

July 2021

1. (a) Define the meaning of the term *alloy*, stating why they are used. (3)
- (b) Describe the changes in the mechanical properties of steel with increasing amounts of carbon. (4)
- (c) List SIX common alloying elements used in the production of steel. (3)

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

An alloy is a mixture of two or more metals, or a metal combined with one or more non-metals. Alloys are used because they often have properties that are superior to those of the pure metals that make them up. For example, alloys can be stronger, harder, more corrosion-resistant, or more conductive than pure metals.

Here are some specific examples of why alloys are used:

- Steel is an alloy of iron and carbon. It is much stronger than pure iron, making it an ideal material for construction, bridges, and tools.
- Brass is an alloy of copper and zinc. It is more resistant to corrosion than pure copper, making it a good material for plumbing fixtures and musical instruments.
- Solder is an alloy of tin and lead. It has a low melting point, making it easy to use for joining metals together.

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

As the amount of carbon in steel increases, its strength and hardness also increase. However, its ductility and toughness decrease. This means that high-carbon steel is strong and hard, but it is also brittle and more likely to crack. Low-carbon steel is less strong and hard, but it is more ductile and tough, making it more resistant to breaking.

The amount of carbon in steel is typically expressed as a percentage. For example, mild steel has a carbon content of about 0.2%, while high-carbon steel has a carbon content of about 1%.

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

Six common alloying elements used in the production of steel are:

1. Carbon: Increases strength and hardness, but decreases ductility and toughness.
2. Manganese: Increases strength, hardenability, and resistance to wear and tear.
3. Silicon: Increases strength, hardenability, and resistance to oxidation.
4. Chromium: Increases strength, hardenability, and resistance to corrosion.
5. Nickel: Increases strength, toughness, and ductility at low temperatures.
6. Molybdenum: Increases strength, hardenability, and resistance to creep (deformation under stress at high temperatures).

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

- (a) crankshaft; (4)
- (b) valve spring; (3)
- (c) used copper washer. (3)

Reasons:

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

(b) Valve Spring:

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

(c) Used Copper Washer:

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

In summary, different engine components require specific heat treatment based on their function and desired properties. Crankshafts and valve springs benefit from hardening processes for strength,

wear resistance, and fatigue resistance. Used copper washers, however, generally don't undergo any heat treatment due to their inherent properties and potential degradation from past use.

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3. With reference to the installation of copper pipes in engine cooling systems:
- (a) describe THREE possible causes for their premature failure; (6)
 - (b) outline FOUR recommendations for the installation of copper pipes. (4)

(a) Three Possible Causes:

1. **Fatigue Stress:** Repeated bending, vibration, and thermal cycling due to engine operation can cause metal fatigue in copper pipes. This leads to micro-cracks that gradually grow, potentially leading to leaks or even pipe rupture.
2. **Improper Brazing or Soldering:** Faulty brazing or soldering joints can create weak points in the pipe system, compromising its integrity and potentially allowing leaks or even complete separation.
3. **Corrosion:** Exposure to aggressive chemicals like antifreeze or seawater can lead to corrosion of the copper pipes, thinning the walls and reducing their strength. This can eventually lead to leaks or burst pipes.

(b) Four Installation Recommendations:

1. **Proper Pipe Support and Routing:** Provide adequate support for the pipes throughout the system to minimize vibration and bending stress. Avoid sharp bends and ensure sufficient clearance from moving parts or potential sources of abrasion.
2. **High-Quality Brazing or Soldering:** Use proper brazing or soldering techniques with appropriate materials and temperatures to create strong, leak-proof joints. Ensure qualified personnel perform the work and follow best practices.
3. **Corrosion Protection:** Use corrosion-resistant materials for brazing/soldering and consider additional protective coatings on the pipes, especially if exposed to aggressive environments like seawater.
4. **Regular Maintenance and Inspection:** Regularly inspect the entire cooling system for signs of leaks, corrosion, or damage. Maintain proper antifreeze levels and monitor its condition to prevent excessive corrosion.

By following these recommendations, you can significantly reduce the risk of premature failure in copper pipes used in engine cooling systems, ensuring their long-term reliability and minimizing potential engine overheating or other consequences of leaks or failures.

Remember, proper installation and maintenance are crucial for the continued safe and efficient operation of your engine cooling system.

