Integral Action. (2)

(d) Explain the purpose of *Derivitive Action.* (2)

(e) Describe the effect of excessive Derivitive Action. (2)

(a) Proportional Action:

Proportional action, also known as "P" action, is the fundamental component of a PID controller. It directly adjusts the controller output based on the error between the desired setpoint and the measured process variable. The output change is proportional to the error magnitude, with a higher error leading to a larger output change. This creates a corrective effect, driving the process variable closer to the setpoint.

(b) Integral Action:

Integral action, also known as "I" action, aims to eliminate steady-state errors. It continuously integrates the error over time and adds this accumulated value to the controller output. This means that even small, persistent errors contribute to the output, eventually forcing the process variable to reach the setpoint even if the proportional action alone is insufficient.

(c) Excessive Integral Action:

While beneficial for correcting steady-state errors, excessive integral action can have drawbacks:

- Overshoot: The integral term's influence might grow too large, causing the controlled variable to rapidly overshoot the setpoint before settling down. This can lead to oscillations and instability in the system.
- Slow Response: Excessive integral action can slow down the system's response to transient changes. The integrator focuses on accumulated errors, potentially neglecting sudden changes requiring quicker adjustments.

(d) Derivative Action:

Derivative action, also known as "D" action, anticipates future changes in the error based on its rate of change. It adds a component to the controller output proportional to the derivative of the error signal. This helps the controller react quickly to changing trends in the error, preventing large deviations from the setpoint.

(e) Excessive Derivative Action:

Excessive derivative action can also cause problems:

- Noise Sensitivity: The derivative term amplifies high-frequency noise in the error signal, leading to erratic controller output and control instability.
- Chattering: If the derivative action is too strong, it can cause the controller output to oscillate rapidly around the setpoint, even in the absence of significant errors. This phenomenon is known as "chattering".

Nov 2020

10. 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:

Settling time refers to the time it takes for the output of a control system to reach and stay within a specified percentage (usually 2% or 5%) of its final value after a step change in the input or a disturbance. It reflects the system's responsiveness and ability to stabilize around the desired operating point. A shorter settling time indicates faster response and better disturbance rejection.

(b) Repeatability:

Repeatability refers to the consistency of a control system's output for repeated applications of the same input under identical conditions. A highly repeatable system produces essentially the same output every time it encounters the same input, demonstrating consistent and reliable behavior.

(c) Dead Zone:

Dead zone is a range of input values around the setpoint where the controller produces no output change. In other words, even if the input deviates slightly from the setpoint within the dead zone, the control system remains inactive. This can be intentional to avoid unnecessary actuator movements for minor fluctuations, but it can also lead to sluggish response and steady-state errors if the dead zone is too large.

(d) Hysteresis:

Hysteresis is a phenomenon where the output of a control system depends not only on the current input value but also on the history of the input. It creates a different response for increasing and decreasing input values around the setpoint, resulting in a "staircase" effect. This can be desirable in some applications for switching actions (e.g., thermostat), but it can also cause oscillations and limit control accuracy.

(e) Proportional Bandwidth (PB):

Proportional bandwidth (PB) is a measure of the range of input values that will produce the full output range of a proportional controller. It is expressed as a percentage of the setpoint and is inversely proportional to the controller gain. A higher PB means a smaller gain, resulting in less sensitive but more stable control. Conversely, a lower PB indicates higher gain, leading to more responsive but potentially less stable behavior.