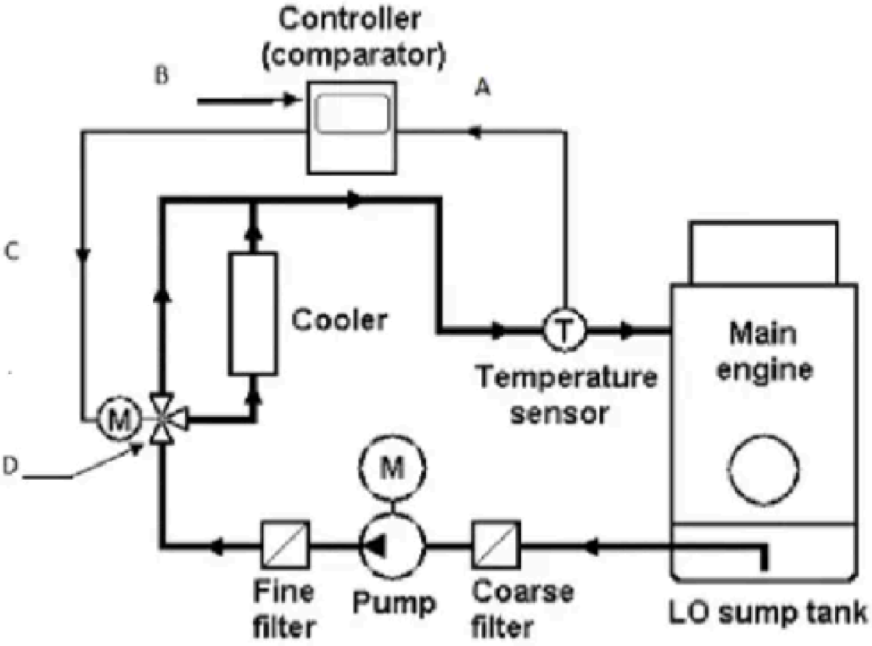
Control systems, Control block diagrams

June 2018

10. 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 comparitor;	(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 Q10

June 2018

Nov 2021

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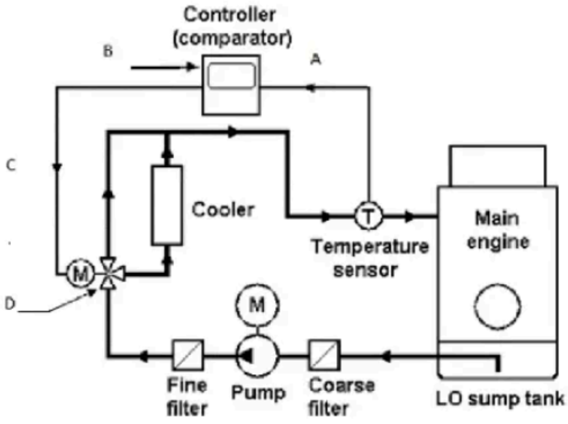

Main engine LO temperature control system

Fig Q9

Nov 2021

June 2019

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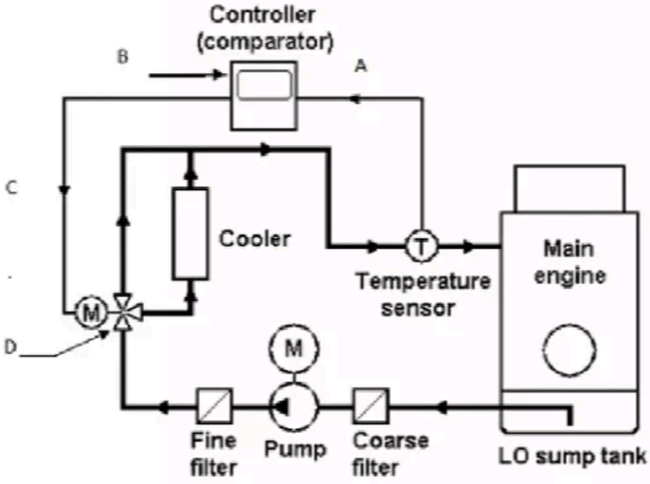


Main engine LO temperature control system

Fig Q8

June 2019

(a) Signal paths:

- 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 2018

9. (a) State the relationship between *proportional band* and *gain*. (2)

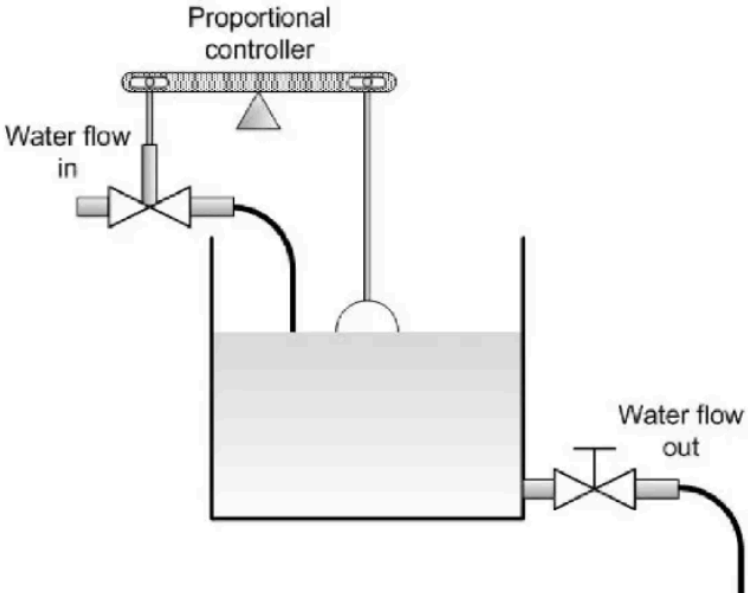
(b) The figure shows the level in a water tank is being controlled by a float and lever proportional system.

(i) Describe how the gain of the control system can be increased and decreased. (2)

(ii) Describe what happens when the flow out is increased. (2)

(iii) Describe the effect of increasing the controller gain with respect to the steady state tank level when the outflow is increased. (2)

(iv) Describe how the introduction of Integral action would affect this system. (2)



Nov 2018

March 2018

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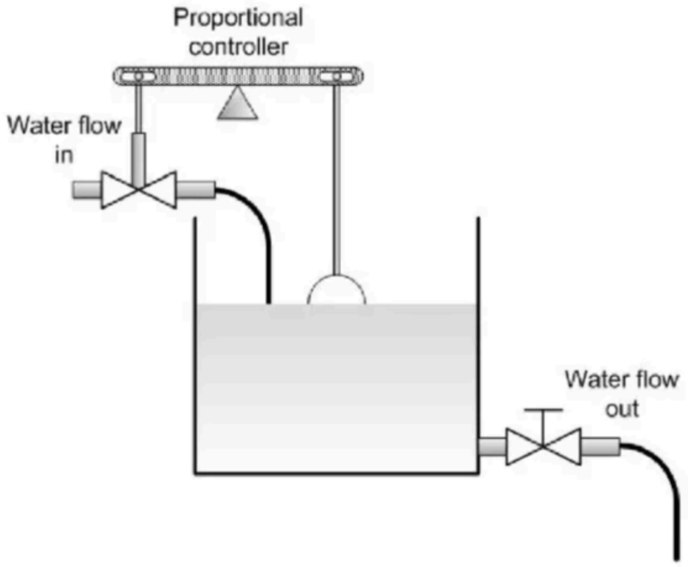
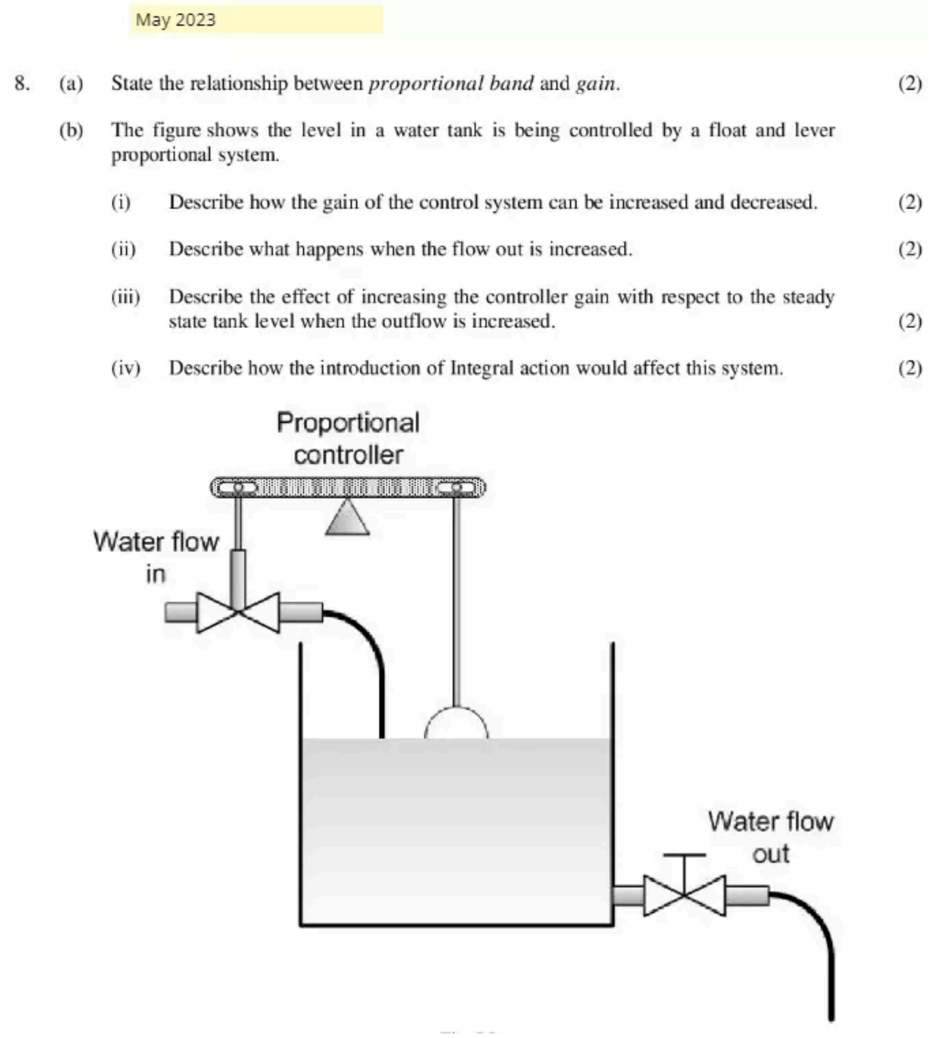


March 2018



May 2023

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May 2023

(a) Relationship between Proportional Band and Gain:

Proportional band (PB) and gain are inversely proportional to each other. This means that as the PB increases, the gain decreases, and vice versa. Mathematically, it can be expressed as:

```
Gain = 1 / PB (expressed as a percentage)
```

For example, if the PB is 20%, the gain is 5 (100 / 20 = 5). Conversely, if the gain is 3, the PB is approximately 33% (100 / 3 = 33.33%).

(b) Level Control in a Water Tank:

(i) Increasing and Decreasing Gain:

In the given lever system, the gain can be adjusted by modifying the length of the lever arm. A shorter lever arm increases the gain because a smaller movement of the float translates to a larger movement of the control valve, resulting in a more significant response to level changes. Conversely, a longer lever arm decreases the gain, as a larger movement of the float produces a smaller movement of the valve, leading to a less pronounced response.

(ii) Increased Flow Out:

When the flow out of the tank increases, the water level will start to drop. The float will move down, and the lever will pivot, opening the control valve further to allow more water inflow. However, with a proportional-only system, the valve opening will only reach a point where the inflow matches the increased outflow, and the water level will stabilize at a new, lower level.

(iii) Increasing Gain with Increased Outflow:

Increasing the gain (shortening the lever arm) in this scenario will make the system more responsive to level changes. The valve will open wider for smaller float movements, attempting to compensate for the increased outflow more aggressively. However, this can lead to hunting, where the water level oscillates around the desired level due to the system's overreaction.

(iv) Introducing Integral Action:

Adding integral action to the system can help address the limitations of proportional control. The integral term essentially remembers the past level deviations and continuously adjusts the valve position to eliminate them. This helps the system reach and maintain the desired level even with changes in outflow, reducing hunting and improving steady-state accuracy.

