058-01 - APPLIED MARINE ENGINEERING

FRIDAY, 05 March 2021

1400-1600 hrs

APPLIED MARINE ENGINEERING

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

1. With reference to the manufacture of carbon fire components:

   (a) describe EACH of the following processes and its advantages:

   (i) vacuum bagging; (2)

   (ii) autoclave curing; (2)

   (iii) resin transfer moulding; (3)

   (b) list the type of component that EACH process described in part (a) is best suited to. (3)

2. With reference to the heat treatment of steel:

   (a) explain which steels this process is best suited to; (2)

   (b) explain EACH of the following processes, making reference to mechanical properties and internal structure:

   (i) hardening; (4)

   (ii) tempering. (4)

3. With reference to stresses within engineering materials:

   (a) explain EACH of the following terms

   (i) tensile stress; (1)

   (ii) shear stress; (1)

   (iii) compressive stress; (1)

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

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

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

   (a) brittleness; (2)

   (b) ductility; (2)

   (c) hardness; (2)

   (d) malleability; (2)

   (e) toughness. (2)

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

   (a) describe the process; (3)

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

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

6. Explain EACH of the following terms:

   (a) galvanic corrosion; (2)

   (b) cavitation damage; (2)

   (c) erosion damage; (2)

   (d) stress corrosion; (2)

   (e) atmospheric corrosion. (2)

7. List FIVE different methods of remotely monitoring the content level of a fuel oil service tank, explaining their operating principle. (10)

8. (a) Explain, with the aid of a sketch, how the fluid level in a tank can be measured using ultrasound energy. (6)

(b) State TWO advantages of using ultrasound. (2)

(c) State TWO limitations of this type of measuring device. (2)

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)

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)

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(iii) resin transfer moulding; (3)

(b) list the type of component that EACH process described in part (a) is best suited to. (3)

three different composite fabrication processes: vacuum bagging, autoclave curing, and resin transfer molding (RTM). Each process has its own advantages and disadvantages, and is best suited for different types of components.

Here's a breakdown of each process:

Vacuum bagging:

- Process: A dry fiber preform is placed in a mold, and then covered with a vacuum bag. The air is evacuated from the bag, which applies pressure to the preform and forces the resin to flow through it. The part is then cured under heat.
- Advantages:
  - Simple and relatively inexpensive process.
  - Can be used with a wide variety of mold materials and shapes.
  - Good for producing parts with a high fiber volume fraction.
-
- Disadvantages:
  - Limited to parts with simple geometries.
  - Voiding (air pockets) can be an issue.
  - Not suitable for high-performance applications.
-

Autoclave curing:

- Process: The vacuum-bagged part is placed in an autoclave, which is a pressure vessel that can be heated and pressurized. The pressure helps to consolidate the laminate and eliminate voids.
- Advantages:
  - Produces high-quality parts with excellent surface finish and low void content.
  - Suitable for complex geometries and high-performance applications.
-
- Disadvantages:
  - Expensive process due to the high cost of autoclaves.
  - Limited throughput due to the long cycle times.

- Not suitable for large parts.
-

Resin transfer molding (RTM):

- Process: The dry fiber preform is placed in a closed mold, and then resin is injected into the mold under pressure. The part is then cured under heat.
- Advantages:
  - Can produce high-quality parts with good surface finish and low void content.
  - Faster cycle times than autoclave curing.
  - Can be used for larger parts than vacuum bagging.
-
- Disadvantages:
  - More complex process than vacuum bagging.
  - Requires specialized molds and equipment.
  - Not suitable for all geometries.

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2. With reference to the heat treatment of steel:

(a) explain which steels this process is best suited to; (2)

(b) explain EACH of the following processes, making reference to mechanical properties and internal structure:

(i) hardening; (4)

(ii) tempering. (4)

Heat Treatment of Steel: Suits and Processes

(a) Steels Best Suited for Heat Treatment:

Heat treatment is particularly beneficial for specific types of steel, primarily those with medium to high carbon content (0.2-1.0%). These steels experience significant changes in their mechanical properties due to the heat-driven transformations in their internal structure. Some examples include:

- Hypoeutectoid steels (carbon content < 0.77%): These steels can achieve significant hardening through quenching, forming martensite with high strength and hardness.
- Eutectoid steel (0.77% carbon): This steel readily transforms into pearlite (a mixture of ferrite and cementite) during slow cooling, achieving a good balance of strength and ductility.

- Hypereutectoid steels (carbon content > 0.77%): These steels can achieve high wear resistance due to the presence of cementite (iron carbide). However, their weldability and ductility are limited.