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4. With reference to fatigue failure of components:
- (a) describe how material fatigue testing is carried out in the laboratory; (2)
 - (b) sketch the surface appearance of a fatigue fracture; (2)
 - (c) describe the THREE stages of the failure; (3)
 - (d) list the methods available on board to limit the possibility of fatigue failure to a propeller shaft. (3)

(a) Material Fatigue Testing in Lab:

https://www.youtube.com/watch?v=LhUclxBUV_E

Laboratory fatigue testing simulates real-world cyclic loading to assess a material's resistance to fatigue failure. Common methods include:

- Rotating Beam Test: A rotating cantilever beam experiences cyclic bending stresses as it spins. The number of cycles to failure at a specific stress level determines the fatigue strength.
- Axial Fatigue Test: A specimen is subjected to cyclic tension and compression loading to evaluate fatigue performance under these conditions.
- Push-Pull Test: A specimen is pulled in one direction and then pushed back in the opposite direction, mimicking cyclic axial stresses.
- Four-Point Bending Test: A specimen is supported at two points and loaded at two other points, creating a constant bending moment region to study fatigue behavior.

These tests measure fatigue life (number of cycles to failure) at various stress levels, generating S-N curves that map stress vs. number of cycles to failure. This data allows material selection, design optimization, and prediction of fatigue life in real applications.

(b) Sketch of Fatigue Fracture Surface:

https://www.youtube.com/watch?v=6y_PF0_Hr9k

A fatigue fracture exhibits distinct features:

- Initiation Site: Often a surface defect like a scratch, corrosion pit, or inclusion acts as the starting point for micro-cracks.
- Beach Marks: Concentric semicircular ridges around the initiation site represent progressive crack growth under each loading cycle.
- Final Fracture Zone: This area displays rougher fracture features due to rapid crack propagation leading to final failure.

Sketch: Imagine a circular area with concentric semi-circular ridges around a central point. The ridges become larger and closer as they move away from the center. The edge shows a rougher fractured area.

(c) Three Stages of Fatigue Failure:

- Crack Initiation: Micro-cracks form and propagate at microscopic levels from stress concentrations at defects or inhomogeneities within the material.
- Crack Propagation: The micro-cracks gradually grow under repeated loading, creating beach marks on the fracture surface. The rate of crack growth depends on stress level, material properties, and environmental factors.
- Final Fracture: When the crack reaches a critical size, it can no longer withstand the applied stress and rapidly propagates across the remaining cross-section, leading to final failure.

(d) Mitigation Methods for Propeller Shaft Fatigue:

Onboard strategies to limit propeller shaft fatigue failure include:

- Preventative Maintenance: Regularly inspecting the shaft for surface defects, cracks, and corrosion allows for early detection and repairs, preventing further crack growth.
- Vibration Control: Minimizing vibrations through shaft balancing, alignment adjustments, and dampening devices reduces dynamic loading and stress concentrations.
- Propeller Maintenance: Ensuring proper propeller balance and blade pitch minimizes uneven loading on the shaft.
- Material Selection: Using fatigue-resistant materials can improve the shaft's overall fatigue life.
- Operational Monitoring: Monitoring stress levels, vibrations, and shaft RPM during operation allows for adjustments to operating conditions and early detection of potential fatigue concerns.

By implementing these mitigation strategies, the risk of fatigue failure in a propeller shaft can be significantly reduced, ensuring its continued reliable operation and preventing catastrophic consequences.

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5. With reference to TIG welding:

- (a) describe the process; (3)
- (b) explain why an ac current is preferred when welding aluminium; (2)
- (c) explain the advantages compared to other methods. (5)

(a) TIG Welding Process:

Tungsten Inert Gas (TIG) welding, also known as GTAW (Gas Tungsten Arc Welding), is a meticulously controlled arc welding process that uses a non-consumable tungsten electrode and an inert shielding gas. Here's how it works:

1. Preparation: Clean the weld area thoroughly to remove any contaminants that could compromise the weld quality.
2. Setup: Choose the appropriate tungsten electrode and shielding gas (e.g., argon) based on the material being welded. Set the welding current and flow rate.

3. Initiation: Create an arc between the tungsten electrode and the workpiece using a high-frequency start or by touching the tip momentarily and retracting.
4. Welding: Hold the torch at the desired angle and distance from the joint. Add filler metal (a separate rod or wire) manually to the molten pool created by the arc, building the weld bead layer by layer.
5. Travel Speed: Move the torch along the joint seam at a controlled pace, maintaining the arc and adding filler metal as needed.
6. Finishing: Allow the weld to cool completely, then remove any slag (residue) with a wire brush or other cleaning tools.

TIG welding offers exceptional control and precision because the filler metal is not continuously fed, allowing the welder to manipulate the molten pool directly.