Remember that the specific behavior of the system will depend on various factors like the tank size, flow rates, and valve characteristics. This is a simplified explanation to illustrate the concepts.

July 2021

10. (a) Identify components A, B, C, D, E, F, G and H shown in the figure. (8)

(b) Explain the difference between a *strainer* and a *filter* in a hydraulic circuit. (2)

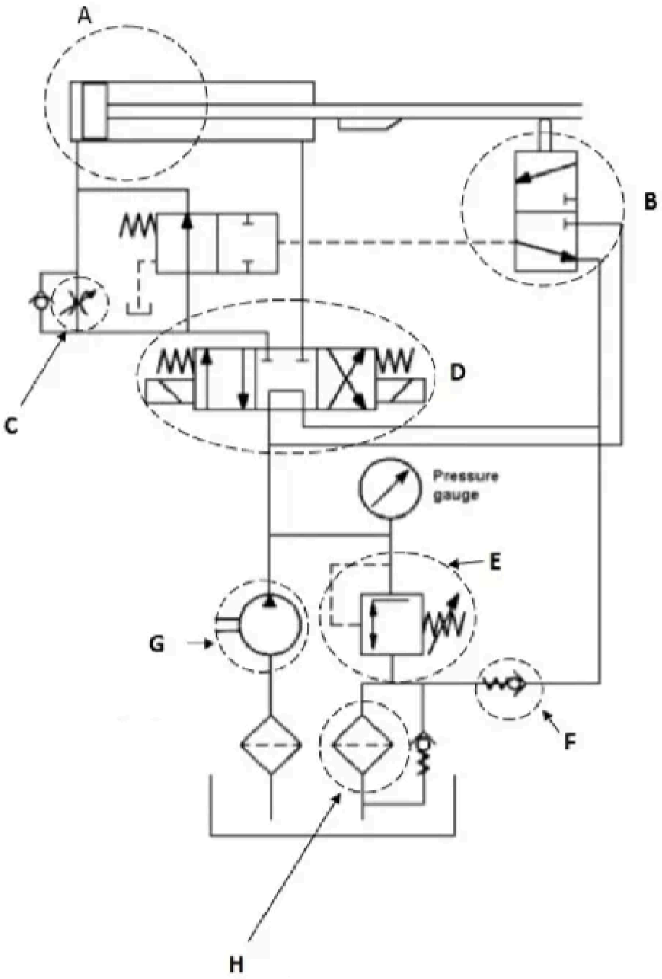
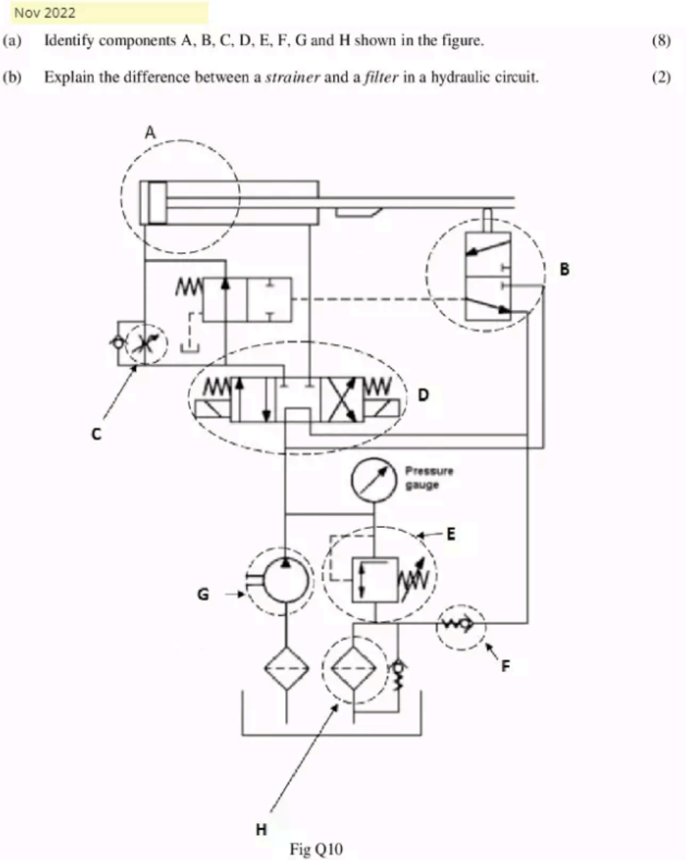


Fig Q10

July 2021



Nov 2022

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Fig Q10

Nov 2022

(a) Component Identification:

- A: Pressure gauge
- B: Hydraulic motor
- C: Relief valve
- D: Directional control valve
- E: Filter
- F: Reservoir
- G: Pump
- H: Strainer

(b) Strainer vs. Filter in Hydraulic Circuits:

While both strainers and filters remove contaminants from hydraulic fluid, they differ in their level of filtration and purpose:

Strainer:

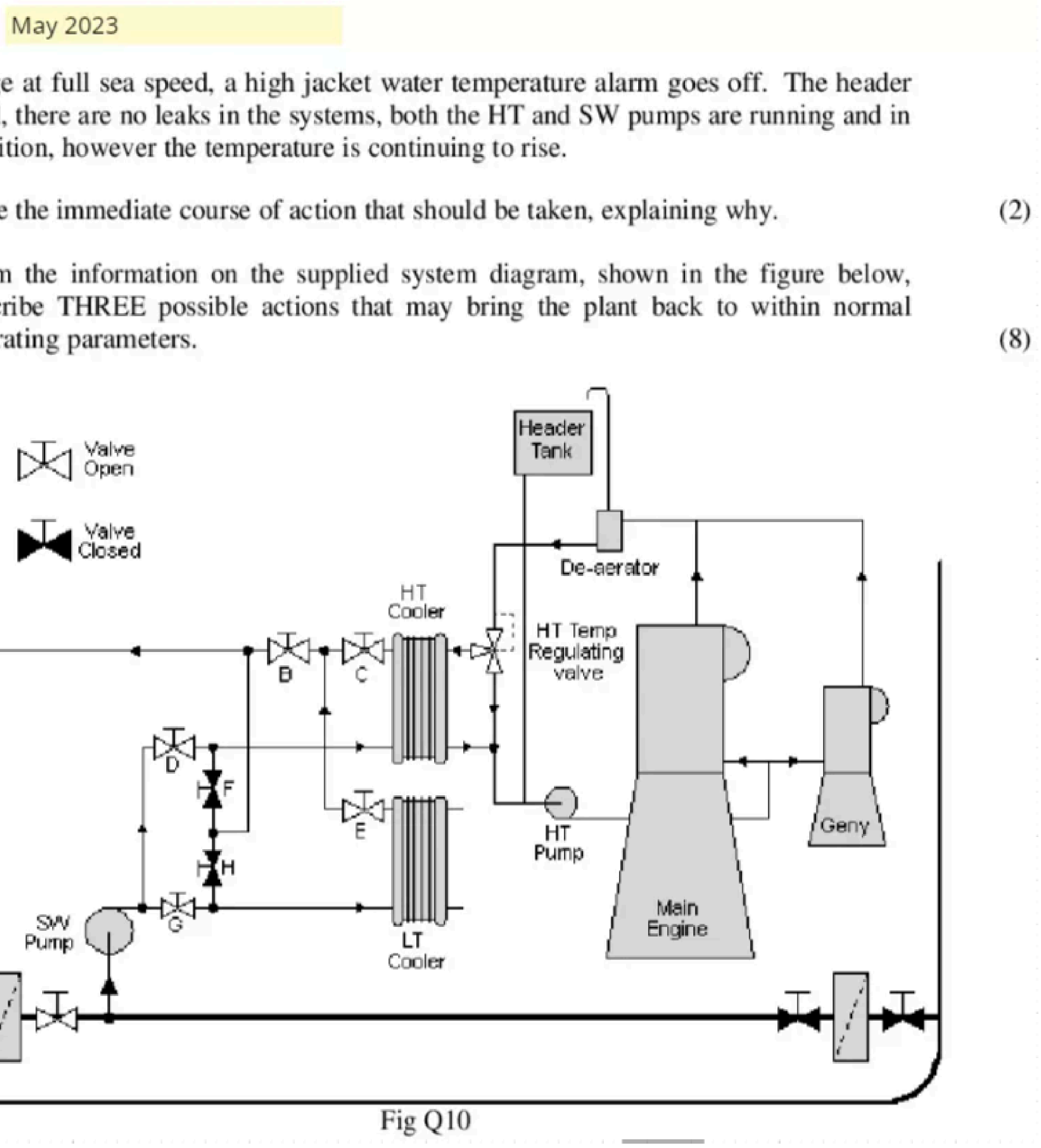
- Function: Removes large particles like dirt, debris, and metal chips to protect pumps and other sensitive components from damage.
- Micron rating: Typically has a larger micron rating (50-200 microns), allowing smaller particles to pass through.
- Cleaning: Usually cleaned periodically by removing and emptying the collected debris.

Filter:

- Function: Removes finer particles and contaminants that could cause wear and tear on components.
- Micron rating: Has a smaller micron rating (10-25 microns) to capture smaller particles than strainers.
- Cleaning: May be replaceable or cleanable, depending on the type.

In essence, a strainer acts as the first line of defense against large debris, while a filter provides finer filtration for optimal system protection.

Remember, this information is based on the specific image you provided. The terminology and component functions may vary depending on the context and specific hydraulic system design.



May 2023

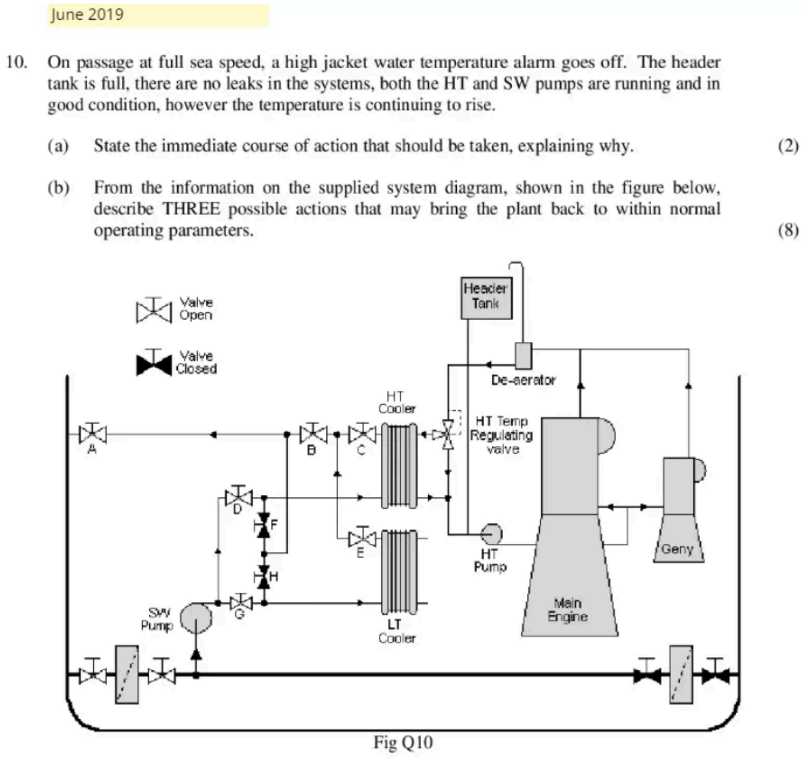
10. On passage at full sea speed, a high jacket water temperature alarm goes off. The header tank is full, there are no leaks in the systems, both the HT and SW pumps are running and in good condition, however the temperature is continuing to rise.

(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

May 2023



June 2019

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Fig Q10

June 2019

Here are three possible actions you can take to bring the plant back to normal operating parameters, based on the information provided:

1. Isolate and Bypass the Freshwater Cooler:

- Looking at the diagram, locate the freshwater cooler (FC) component. This heat exchanger uses seawater to cool the jacket water.
- If the seawater flow or temperature is suspected to be abnormal, isolate the FC by closing valves V21 and V22 at the inlet and outlet, respectively.
- Simultaneously, bypass the FC by opening valves V19 and V20 to create a direct path for the jacket water to circulate back to the engine without going through the cooler.
- Monitor the jacket water temperature. If it starts to decrease, this indicates a problem with the FC, and further investigation or repairs may be needed.