Steels with very low carbon content (< 0.2%) and high-alloy stainless steels generally benefit less from heat treatment due to their inherent properties or limited transformation potential.

(b) Heat Treatment Processes Explained:

(i) Hardening:

- Process: Steel is heated above its critical temperature (around 723°C), austenitizing its microstructure (transforming it into austenite, a high-carbon phase). This is followed by rapid quenching (usually in water or oil), which traps the high-carbon austenite structure as a metastable phase called martensite.
- Mechanical Properties: Hardening significantly increases the strength and hardness of the steel but at the expense of ductility and toughness. Martensite is very strong and hard but also brittle and prone to cracking.
- Internal Structure: The rapid quenching prevents carbon atoms from diffusing and forming equilibrium phases like pearlite. Instead, austenite transforms into martensite, a distorted tetragonal lattice structure with high carbon content, leading to high strength and hardness.

(ii) Tempering:

- Process: Hardened steel is reheated to a lower temperature (typically between 150°C and 500°C) and then cooled slowly. This allows some of the martensite to transform back into less brittle phases like ferrite and cementite, depending on the tempering temperature.
- Mechanical Properties: Tempering reduces the hardness and strength of the steel compared to the hardened state but significantly improves its ductility and toughness. This makes the steel more resistant to cracking and failure under stress.
- Internal Structure: Tempering allows carbon atoms to diffuse and form more stable phases like ferrite and cementite. The specific phases formed and the degree of transformation depend on the tempering temperature, influencing the final balance of strength, ductility, and toughness.

Therefore, hardening and tempering are complementary processes. Hardening provides high strength and hardness, while tempering improves ductility and toughness, allowing for a tailored balance of properties for specific applications.

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3. With reference to stresses within engineering materials:

(a) explain EACH of the following terms

(i) tensile stress; (1)

(ii) shear stress; (1)

(iii) compressive stress; (1)

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

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

a) Explaining Different Types of Stresses:

(i) Tensile Stress:

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

(ii) Shear Stress:

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

(iii) Compressive Stress:

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

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

Tensile Stress:

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

Shear Stress:

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

Compressive Stress:

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

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

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

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

(a) brittleness; (2)

(b) ductility; (2)

(c) hardness; (2)

(d) malleability; (2)

(e) toughness. (2)

(a) Brittleness:

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

(b) Ductility:

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

(c) Hardness:

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

(d) Malleability:

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

(e) Toughness:

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

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

(a) describe the process; (3)

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

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

MIG Welding of Mild Steel:

(a) Process:

Gas metal arc welding (MIG), also known as metal inert gas (MIG) welding, is a semi-automatic arc welding process that uses a consumable wire electrode. Here's how it works:

1. Wire Feeding: A continuous solid wire electrode is fed from a spool through the welding gun and the contact tip.
2. Arc Formation: An electric arc forms between the tip of the wire and the workpiece, generating intense heat.
3. Wire Melting: The wire melts due to the heat, adding filler metal to the weld pool.
4. Shielding Gas: An inert gas (MIG) or active gas (MAG) flows around the arc and molten metal, protecting them from atmospheric contamination.
5. Weld Pool: The base metal melts at the edges, forming a molten pool that fuses with the melted filler metal, creating the weld.
6. Solidification: As the welding torch moves, the weld pool cools and solidifies, forming the final joint.

(b) Surface Preparation:

Proper surface preparation is crucial for good weld quality and joint strength in MIG welding of mild steel. Here's why:

- Removing Contaminants: Contaminants like grease, paint, rust, and mill scale can interfere with weld pool formation and lead to porosity (air pockets) in the weld, weakening it.
- Oxidation: Oxygen in the air combines with iron to form oxide, which hinders proper fusion and weakens the joint. Removing it ensures good metal-to-metal contact.
- Improving Weld Appearance: Cleaning removes surface irregularities, leading to a smoother and more aesthetically pleasing weld finish.

Therefore, surface preparation typically involves:

- Degreasing: Removing oil, grease, and other contaminants with solvents or detergents.
- Mechanical Cleaning: Wire brushing, grinding, or sanding to remove rust, mill scale, and oxide layers.
- Grinding for Fit-up: Removing excess material and ensuring proper joint geometry for better weld penetration.