(b) AC Current for Aluminum:

When welding aluminum, AC current is often preferred over DC current for several reasons:

- Penetration: The alternating polarity of AC creates a cleaning action during the positive cycle, breaking up the tenacious oxide layer (aluminum oxide) that forms on the surface. This allows for deeper weld penetration compared to DC.
- Cathode Cleaning: During the negative cycle, the aluminum melts and cleans the tungsten electrode, preventing contamination and maintaining a stable arc.
- Weld Quality: The combined cleaning and penetration effects of AC lead to cleaner welds with reduced porosity and improved visual appearance.

Though DC can be used for specific aluminum applications, AC generally offers better overall performance and ease of welding.

(c) Advantages of TIG Welding:

TIG welding offers several advantages over other welding methods, particularly for critical applications or materials like aluminum:

- High Precision and Control: The ability to manually add filler metal and control the arc allows for precise weld profiles and minimal distortion.
- Excellent Weld Quality: TIG produces strong, clean welds with minimal spatter and high weld integrity due to the shielding gas and controlled conditions.
- Versatility: Works with a wide range of materials, including thin sheets, delicate parts, and even dissimilar metals.
- Minimal Heat Input: Less heat-affected zone minimizes warping and distortion, particularly beneficial for thin materials.

However, TIG welding requires more skill and practice compared to other methods, and its slower deposition rate might not be suitable for high-production applications.

In conclusion, TIG welding stands out for its precision, control, and excellent weld quality, making it a preferred choice for critical applications, aluminum welding, and scenarios where meticulous technique is paramount.

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6. (a) With reference to fretting corrosion:
- (i) explain the process; (3)
 - (ii) state a common cause; (1)
 - (iii) state how it is normally detected. (1)
- (b) With reference to pitting corrosion:
- (i) explain the term *pitting corrosion*; (1)
 - (ii) state TWO common causes; (2)
 - (iii) explain why it is considered to be dangerous. (2)

(a) Fretting Corrosion:

(i) The Process: Imagine two surfaces in tight contact, experiencing slight, relative movement due to vibration or thermal expansion. The microscopic rubbing and slipping create wear particles, which further abrade the surfaces. This combined mechanical wear and oxidation generates a reddish-brown powder and localized pitting, known as fretting corrosion.

(ii) Common Cause: Vibration is a common culprit, particularly in components like bearings, gears, and bolted connections. Even seemingly insignificant vibrations can trigger fretting over time, especially when compounded by high pressure or poor lubrication.

(iii) Detection: Visual inspection can reveal reddish-brown powder or discoloration at contact points. However, early detection often requires non-destructive testing methods like ultrasonic testing or eddy current testing, which can detect subsurface damage before it becomes visible.

(b) Pitting Corrosion:

(i) Explanation: Pitting corrosion isn't a uniform attack on the metal surface, but rather the formation of isolated, deep cavities called pits. These pits can penetrate deep into the material, often invisible to the naked eye until significant damage has occurred.

(ii) Common Causes: Pitting can be caused by several factors, including:

- Chloride Ions: These are particularly aggressive towards many metals, particularly stainless steel, and can initiate pitting by breaking down the protective passive layer. Seawater and environments with high salt content are prime culprits.

- Acidic or Alkaline Environments: Extreme pH levels can disrupt the passive layer and make metals more susceptible to pitting corrosion. This can occur in industrial environments with chemical spills or even in rainwater with acidic pollutants.

(iii) Danger of Pitting Corrosion: Pitting's insidious nature lies in its localized attack. The deep, narrow pits can significantly weaken the material, even if the overall surface area affected is small. This can lead to sudden and catastrophic failures, especially in components under high stress, like pressure vessels or aircraft structures.

Understanding the mechanisms and detection methods for both fretting and pitting corrosion is crucial for ensuring the structural integrity and safety of components in various applications. Implementing strategies like vibration dampening, lubrication, protective coatings, and regular inspection can significantly mitigate these forms of corrosion and extend the lifespan of your materials.

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7. With reference to a PT100 probe (resistance thermometer):

- (a) explain the principle of operation by which it is able to give a temperature measurement; (3)
- (b) describe how the sensing element is constructed, explaining why it is called a PT100 probe; (4)
- (c) explain why these probes typically have three or four wires to connect them to the temperature indicating device. (3)

(a) Temperature Measurement through Resistance:

Think of a PT100 probe as a miniature conductor whose electrical resistance changes precisely with temperature. This principle, known as resistive temperature detection (RTD), forms the core of its operation. Here's how it works:

1. Platinum Magic: The sensing element inside the probe is made of pure platinum, chosen for its remarkably linear and predictable relationship between temperature and resistance. As the temperature increases, the platinum atoms vibrate more, disrupting the orderly flow of electrons, thereby increasing the resistance.
2. Measuring the Change: An external device connected to the probe measures the resistance of the platinum element. This measured resistance directly corresponds to the temperature within the probe through the platinum's inherent temperature-resistance characteristic.
3. Conversion to Temperature: Finally, the measuring device utilizes this resistance value and converts it into a temperature reading using pre-programmed calibration equations specific to Pt100 probes.