2. Increase Jacket Water Circulation:

- Identify the jacket water pump (JWP) on the diagram.
- If the JWP flow is insufficient, consider increasing its speed if possible. This might be achievable manually or through an onboard control system.
- Alternatively, check if there's a bypass valve (V18) around the JWP. If so, partially closing it can force more water to flow through the pump, increasing circulation.
- Monitor the jacket water temperature and pump parameters to ensure safe operation within specified limits.

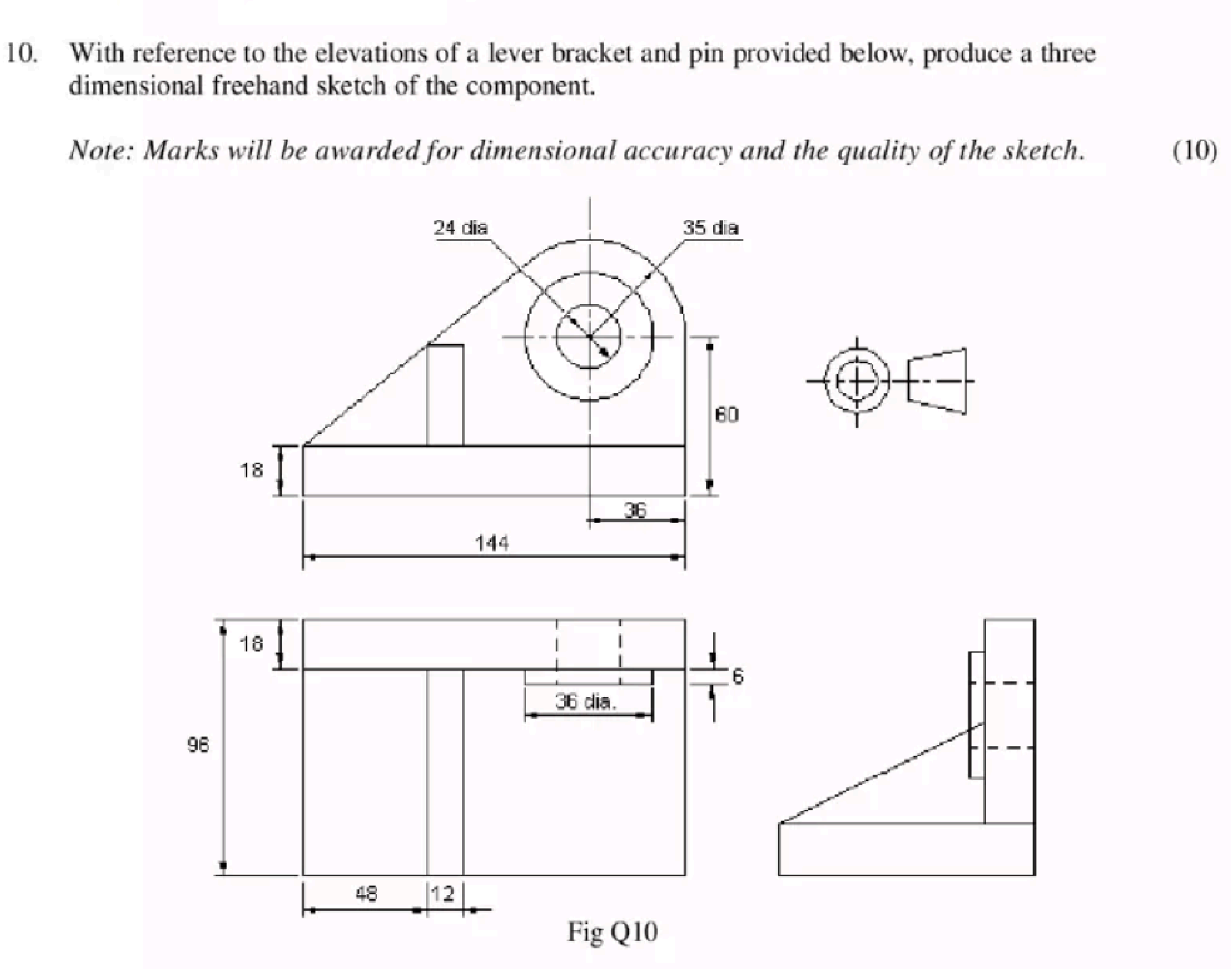
3. Utilize the Auxiliary Jacket Water Pump (if available):

- If your system has an auxiliary jacket water pump (AJWP), locate it on the diagram.
- Start the AJWP to provide additional cooling capacity to the jacket water circuit. This can be particularly helpful if the primary JWP is overloaded or malfunctioning.
- Ensure proper coordination with other crew members if the AJWP activation involves specific procedures or safety precautions.

Remember, these are just potential actions based on the limited information available. It's crucial to:

- Consult the vessel's operation and maintenance manuals for specific instructions and procedures.
- Prioritize safety by monitoring critical parameters like engine RPM, exhaust gas temperature, lube oil temperature, and jacket water pressure.
- Seek guidance from qualified personnel onboard or onshore if the situation is unclear or worsens.

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

Nov 2021

Nov 2022

9. The figure shows a tank filling with fluid at a variable rate, and an output regulated manually by an operator controlling a value.

Explain, with the aid of a control block diagram, the control process taking place that enables the operator to maintain a constant tank level, 'h' for varying rates of fluid flow input.

Note: fluid flow in will always be less than the maximum flow out with the valve full open.

(10)

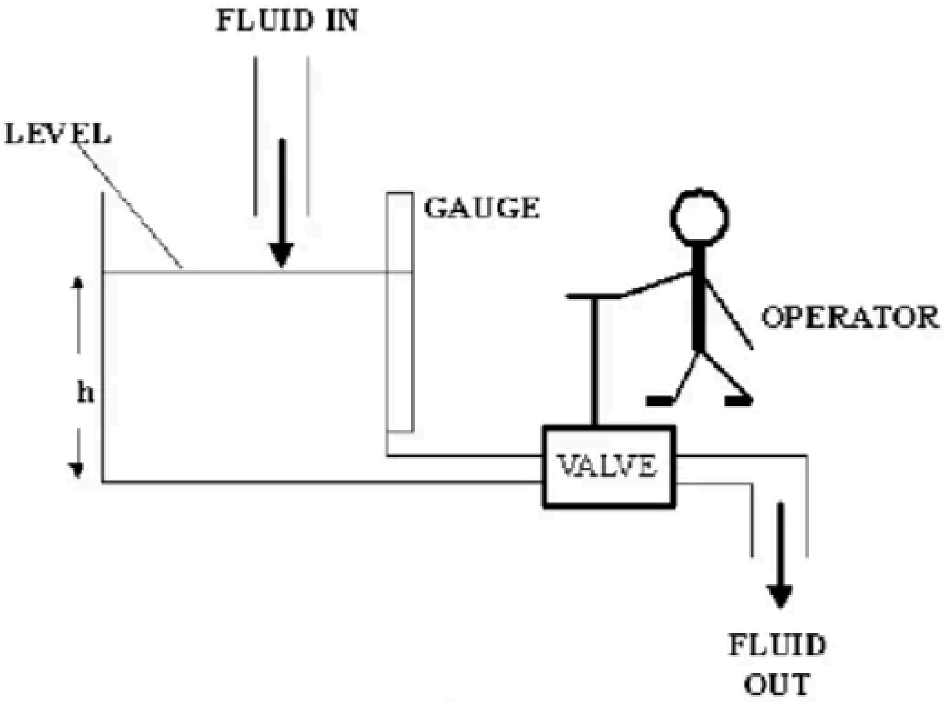


Fig Q9

Nov 2022

July 2021

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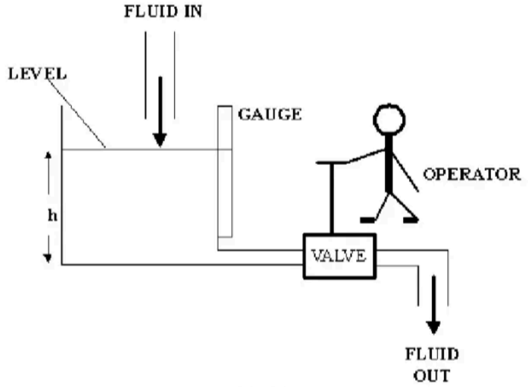


Fig Q8

July 2021

System Description:

The image shows a tank with a variable flow input and an outlet valve manually controlled by an operator. The tank level is measured by a sight glass.

Control Process:

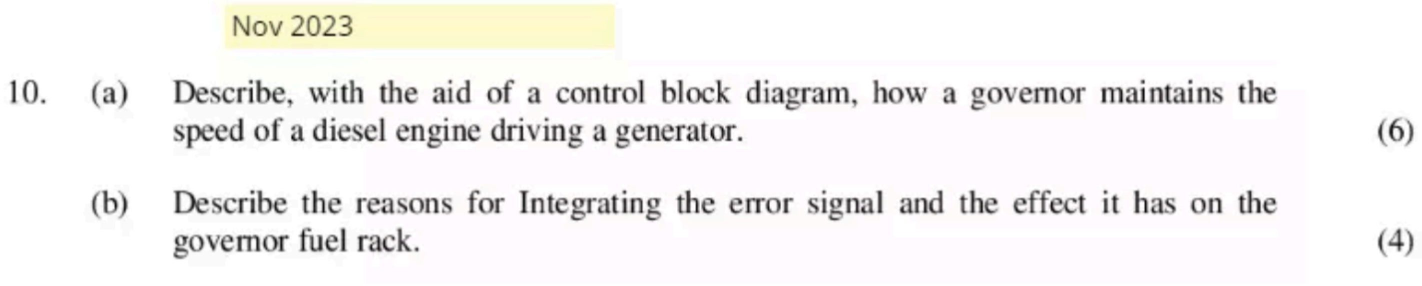
1. Measurement: The operator observes the tank level through the sight glass, visually measuring the current level (h).
2. Feedback Signal: The observed level serves as the feedback signal for the operator.
3. Comparison: The operator compares the observed level (h) with the desired level (setpoint), which is usually indicated on the sight glass or known based on operational requirements.
4. Error Calculation: The operator mentally calculates the difference (error) between the current level and the setpoint.
5. Control Action: Based on the error, the operator adjusts the handwheel of the valve, opening it more to increase inflow (positive error) or closing it partially to decrease inflow (negative error).
6. System Response: The change in valve opening affects the inflow rate, causing the tank level to rise or fall.
7. Adjustment: The operator continuously monitors the level and adjusts the valve opening as needed to maintain the desired level.

Control Block Diagram:

```
+--------------+          +--------------+
| Sight Glass  |          | Valve        |
| (h)          |          | (Output)     |
+--------------+          +--------------+
           |
           v
+--------------+
| Operator     |
| (Controller) |
+--------------+
           |
           v
+--------------+
| Setpoint     |
| (h_desired)  |
+--------------+
              |
              v
   +---------+
   |  Error  |
   +---------+
```

Additional Notes:

- In this manual system, the operator acts as both the controller and the actuator, making adjustments based on their visual observation and judgment.
- The accuracy of level control depends on the operator's skill, experience, and ability to react to changes quickly.
- This system is relatively simple and inexpensive, but it can be challenging to maintain precise level control, especially with varying flow rates.
- For more accurate and automated control, an electronic level controller and an actuated valve could be implemented.