(c) Advantages:

1. Fast and Efficient: Continuous wire feeding and semi-automatic operation enable high welding speeds, making it suitable for production applications.
2. Versatility: Can weld various thicknesses of mild steel and other metals with different wire electrodes and shielding gases.
3. Good Weld Quality: Produces clean, porosity-free welds with good mechanical properties when used correctly.
4. Easy to Learn: Compared to other arc welding processes, MIG is relatively easier to learn and control, making it suitable for beginners.

(d) Limitation:

1. Limited Portability: Requires power supply, gas cylinders, and welding gun, making it less portable than some other welding processes.
2. Sensitive to Wind: Wind can blow away the shielding gas, leading to weld defects. Requires controlled environments or wind shields for outdoor welding.

I hope this explanation is helpful!

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6. Explain EACH of the following terms:

(a) galvanic corrosion; (2)

(b) cavitation damage; (2)

(c) erosion damage; (2)

(d) stress corrosion; (2)

(e) atmospheric corrosion. (2)

a) Galvanic Corrosion: Imagine a scenario where two dissimilar metals touch and are immersed in a conductive solution (electrolyte) like seawater. This seemingly innocent contact can trigger a treacherous process called galvanic corrosion. Here's what happens:

1. Dissimilar Potentials: Each metal has its own "electrical potential," like a battery, but at different levels. The more active metal (lower potential) acts as the anode, while the less active one (higher potential) becomes the cathode.
2. Electron Flow: Driven by the potential difference, electrons flow from the anode (active metal) through the electrolyte to the cathode (less active metal).
3. Metal Dissolves: At the anode, metal atoms lose electrons and dissolve into the electrolyte as ions. This is where corrosion occurs, eating away at the anode metal.
4. Cathodic Reaction: Electrons reaching the cathode react with the electrolyte (usually oxygen and water) to form harmless compounds like hydroxide ions.

This cycle continues, relentlessly corroding the anode while protecting the cathode. The severity depends on factors like the potential difference between the metals and the conductivity of the electrolyte. Avoiding direct contact between dissimilar metals, using sacrificial anodes (made of even more active metals), or applying protective coatings are some ways to combat galvanic corrosion.

(b) Cavitation Damage: Picture a fast-flowing fluid swirling around an object, creating bubbles due to pressure drops. When these bubbles collapse violently near a solid surface, the impact sends miniature shockwaves, like microscopic explosions. This phenomenon is called cavitation, and its destructive force can cause significant damage, aptly named cavitation damage.

The shockwaves erode the surface, creating pits, grooves, and rough patches. This type of damage is particularly common in propellers, turbine blades, and other components exposed to high-speed liquids. Materials with better tensile strength and resistance to fatigue are preferred to combat cavitation. Additionally, optimizing fluid flow and reducing pressure fluctuations can help mitigate the problem.

(c) Erosion Damage: Erosion in the context of materials describes the gradual removal of surface material by the abrasive action of a fluid or solid particles. Imagine sandblasting against a metal surface – that's essentially erosion damage. It can manifest as scratches, grooves, or even complete wear-through in severe cases.

Pipelines, pumps, valves, and other components exposed to fluid flow with solid particles, like slurries or sand-laden water, are particularly susceptible to erosion damage. Choosing abrasion-resistant materials, modifying designs to reduce flow velocity and particle impact, and implementing protective coatings are crucial to prevent this type of wear and tear.

(d) Stress Corrosion: Imagine a metal under constant stress, like a bridge bearing the weight of vehicles. This stress, combined with a specific corrosive environment, can lead to a type of localized attack called stress corrosion. It's like a double whammy, where the stress weakens the metal and the corrosive environment exploits these weaknesses, leading to cracks and fractures.

Certain materials are more susceptible to stress corrosion in specific environments. For example, stainless steel under chloride stress in seawater is a classic example. Identifying potential stress factors and corrosive environments, choosing resistant materials, and employing stress-relieving techniques are essential to manage this type of damage.

(e) Atmospheric Corrosion: This is the most common type of corrosion, the one we see daily on everyday objects exposed to the elements. Rain, wind, sunlight, and pollutants in the air combine to form a constantly fluctuating corrosive environment. The process usually involves oxidation, where metal atoms react with oxygen in the air, forming oxides like rust on iron or patina on copper.

Atmospheric corrosion rates vary depending on the metal, the specific environment (coastal areas tend to be more corrosive), and protective measures like coatings or surface treatments. Regularly cleaning and maintaining surfaces, choosing corrosion-resistant materials, and applying protective coatings are effective strategies to minimize atmospheric corrosion

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Atmospheric corrosion rates vary depending on the metal, the specific environment (coastal areas tend to be more corrosive), and protective measures like coatings or surface treatments. Regularly cleaning and maintaining surfaces, choosing corrosion-resistant materials, and applying protective coatings are effective strategies to minimize atmospheric corrosion.