This simple yet precise method allows PT100 probes to measure temperatures accurately and reliably across a wide range.

(b) Construction of the Sensing Element: The "PT" in PT100:

The heart of the PT100 probe lies in its sensing element, often a thin coil of pure platinum wire wrapped around a ceramic core. This construction offers several advantages:

- **High Purity:** Pure platinum ensures consistent and predictable temperature-resistance behavior, crucial for accurate measurements.
- **Compactness:** The coiled wire design creates a small and sensitive element, allowing for quick thermal response and versatility in placement.
- **Durability:** The ceramic core provides mechanical support and protects the delicate platinum wire from physical damage.

Now, the "PT" in PT100 stands for "Platinum," and the "100" signifies the nominal resistance of the element at 0°C, which in this case is 100 ohms. This standard naming convention allows for easy identification and interchangeability of these probes.

(c) The Mystery of the Wires: Three or Four?

While two wires might seem sufficient to carry the current and measure the resistance, PT100 probes typically have three or four wires. Here's why:

- **Three-Wire Configuration:** This setup uses three wires, one each for supplying current, measuring voltage across the element, and compensating for lead resistance. The lead resistance can introduce errors, and the third wire effectively cancels it out for accurate temperature readings.
- **Four-Wire Configuration:** This offers enhanced precision, especially for long lead lengths. Four wires are used, two for providing current and two for measuring voltage, completely eliminating the influence of lead resistance on the measurement.

The choice between three and four wires depends on the required accuracy, lead length, and cost considerations. In most cases, three-wire probes offer sufficient accuracy for common applications.

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

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)

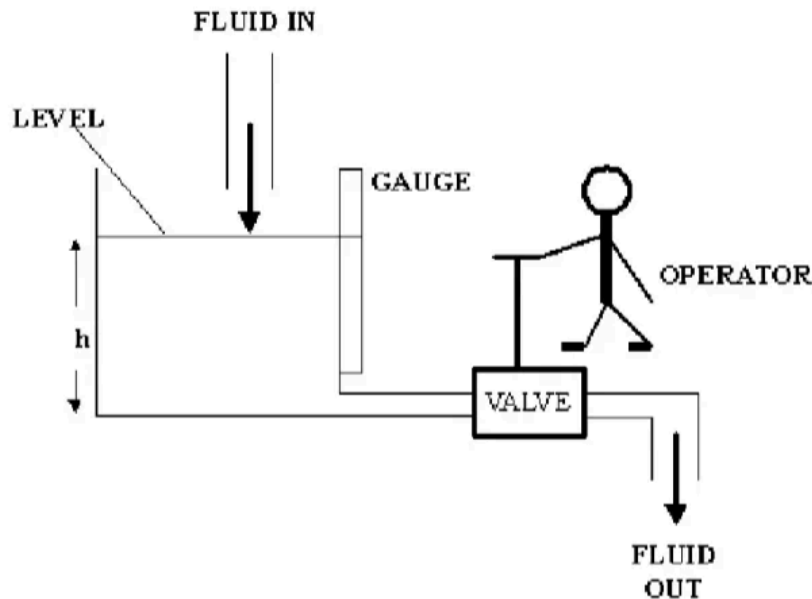


Fig Q8

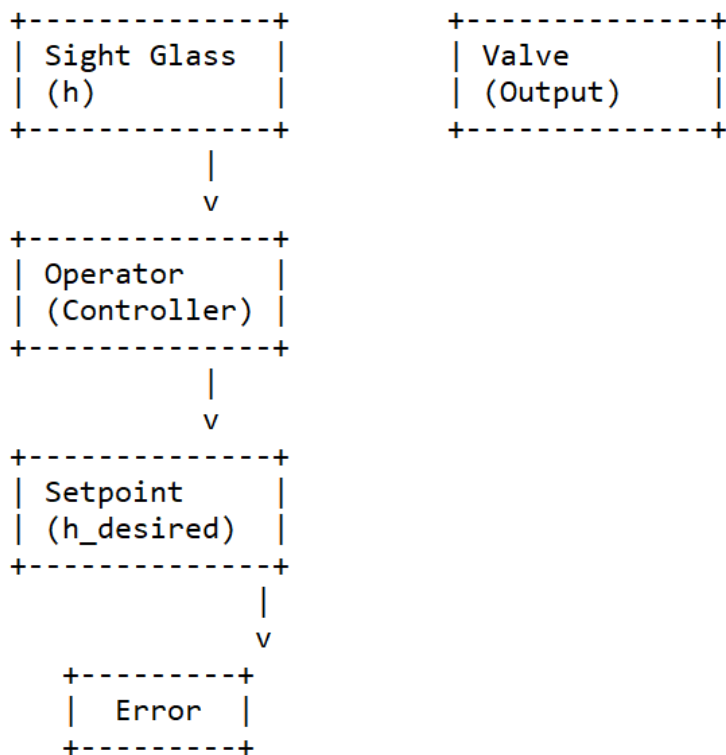
System Description:

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:



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.

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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)

(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.

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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)

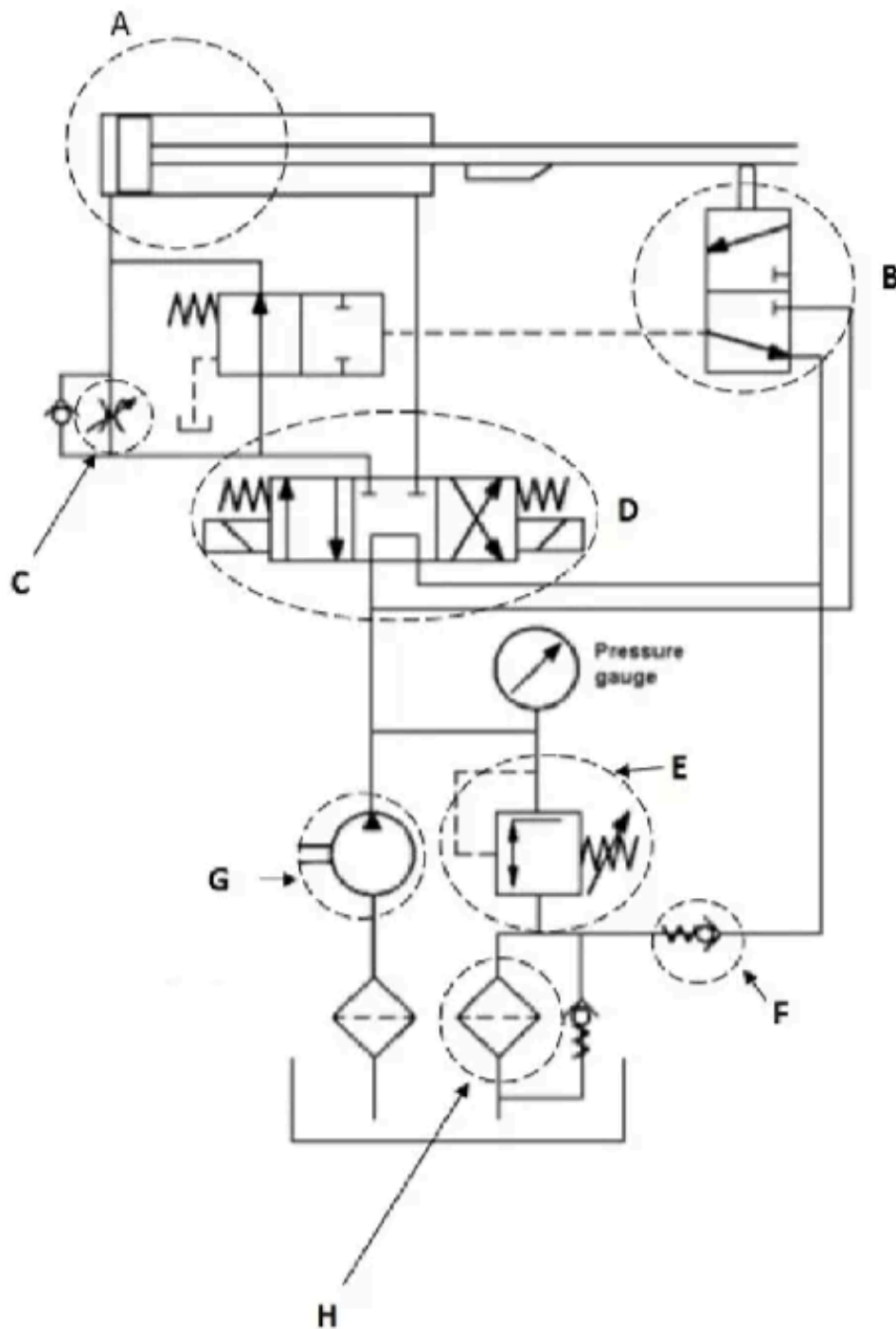


Fig Q10

(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.