Nov 2023

10. (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)

Nov 2023

(a) Control Block Diagram:

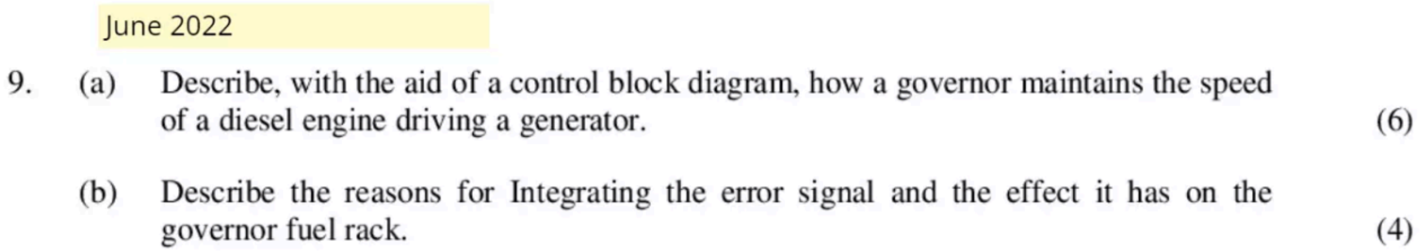
The following control block diagram illustrates the essential components of a governor maintaining engine speed:

```
+-----------------+  +-------------------+  +-----------------+  +-------------------+
|  Speed Sensor   |  |   Speed Droop     |  |   Integral      |  |  Fuel Actuator    |
|                 |  | (Proportional)    |  | (Reset)         |  |                   |
| (Measures RPM)  |  |-----------------+    |-----------------+  |                   |
+-----------------+  |                   |                         +-----------------+
                     |                   |
                     |   Error           |
                     +-----------------+
                              |
                     +-----------------+
                     |                 |
                     | Governor Setpoint|
                     | (Desired RPM)   |
                     +-----------------+
|
```

```
Output: Fuel Rack Position
```

(b) Integrating the Error Signal and its Effect:

1. Purpose of Integration: The integral action in the governor accumulates the error between the measured engine speed (from the sensor) and the desired setpoint (governor setting) over time. This helps eliminate steady-state errors, even if the proportional action alone cannot fully correct them.
2. Effect on Fuel Rack: The integrator's output adds an additional adjustment to the fuel rack position based on the accumulated error history.
    - Positive Error (Engine Speed Lower than Setpoint): The positive accumulated error triggers an increase in fuel delivery (fuel rack moves towards open position). This increases engine speed, reducing the error over time.
    - Negative Error (Engine Speed Higher than Setpoint): The negative accumulated error leads to a decrease in fuel delivery (fuel rack moves towards closed position). This slows down the engine, bringing the speed closer to the setpoint.
3.
4. Benefits of Integration:
    - Improved Steady-State Accuracy: Eliminates errors that might persist with only proportional control, ensuring the engine speed settles exactly at the desired setpoint.
    - Reduced Hunting: Helps dampen oscillations around the setpoint, promoting smoother speed regulation.
5.
6. Challenges of Integration:
    - Slow Response: The integrator acts slowly, taking time to accumulate the error. This can be a drawback for quick load changes requiring faster adjustments.
    - Overcorrection: Excessive integral gain can lead to overshooting the setpoint and cause instability if not tuned properly.



June 2022

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June 2022

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).

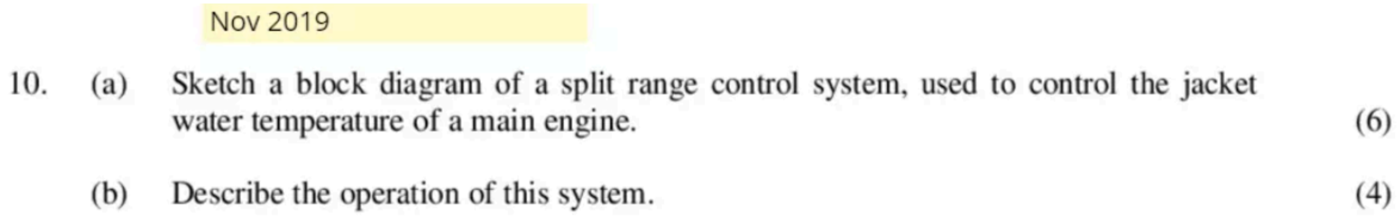
(b) Integrating the Error Signal:

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.



Nov 2019

10. (a) Sketch a block diagram of a split range control system, used to control the jacket water temperature of a main engine. (6)

(b) Describe the operation of this system. (4)

Nov 2019

(a) Block Diagram:

Here's a block diagram of a split-range control system for jacket water temperature:

```
+-------------------+           +-------------------+           +-------------------+
| Temperature Sensor |          | Controller        |             | Cooling Valve     |
| (T_jacket)        |           | (Split-Range)     |        |    | (Output)          |
+-------------------+           +-------------------+           +-------------------+
                   |
                   v
 +-------------------+           +-------------------+
 | Setpoint (Low)     |          | Setpoint (High)   |
 | (T_min)            |          | (T_max)           |
 +-------------------+           +-------------------+
               |                     |
               v                     v
            +-------+       +-------+  +-------+
            | Gain  |       | Gain  |  | Gain  |
            | Low   |       | High  |  | High  |
            +-------+       +-------+  +-------+
                   |                       |
                   v                       v
+-------------------+           +-------------------+           +-------------------+
| Heating Valve     |           | Bypass Valve      |           | (Output)          |
| (Output)          |           | (Optional)        |           +-------------------+
+-------------------+           +-------------------+
  ^                                                ^
  |                                                |
Cooler Inlet                                     Heater Inlet
```

Components and Functions:

- Temperature Sensor: Measures the jacket water temperature (T_jacket).
- Controller (Split-Range): Receives the temperature signal and compares it to two setpoints:
  - Setpoint (Low): Minimum desired temperature (T_min).
  - Setpoint (High): Maximum desired temperature (T_max).
  - Calculates separate errors for each setpoint.
  - Uses separate gains for each error (Gain_Low, Gain_High).
  - Generates two output signals based on the errors and gains.
-
- Cooling Valve: Opens or closes based on the low-range output signal to regulate cooling water flow.
- Heating Valve (Optional): Opens or closes based on the high-range output signal to regulate heating water flow (if needed).
- Bypass Valve (Optional): Allows bypassing the cooler or heater when unnecessary.

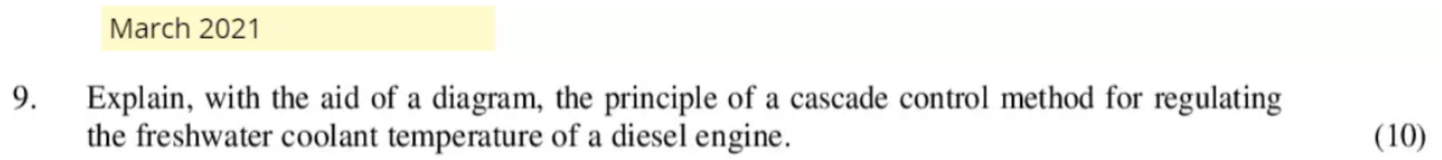
(b) System Operation:

1. Temperature Measurement: The sensor continuously measures the T_jacket.

2. Error Calculation:
    - The controller compares T_jacket with both setpoints (T_min and T_max).
    - If T_jacket is below T_min, a positive error occurs for the low-range control.
    - If T_jacket is above T_max, a positive error occurs for the high-range control.
    - If T_jacket is within the desired range (T_min <= T_jacket <= T_max), both errors are zero.
3.
4. Output Signal Generation:
    - The controller uses separate gains (Gain_Low and Gain_High) to amplify the calculated errors.
    - The low-range output signal controls the cooling valve.
        - Higher error (T_jacket below T_min) opens the valve more for increased cooling.
        - Lower error (T_jacket closer to T_min) closes the valve partially.
    -
    - The high-range output signal controls the heating valve (if present).
        - Higher error (T_jacket above T_max) opens the valve more for increased heating.
        - Lower error (T_jacket closer to T_max) closes the valve partially.
    -
    - The bypass valve might be used to avoid unnecessary operation of the cooler or heater when T_jacket is within the desired range.
5.
6. System Response:
    - The controlled valve openings adjust the cooling or heating water flow, affecting T_jacket.
    - The system continuously monitors and adjusts to maintain T_jacket within the desired range despite disturbances.
7.

Additional Notes:

- The specific gains and setpoints are chosen based on engine requirements and operating conditions.
- This is a simplified explanation, and actual systems may have additional features and complexities.



March 2021

9. Explain, with the aid of a diagram, the principle of a cascade control method for regulating the freshwater coolant temperature of a diesel engine. (10)

March 2021

Cascade Control for Diesel Engine Coolant Temperature:

The cascade control method involves two nested control loops to regulate the freshwater coolant temperature in a diesel engine with increased stability and accuracy. Here's the explanation with a diagram:

Components:

1. Primary Loop:
   - Sensor: Measures freshwater coolant temperature (T_coolant).
   - Primary Controller: Compares T_coolant with the desired setpoint (T_setpoint).
   - Actuator: Regulates the coolant flow rate (e.g., by adjusting a control valve).
2.
3. Secondary Loop:
   - Measured Variable: Represents the manipulated variable of the primary loop (e.g., valve position or flow rate).
   - Secondary Controller: Maintains the manipulated variable at the desired value set by the primary controller.
   - Secondary Actuator: Directly controls the manipulated variable (e.g., adjusts the valve motor).
4.

Diagram:

```
+-------------------+           +-------------------+           +-------------------+
| Coolant Sensor    |           | Primary Controller|           | Coolant Flow Valve|
| (T_coolant)       |           | (T_coolant Setpoint)|         | (Actuator)        |
+-------------------+           +-------------------+           +-------------------+
                 |
                 v
              +-------+
              | Gain  |
              +-------+
                 |
                 v
+-------------------+           +-------------------+
| Secondary Sensor  |           | Secondary Controller|
| (Manipulated Var.)|           | (Valve Position Setpoint)|
+-------------------+           +-------------------+
                 |
                 v
              +-------+
              | Gain  |
              +-------+
                 |
                 v
+-------------------+           +-------------------+
| Valve Motor       |           | Actual Valve Position|
|(Secondary Actuator)|   |      | (Measured Variable)  |
+-------------------+           +-------------------+
             ^                     ^
             |                     |
           External                Engine Load
           Disturbances             |
```

Operation:

1. Primary Loop:
   - The sensor measures T_coolant and sends the signal to the primary controller.
   - The controller compares T_coolant with T_setpoint and calculates the error.
   - The error is multiplied by the primary gain to generate a control signal.
   - This signal adjusts the actuator (e.g., valve) to regulate the coolant flow rate.
2.
3. Secondary Loop:
   - The secondary sensor measures the manipulated variable (e.g., valve position or flow rate).
   - This value is compared with the desired value set by the primary controller.
   - Any deviation triggers the secondary controller.
   - The secondary controller generates a signal to adjust the secondary actuator (e.g., valve motor).

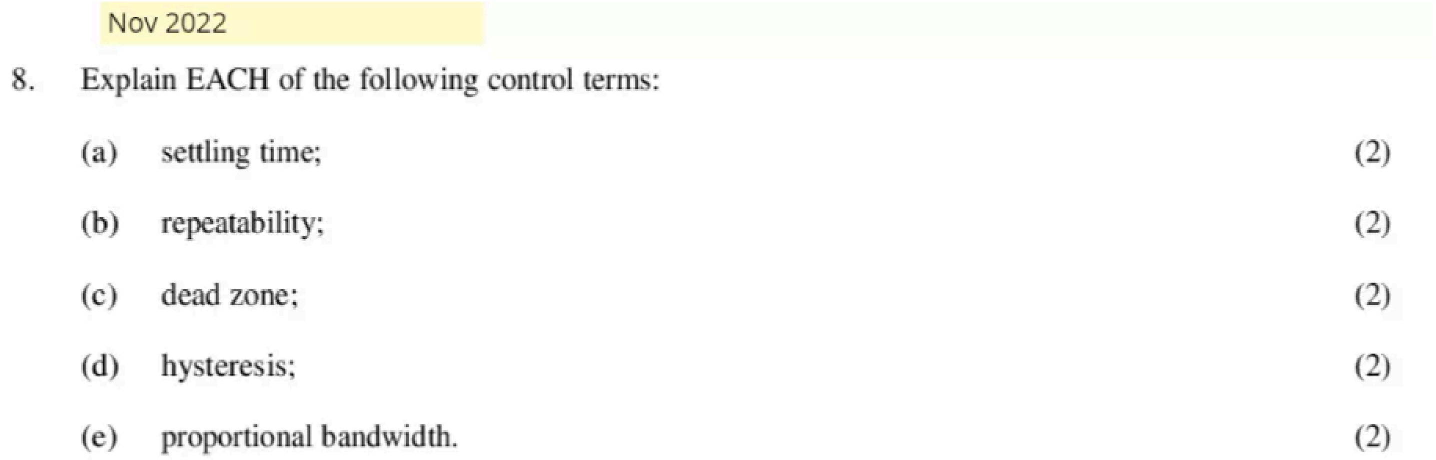
- This fine-tunes the manipulated variable to precisely match the primary controller's demand.