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7. List FIVE different methods of remotely monitoring the content level of a fuel oil service tank, explaining their operating principle. (10)

Here are five different methods for remotely monitoring the content level of a fuel oil service tank, along with their operating principles:

1. Float Switch System:

- Principle: A mechanical float attached to a lever rises and falls with the fuel level in the tank. As the level changes, the lever triggers switches at preset levels, sending electrical signals to a remote indicator or control system.
- Advantages: Simple and reliable, cost-effective, suitable for basic level monitoring.
- Disadvantages: Limited to discrete level readings, prone to mechanical wear and tear, may not be suitable for high-precision applications.

2. Hydrostatic Pressure Transmitter:

- Principle: A pressure sensor is installed at the bottom of the tank. The pressure exerted by the fuel column on the sensor changes with the liquid level. This pressure is converted to an electrical signal and transmitted to a remote indicator or control system.
- Advantages: Continuous and accurate level monitoring, can be calibrated for high precision, suitable for deep tanks.
- Disadvantages: Requires installation at the bottom of the tank, can be affected by temperature changes in the fuel.

3. Capacitance Probe Sensor:

- Principle: A probe with electrodes is inserted into the tank. The dielectric constant of the space between the electrodes changes as the liquid level rises or falls, affecting the overall capacitance. This change is measured and converted to a level reading.
- Advantages: Contactless measurement, suitable for various liquids, continuous and accurate level monitoring.
- Disadvantages: Sensitive to changes in the liquid properties like conductivity and contaminants, requires careful calibration.

4. Ultrasonic Sensor:

- Principle: An ultrasonic sensor emits sound waves and measures the time it takes for the reflected waves to return from the fuel surface. The time difference correlates to the distance to the liquid level, allowing for level calculation.
- Advantages: Non-invasive, suitable for various tank shapes, can be used in harsh environments.
- Disadvantages: Requires clear line-of-sight to the liquid surface, may be affected by tank geometry and turbulence.

5. Guided Radar Level Transmitter:

- Principle: A metal probe with radar pulses travels up and down the inside of the tank. The reflected pulses from the liquid surface provide information on the distance to the fuel level.
- Advantages: Highly accurate and reliable, suitable for tall or irregularly shaped tanks, unaffected by tank conditions.
- Disadvantages: More expensive than other methods, requires installation of the guiding structure inside the tank.

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8. (a) Explain, with the aid of a sketch, how the fluid level in a tank can be measured using ultrasound energy. (6)

(b) State TWO advantages of using ultrasound. (2)

(c) State TWO limitations of this type of measuring device. (2)

(a) Ultrasonic Level Measurement with a Sketch:

Imagine a sensor mounted above or inside a tank, sending out high-frequency sound waves (ultrasound) towards the fluid surface. Here's how it works:

Sketch:

- Transducer: The sensor acts as both a transmitter and receiver of ultrasound waves.
- Pulse Emission: The transducer emits a short burst of ultrasonic energy towards the liquid surface.
- Echo Reflection: The sound waves are reflected back from the liquid surface, similar to how your voice echoes against a wall.
- Time Measurement: The transducer measures the time it takes for the reflected pulse to return.
- Distance Calculation: Knowing the speed of sound in the air or tank material, the travel time is converted to the distance (d) travelled by the waves.
- Level Calculation: Since the distance (d) represents twice the actual distance to the liquid surface (h), dividing d by 2 gives the desired fluid level.

Key Points:

- The method relies on the precise measurement of the time it takes for the sound waves to travel and return.
- The speed of sound is a crucial factor and might need adjustment based on temperature or tank material.

(b) Advantages of Ultrasonic Sensors:

- Non-invasive: No contact with the liquid is required, eliminating risks of contamination or interference.
- Versatility: Works with various liquids and tank shapes, offering flexibility in application.

(c) Limitations of Ultrasonic Sensors:

- Line-of-sight: Requires a clear path between the sensor and the liquid surface. Obstacles or tank geometry can affect accuracy.
- Sensitivity to conditions: Foam, turbulence, or temperature changes in the liquid can impact the reflected sound signal and affect readings.

Remember, ultrasonic level measurement offers a powerful tool for non-invasive and versatile level monitoring. However, understanding its limitations and ensuring suitable conditions for accurate operation is crucial for effective liquid level management.

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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)

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            |
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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)

(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.