4.

Benefits of Cascade Control:

- Improved Stability: The secondary loop compensates for disturbances affecting the manipulated variable, preventing them from influencing the primary loop and coolant temperature.
- Faster Response: The secondary loop acts directly on the manipulated variable, leading to quicker adjustments and reduced settling time.
- Reduced Sensitivity: The primary controller focuses on the overall temperature control, while the secondary loop handles the actuator dynamics, making the system less sensitive to actuator characteristics.

Overall, cascade control provides a more robust and accurate solution for regulating the freshwater coolant temperature in a diesel engine, especially when dealing with external disturbances or complex actuator dynamics.



Nov 2022

8. Explain EACH of the following control terms:

(a) settling time; (2)

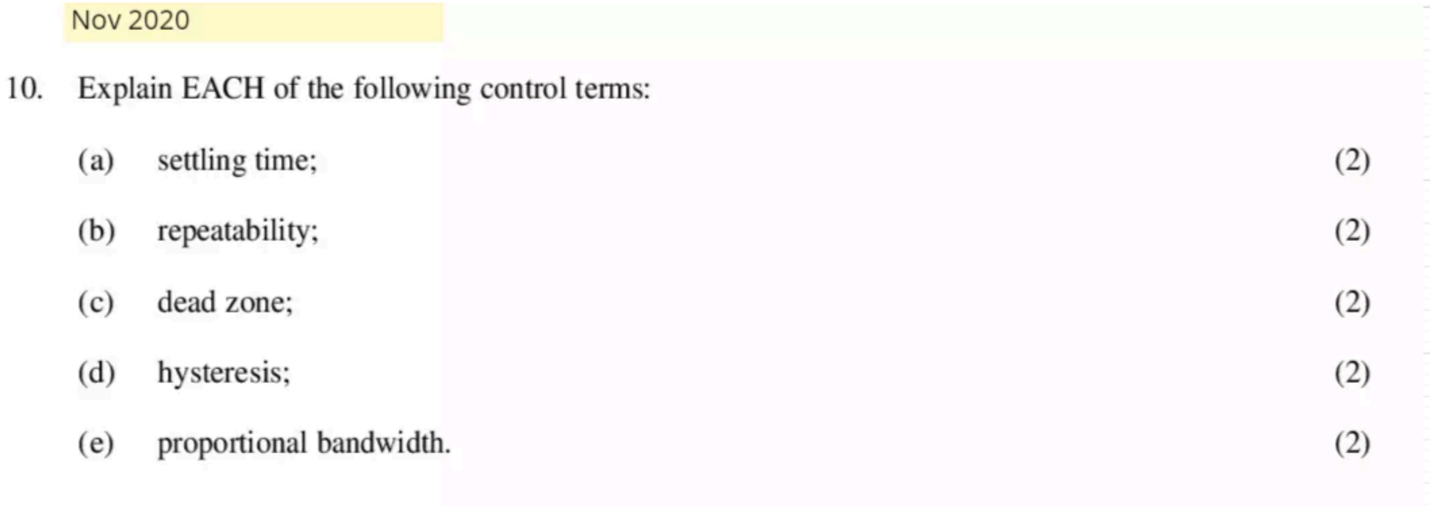
(b) repeatability; (2)

(c) dead zone; (2)

(d) hysteresis; (2)

(e) proportional bandwidth. (2)

Nov 2022



Nov 2020

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(a) settling time; (2)

(b) repeatability; (2)

(c) dead zone; (2)

(d) hysteresis; (2)

(e) proportional bandwidth. (2)

Nov 2020

(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:

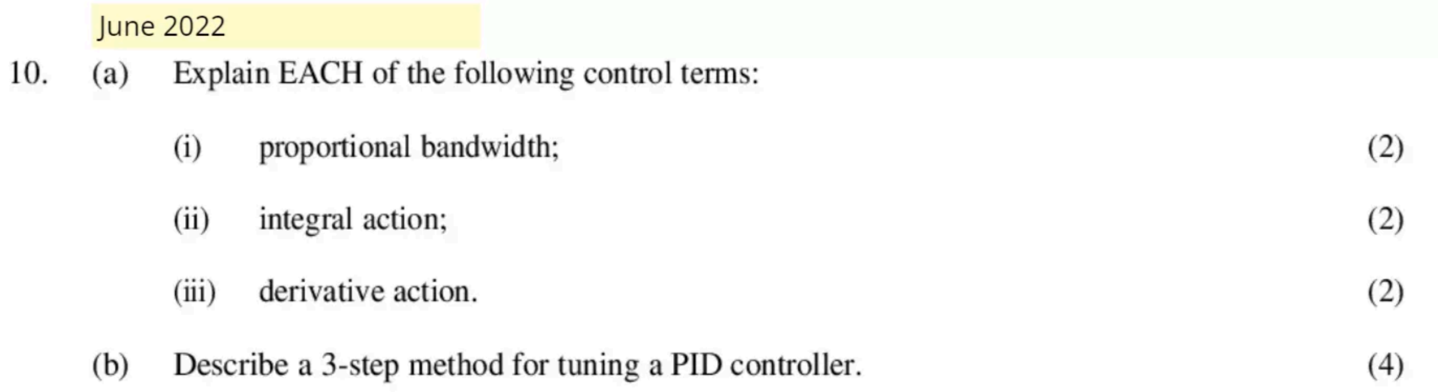
Dead zone is a range of input values around the setpoint where the controller produces no output change. In other words, even if the input deviates slightly from the setpoint within the dead zone, the control system remains inactive. This can be intentional to avoid unnecessary actuator movements for 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.



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)

June 2022

(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:

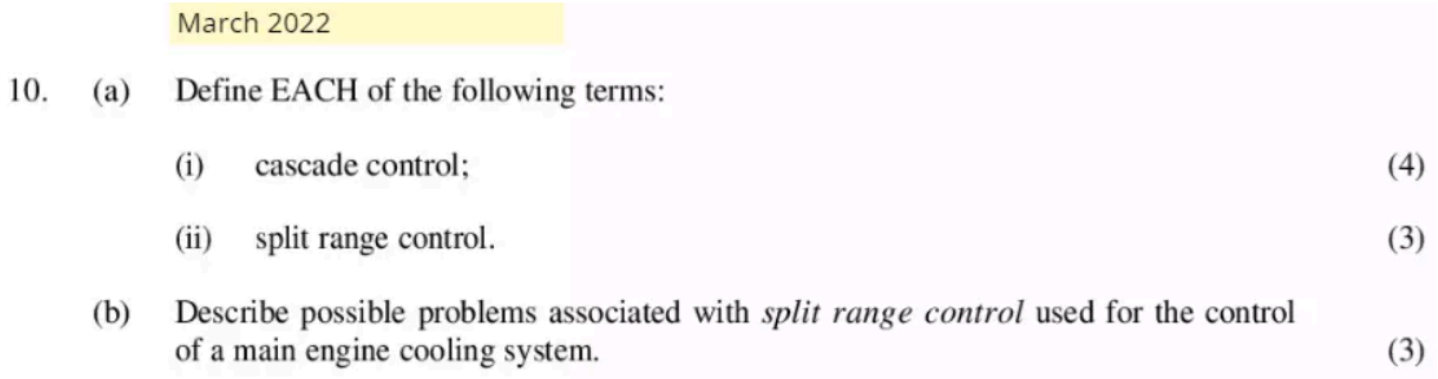
Derivative action, also known as "rate" or "D action," considers the rate of change of the error signal and adjusts the controller output accordingly. This helps to anticipate future changes and provides faster response to transient disturbances.

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.
3. 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.
4.
5. 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.



March 2022

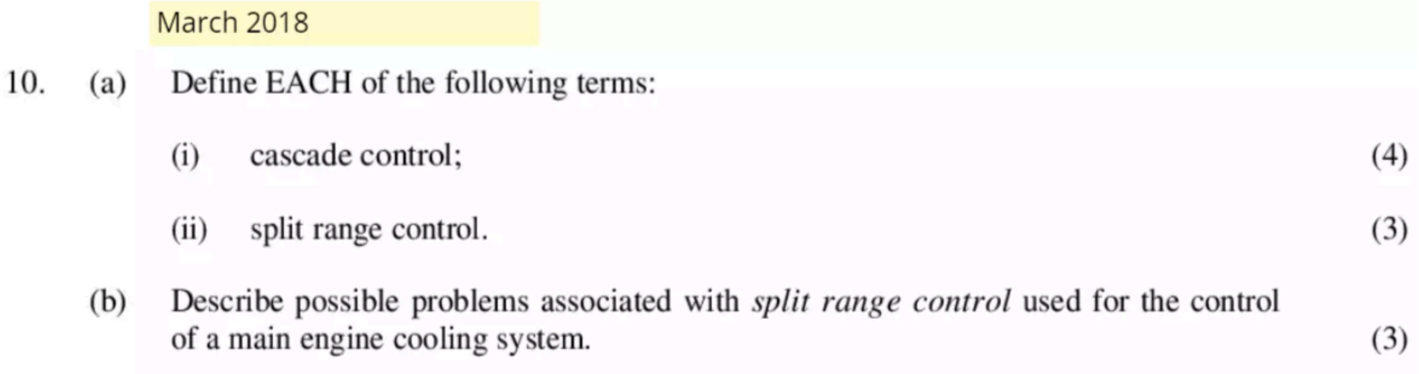
10. (a) Define EACH of the following terms:

(i) cascade control; (4)

(ii) split range control. (3)

(b) Describe possible problems associated with *split range control* used for the control of a main engine cooling system. (3)

March 2022



March 2018

10. (a) Define EACH of the following terms:

(i) cascade control; (4)

(ii) split range control. (3)

(b) Describe possible problems associated with *split range control* used for the control of a main engine cooling system. (3)

March 2018

(a) Definitions:

(i) Cascade Control:

Cascade control involves nesting two or more feedback loops to regulate a single process variable. The outer loop (primary loop) sets the desired value for the inner loop (secondary loop). This enables precise control and improved stability by responding to disturbances affecting the manipulated variable directly in the inner loop.

(ii) Split Range Control:

Split range control uses a single controller with multiple outputs to manage a process variable that needs different control strategies depending on its operating range. Each output controls a separate actuator, typically responsible for heating or cooling the process.

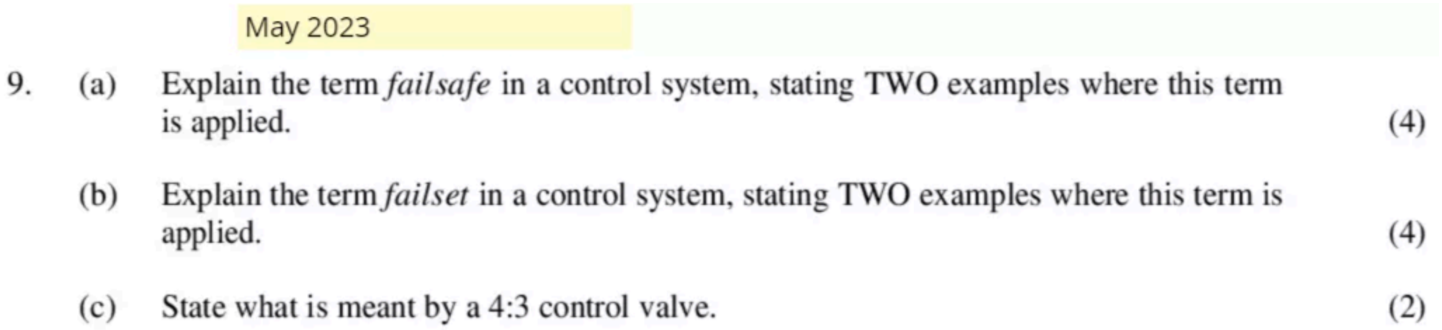
(b) Problems with Split Range Control for Main Engine Cooling:

1. Interaction Between Heating and Cooling: Coordinating the heating and cooling systems through a single controller can be challenging, especially during transitions between heating and cooling modes. Improper tuning could lead to overshooting, hunting, or instability.
2. Dead Zone Issues: Each output might have a dead zone, creating a small range around the setpoint where neither heating nor cooling occurs. This can cause sluggish response and temperature deviations if the dead zones are too large.
3. Complexities in Tuning: With multiple outputs and setpoints, tuning the controller gains and dead zones becomes more complex. Finding the optimal settings for both heating and cooling simultaneously can be time-consuming and require expertise.
4. Potential for Single Point Failure: A single controller failure could disrupt both heating and cooling, compromising engine safety and performance.
5. Limited Applicability: Split range control might not be suitable for all engine types or operating conditions. Some engines might require more flexibility or independent control of heating and cooling, making another control strategy more appropriate.

Alternatives to Split Range Control:

- Two separate PID controllers: This offers independent control of heating and cooling with simpler tuning but requires more hardware and coordination.
- Fuzzy logic control: This can handle more complex relationships between variables and operating conditions, but it requires expertise in fuzzy logic implementation.

Overall, split range control can be a cost-effective solution for basic engine cooling control. However, its limitations and potential problems should be carefully considered before implementation, and alternative control strategies might be better suited for specific requirements.



May 2023

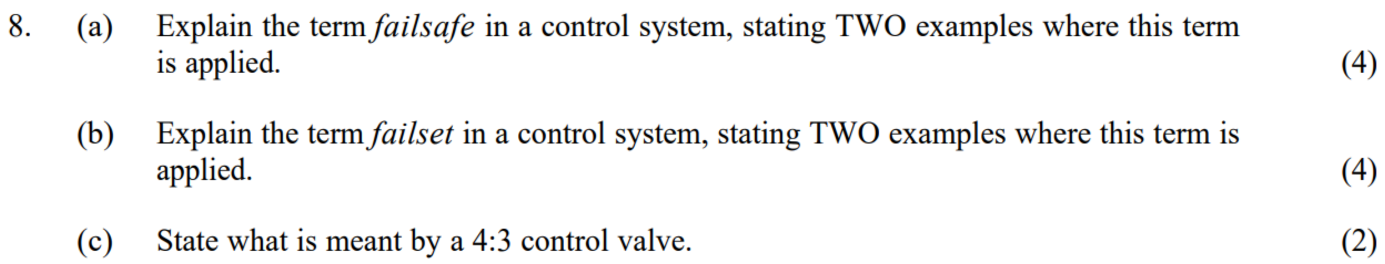
9. (a) Explain the term *failsafe* in a control system, stating TWO examples where this term is applied. (4)

(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)

May 2023

Nov 2021



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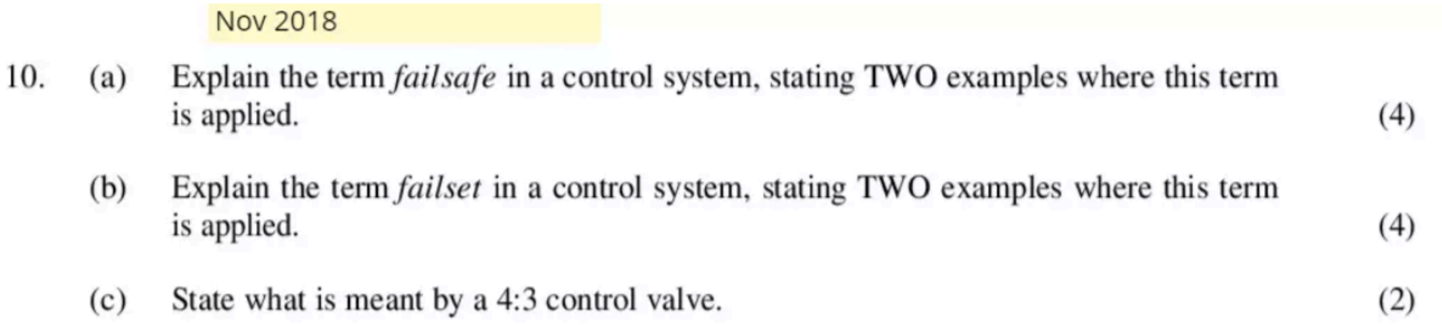

Nov 2018

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(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)

Nov 2018

(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:

$A \propto x^4 / 3$

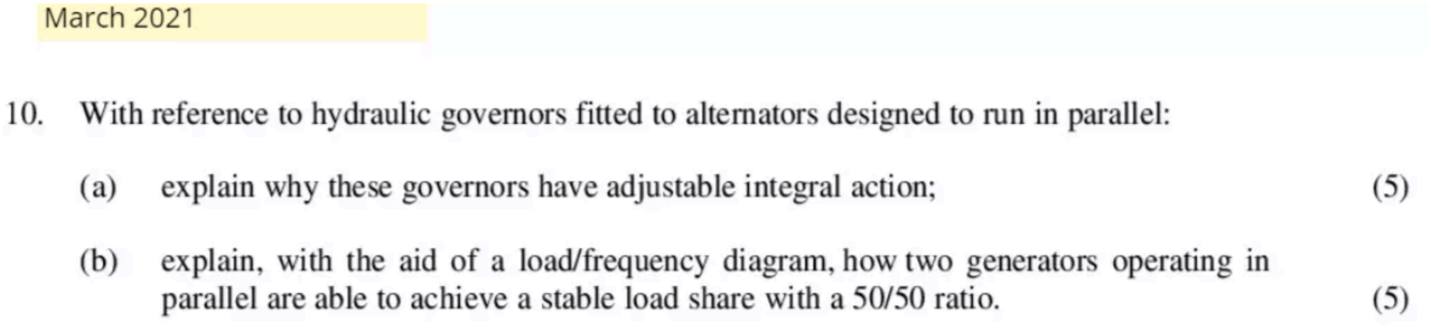
This characteristic leads to two key features:

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.



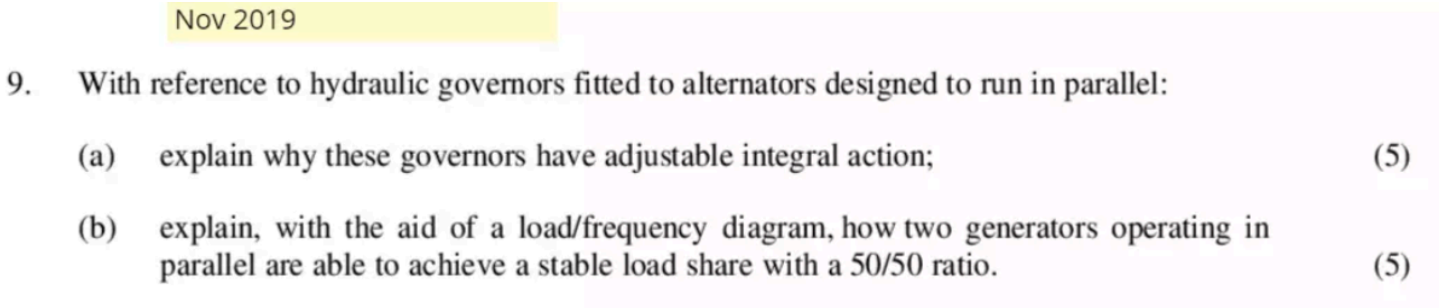
March 2021

10. With reference to hydraulic governors fitted to alternators designed to run in parallel:

(a) explain why these governors have adjustable integral action; (5)

(b) explain, with the aid of a load/frequency diagram, how two generators operating in parallel are able to achieve a stable load share with a 50/50 ratio. (5)

March 2021



Nov 2019

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   (a) explain why these governors have adjustable integral action; (5)

   (b) explain, with the aid of a load/frequency diagram, how two generators operating in parallel are able to achieve a stable load share with a 50/50 ratio. (5)

Nov 2019

Hydraulic Governors in Parallel Alternators:

(a) Adjustable Integral Action:

Hydraulic governors in parallel alternators have adjustable integral action for two main reasons:

1. Eliminating Steady-State Speed Errors: In a system with multiple generators sharing a load, slight differences in governor characteristics or mechanical imperfections can lead to steady-state speed errors between generators. Integral action in the governor accumulates the error signal over time, gradually adjusting the fuel supply until the speed error is eliminated. This ensures all generators maintain the same speed (synchronism) regardless of minor variations, promoting stable parallel operation and load sharing.
2. Achieving Desired Droop Characteristics: In parallel operation, governors are configured with a specific "droop" characteristic. This refers to the decrease in generator speed with increasing load. Adjustable integral action allows fine-tuning of the droop, which determines how much each generator contributes to the total load change. By adjusting the integral gain, engineers can achieve the desired load-sharing ratio between generators, such as a 50/50 split as specified in your question.

(b) Load/Frequency Diagram and 50/50 Load Sharing:

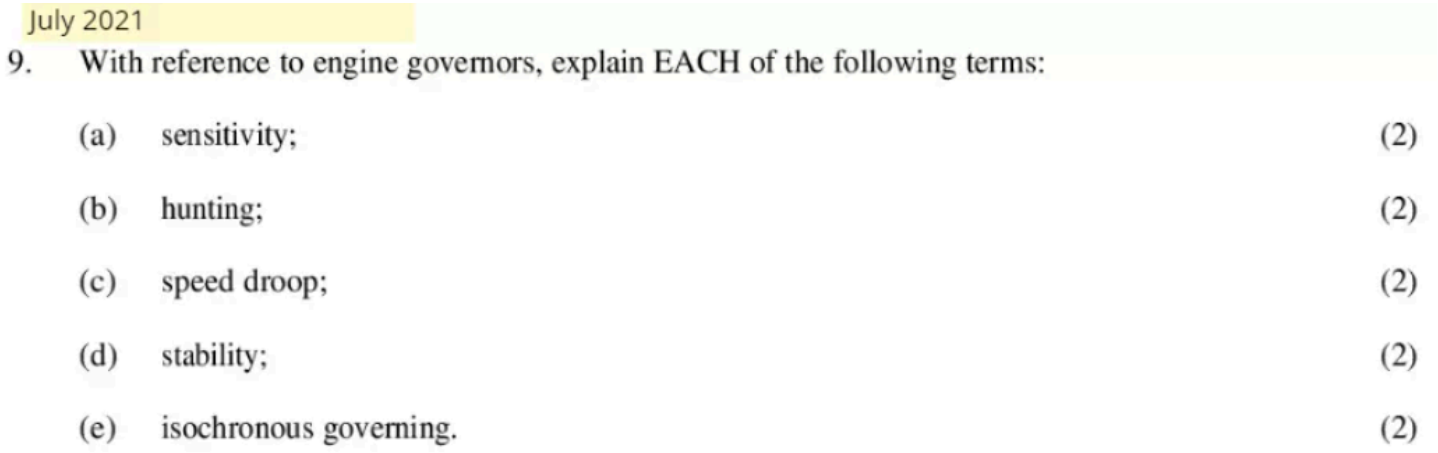
A load/frequency diagram helps visualize the behavior of generators in parallel operation. Here's how two generators achieve a 50/50 load share:

1. Initial Conditions: Let's assume both generators share the total load equally (50% each) and operate at the nominal frequency (f_0). This point is represented by the intersection of the individual generator droop curves (G1 and G2) with the total load line (P_tot).
2. Load Change: When the total load increases (P_tot increases), both generators experience a slight decrease in speed due to their inherent droop characteristics. The speed drop is larger for the generator with a steeper droop curve (greater integral gain).
3. Integral Action and Load Sharing: The integral action in each governor integrates the speed error over time. In response, the governor with the larger speed drop adjusts its fuel supply more significantly, causing its frequency to recover faster and take on a larger share of the increased load. The other generator's frequency recovers slower, resulting in a smaller load increase.

4. Equilibrium: This process continues until a new equilibrium is reached where the speed difference between generators is minimal, and they share the increased load according to their droop characteristics. With properly adjusted integral gains, both generators can achieve a 50/50 load share at the new operating point.

Diagram Illustration:

Imagine two downward-sloping curves (G1 and G2) representing the droop characteristics of generators. A horizontal line (P_tot) represents the total load. The intersection of these lines represents the operating points at different load levels. When the load increases, both curves shift down, but the one with higher integral gain shifts more, leading to a new equilibrium point where the load is shared equally.



July 2021

9. With reference to engine governors, explain EACH of the following terms:

(a) sensitivity; (2)

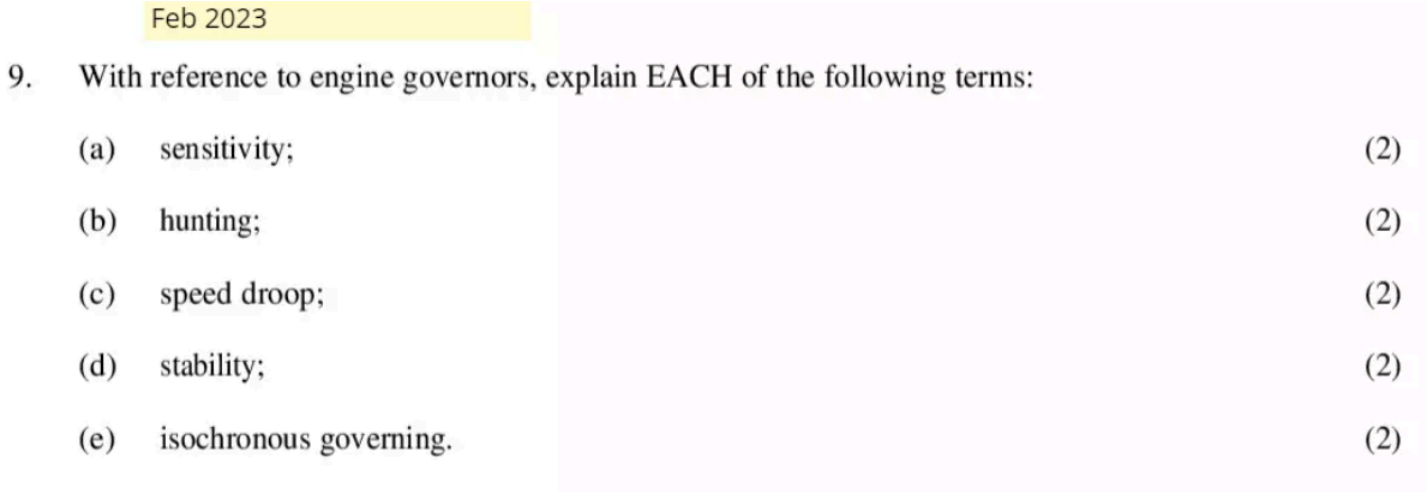
(b) hunting; (2)

(c) speed droop; (2)

(d) stability; (2)

(e) isochronous governing. (2)

July 2021



Feb 2023

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(b) hunting; (2)

(c) speed droop; (2)

(d) stability; (2)

(e) isochronous governing. (2)

Feb 2023

(a) Sensitivity:

Sensitivity in an engine governor refers to the responsiveness of the governor to changes in engine speed. A highly sensitive governor reacts quickly to even small speed variations, adjusting fuel delivery promptly to maintain speed stability. However, excessive sensitivity can lead to hunting, so achieving the optimal balance is crucial.

(b) Hunting:

Hunting describes an undesirable oscillation in engine speed caused by an overly sensitive governor. The governor overreacts to minor speed deviations, leading to adjustments in fuel supply that overshoot the correction needed. This creates a feedback loop where corrections become too large, causing speed to swing back and forth around the desired value.

(c) Speed Droop:

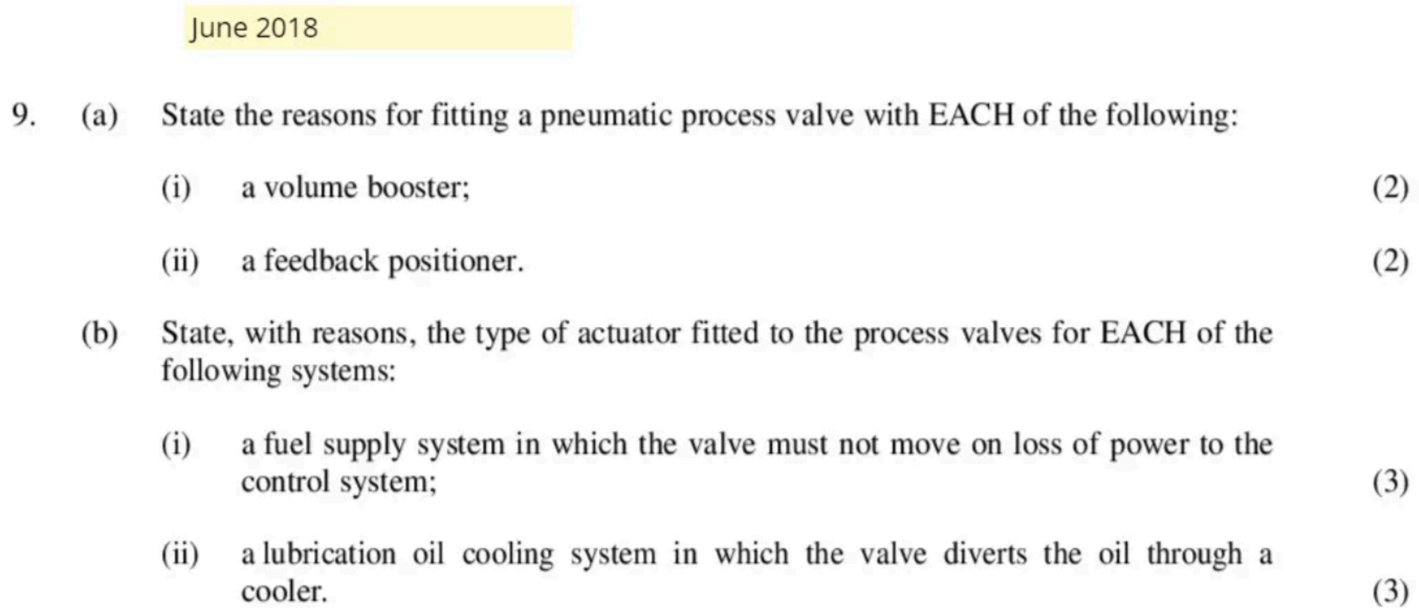
Speed droop is a fundamental characteristic of most engine governors. It defines the relationship between engine speed and load: as the load on the engine increases, the governor allows the engine speed to decrease slightly. This intentional "droop" ensures stable load sharing between multiple engines operating in parallel on a common bus. Without droop, load changes would cause large speed variations and unstable operation.

(d) Stability:

Stability in an engine governor refers to the system's ability to maintain the desired engine speed despite external disturbances or load changes. A stable governor minimizes speed fluctuations and quickly returns to the setpoint after any transient event. Various factors, including governor sensitivity, droop settings, and control algorithms, contribute to achieving stable governor performance.

(e) Isochronous Governing:

Isochronous governing, also known as constant-speed governing, aims to maintain engine speed exactly at the setpoint regardless of load variations. Unlike governors with droop, an isochronous governor completely compensates for load changes by adjusting fuel delivery to keep the speed constant. This is desirable for applications requiring precise and constant speed, such as generators supplying critical equipment. However, isochronous governors may require more complex control algorithms and can be less tolerant of disturbances compared to droop governors.



June 2018

9. (a) State the reasons for fitting a pneumatic process valve with EACH of the following:

   (i) a volume booster; (2)

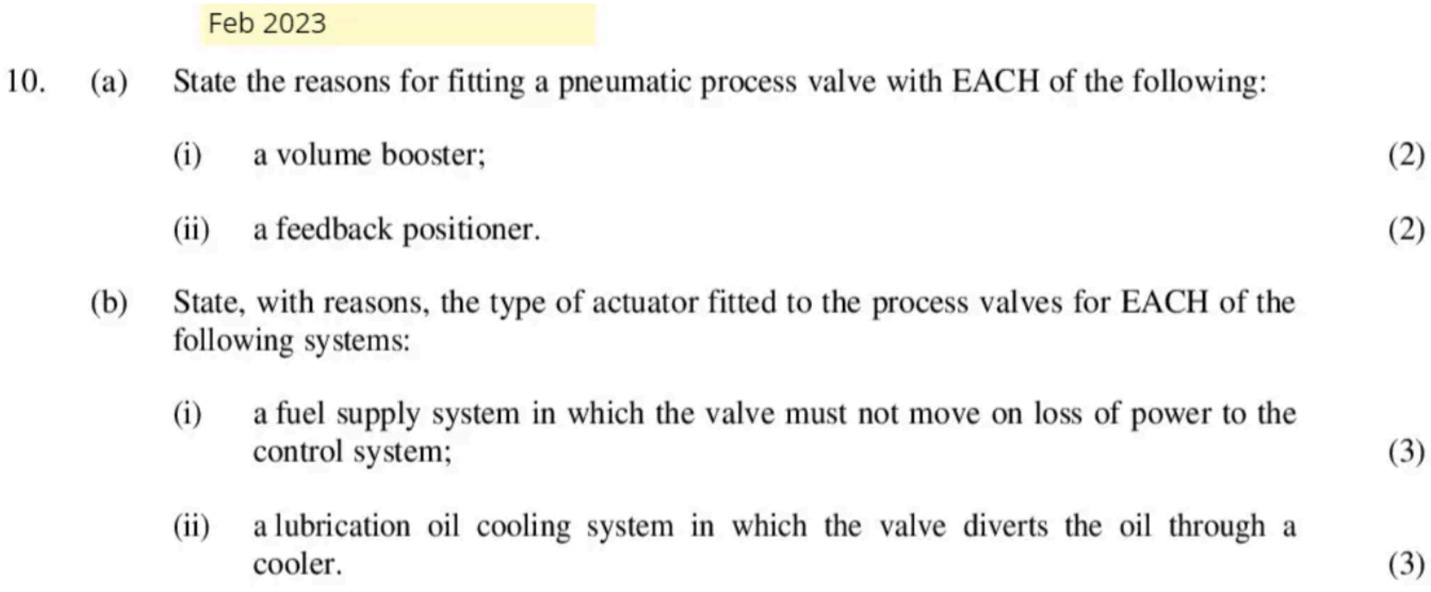
   (ii) a feedback positioner. (2)

   (b) State, with reasons, the type of actuator fitted to the process valves for EACH of the following systems:

   (i) a fuel supply system in which the valve must not move on loss of power to the control system; (3)

   (ii) a lubrication oil cooling system in which the valve diverts the oil through a cooler. (3)

June 2018



Feb 2023

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Feb 2023

Pneumatic Process Valve Accessories:

(a) Reasons for Fittings:

(i) Volume Booster:

- Increases air flow rate: A volume booster amplifies the low-flow pneumatic control signal from the controller to provide a high-flow output to the actuator. This is necessary when the actuator has a large volume or requires significant force to operate, which a standard control signal might not be able to provide effectively.
- Faster valve response: By increasing the air flow rate, the booster speeds up the actuator's response to control signals, leading to faster process adjustments and improved system dynamics.

(ii) Feedback Positioner:

- Improves accuracy and stability: A positioner measures the actual valve position and compares it to the desired position from the controller. Any deviation triggers the positioner to adjust the air pressure to the actuator, ensuring the valve reaches the exact desired position even if external forces or friction affect it. This significantly improves control accuracy and reduces steady-state errors.
- Overcomes friction and disturbances: Positioners compensate for frictional forces in the valve mechanism and external disturbances affecting the valve movement, ensuring the valve responds faithfully to the control signal despite these challenges.

(b) Actuator Types and Reasons:

(i) Fuel Supply System (Fail-Safe Operation):

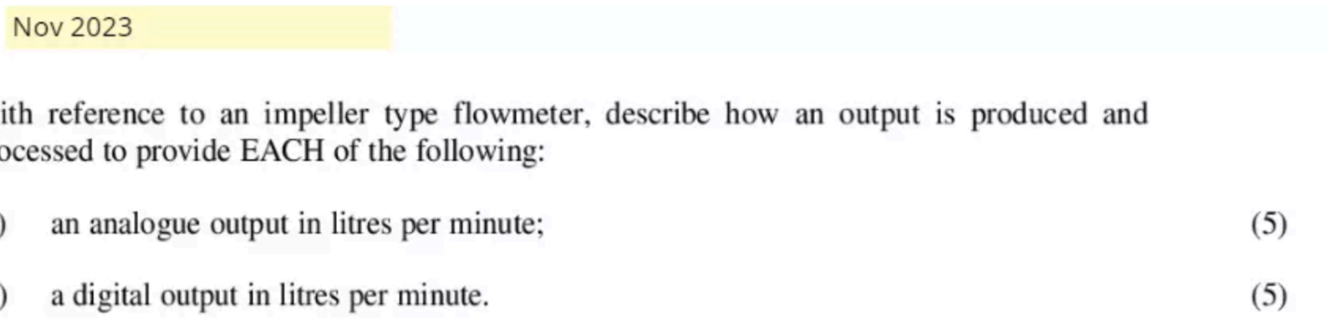
- Spring-to-Close Actuator: Ideally, this actuator would close the valve (stopping fuel flow) when air pressure fails due to a control system outage. This provides a fail-safe mechanism to prevent uncontrolled fuel release, ensuring safety and system integrity.

(ii) Lubrication Oil Cooling System (Diversion Valve):

- Double-Acting Actuator: This actuator uses air pressure in both directions (open and close). In case of air pressure loss, the valve would stay in its last position, maintaining the current oil flow path (either through the cooler or bypass, depending on the valve state before failure). This avoids uncontrolled changes in oil flow that could affect lubrication and engine health.

Additional Notes:

- The specific choice of actuator and accessories depends on various factors like process requirements, safety considerations, and control performance objectives.
- Some applications might require specific valve designs or fail-safe features beyond the basic categories mentioned here.



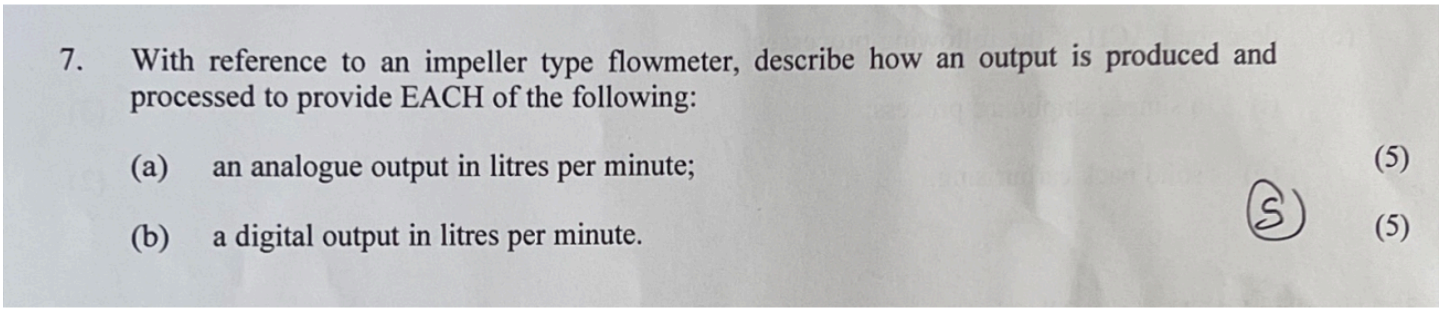
Nov 2023

8. With reference to an impeller type flowmeter, describe how an output is produced and processed to provide EACH of the following:

(a) an analogue output in litres per minute; (5)

(b) a digital output in litres per minute. (5)

Nov 2023



7. With reference to an impeller type flowmeter, describe how an output is produced and processed to provide EACH of the following:

(a) an analogue output in litres per minute; (5)

(b) a digital output in litres per minute. ⑤ (5)

March 2022

Impeller Flowmeter Output Generation:

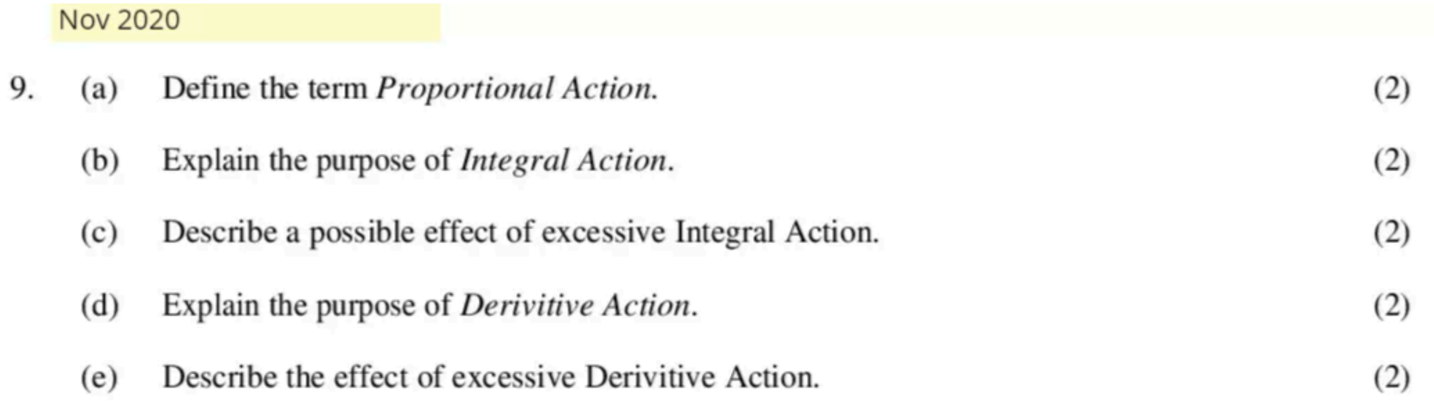
(a) Analogue Output (Litres per Minute):

1. Impeller Rotation: As fluid flows through the meter, the impeller rotates at a speed proportional to the flow rate. The impeller blades are designed to minimize drag and ensure consistent rotation with flow changes.
2. Magnetic Coupling: The impeller shaft is coupled to a magnet inside the meter housing. This magnet rotates with the impeller, creating a changing magnetic field around it.
3. Pick-up Coil: A stationary pick-up coil positioned near the rotating magnet senses the changing magnetic field. This induces a voltage signal in the coil whose frequency is directly proportional to the impeller rotation speed (and hence, the flow rate).
4. Signal Conditioning: The induced voltage signal from the pick-up coil is typically weak and noisy. Electronic circuitry amplifies and filters the signal to remove noise and ensure a clean, reliable representation of the flow rate.
5. Scaling and Calibration: The conditioned signal is then scaled and calibrated based on the meter's specific characteristics. This converts the signal voltage into an analogue voltage proportional to the flow rate in litres per minute (LPM). The scaling factor is determined during the meter's calibration process using known flow rates.
6. Analogue Output: The resulting voltage signal, representing the flow rate in LPM, is available as the analogue output of the flowmeter. This can be directly connected to an analogue-to-digital converter (ADC) for further processing or used directly in analogue control systems.

(b) Digital Output (Litres per Minute):

1. Signal Conditioning: Similar to the analogue output, the induced voltage signal from the pick-up coil is amplified and filtered.
2. Frequency-to-Digital Conversion: Instead of scaling the signal directly, a frequency-to-digital converter (FDC) is used. This chip measures the frequency of the signal, which is directly proportional to the impeller rotation speed and flow rate.
3. Microprocessor and Calculations: The FDC's digital output (representing frequency) is fed into a microprocessor within the flowmeter. The microprocessor uses the meter's calibration data and internal algorithms to convert the frequency data into a flow rate value in litres per minute (LPM).
4. Digital Output: The calculated flow rate in LPM is available as the digital output of the flowmeter. This can be displayed on the meter itself, transmitted through serial communication protocols, or used for digital control systems.

In both cases, the impeller rotation serves as the basis for flow measurement. However, the processing and interpretation of the signal differ, resulting in either an analogue voltage or a digital flow rate value as the output.



Nov 2020

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)

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(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.

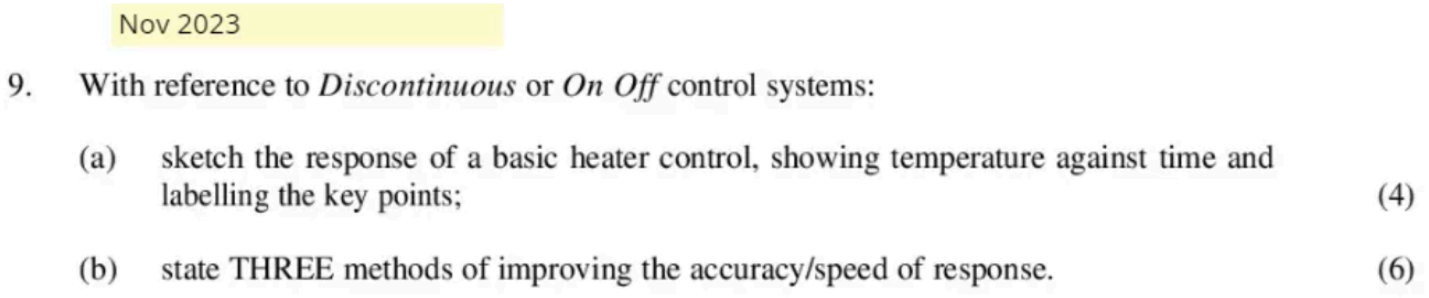
(d) Derivative Action:

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".



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9. With reference to *Discontinuous* or *On Off* control systems:

(a) sketch the response of a basic heater control, showing temperature against time and labelling the key points; (4)

(b) state THREE methods of improving the accuracy/speed of response. (6)

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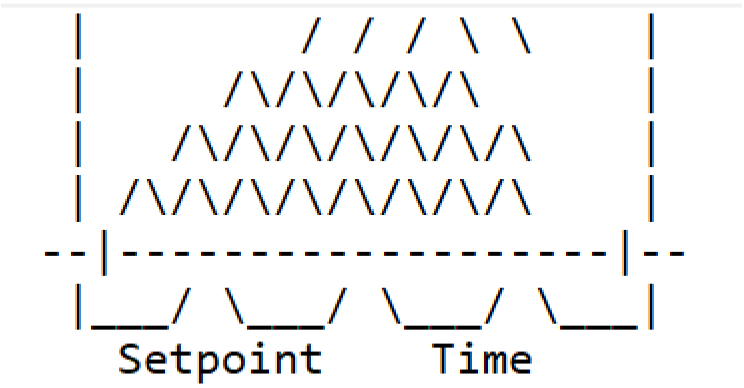
a) Response Sketch:

Here's the response sketch of a basic heater control showing temperature against time:



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    Setpoint    Time
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Key Points:

- Horizontal line: Desired temperature (setpoint).

- Sawtooth waveform: Actual temperature fluctuates around the setpoint.

- Peaks: Heater turns on, increasing temperature rapidly.

- Valleys: Heater turns off, temperature drops until the setpoint is reached and the cycle repeats.

- Hysteresis: Dead zone around the setpoint where the heater remains off (below) or on (above).

(b) Improving Accuracy/Speed of Response:

1. Proportional Band Reduction: Decrease the hysteresis band to reduce the temperature swing and improve accuracy. However, too small a band can lead to frequent switching and increased wear on the heater.
2. Rate Limiting: Limit the rate of temperature change by delaying heater activation or deactivation based on the rate of previous changes. This prevents large overshoots and improves stability.
3. Pulse Width Modulation (PWM): Instead of full on/off cycles, rapidly switch the heater on and off at a high frequency. By varying the "on" time per cycle (duty cycle), the average power delivered can be controlled, providing more precise temperature control compared to simple on/off cycles.
4. Feedback Controller: Introduce a simple feedback loop with a sensor measuring the actual temperature. The controller compares it to the setpoint and adjusts the heater state (on/off) based on the difference, aiming for a more continuous and accurate response.

Remember, each method has its advantages and limitations. Choosing the best approach depends on specific requirements for accuracy, speed, complexity, and cost.