Oct 2020

October 2020 MDE

1. With reference to four stroke engines, explain the effects of EACH of the following:

   (a) advanced fuel injection; (3)

   (b) retarded fuel injection; (4)

   (c) low compression pressure. (3)

Effects of Injection Timing and Compression Pressure in Four-Stroke Engines:

Here's a breakdown of how injection timing and compression pressure affect four-stroke engines:

(a) Advanced Fuel Injection:

Injecting fuel earlier in the compression stroke can have both positive and negative effects:

- **Positives:**
  - **Improved Power Output:** In some cases, advanced injection can allow for a longer ignition delay, leading to a more complete burn and potentially higher power output.
  - **Reduced NOx Emissions:** Earlier injection allows for more time for fuel-air mixing before combustion, potentially reducing peak combustion temperatures and thereby lowering NOx emissions.
- **Negatives:**
  - **Increased Noise and Knocking:** Early injection can lead to pre-ignition (fuel igniting before the optimal timing), causing knocking and increased noise during operation.
  - **Potential Power Loss:** Excessive advancement can result in incomplete combustion as the fuel and air haven't fully mixed by the time ignition occurs, leading to power loss.

(b) Retarded Fuel Injection:

Delaying fuel injection timing towards the end of the compression stroke also has both advantages and disadvantages:

- **Positives:**
  - **Reduced NOx Emissions:** Similar to advanced injection with a slightly longer mixing time, retarded injection can contribute to lower peak combustion temperatures and potentially lower NOx emissions.
  - **Improved Fuel Economy:** In some cases, retarded injection can improve fuel efficiency as the fuel burns closer to the expansion stroke, potentially utilizing more of the energy from the combustion process.
- **Negatives:**
  - **Reduced Power Output:** Delayed injection leaves less time for complete combustion before the expansion stroke, potentially leading to a decrease in power output.
  - **Increased Hydrocarbon Emissions:** If the fuel injection is too late, there might be insufficient time for complete combustion, resulting in higher unburned hydrocarbon emissions in the exhaust.

(c) Low Compression Pressure:

Compression pressure is a crucial factor in the efficiency and performance of a four-stroke engine. Here's how low compression pressure affects the engine:

- **Reduced Power Output:** Lower compression pressure reduces the force pushing down on the piston during the power stroke, leading to a significant decrease in engine power output.
- **Increased Fuel Consumption:** Due to the lower efficiency of the combustion process with lower compression, the engine needs to burn more fuel to achieve the same power output, resulting in higher fuel consumption.
- **Incomplete Combustion:** In severe cases of low compression, there might be insufficient pressure and temperature for complete combustion, leading to increased emissions of unburned hydrocarbons and carbon monoxide.

Finding the Optimal Balance:

Engine manufacturers carefully design the injection timing and compression ratio to achieve a balance between power, efficiency, and emissions for a specific engine application. While adjustments might be possible in some cases, it's crucial to follow the manufacturer's recommendations to maintain optimal engine performance and avoid potential damage.

April 2020

April 2023 MDE

4. Describe FIVE defects which may occur with main engine fuel injectors. (10)

Diesel engine fuel injectors play a vital role in efficient combustion, and several defects can arise during operation, affecting performance and potentially causing engine problems. Here are five common injector defects:

1. **Sticking or Leaking Injector Needle Valve:**

- **Description:** Wear or deposits on the needle valve can cause it to stick partially open or leak even when closed.
- **Effect:** This disrupts the precise metering of fuel intended by the injection system.
- **Symptoms:**
  - **Reduced Engine Power:** Poor fuel delivery due to a sticking or leaking valve can lead to a noticeable decrease in engine power output.
  - **Increased Fuel Consumption:** Incomplete combustion caused by improper fuel metering can result in higher fuel consumption.
  - **Black Smoke Emission:** Excessive black smoke emission from the exhaust can indicate poor fuel atomization and incomplete combustion.
  - **Rough Engine Running:** Uneven fuel delivery due to a faulty injector can cause rough engine operation and vibrations.

2. **Blocked or Worn Nozzle Orifices:**

- **Description:** Deposits from the fuel or wear on the tiny orifices at the injector tip can restrict fuel flow and disrupt the spray pattern.
- **Effect:** This hinders proper atomization of the fuel, essential for efficient air-fuel mixing and combustion.

- **Symptoms:** Similar to a sticking/leaking valve, blocked or worn orifices can lead to reduced power, increased fuel consumption, black smoke emission, and rough engine running.

3. **Internal Leakage:**

- **Description:** Worn seals or internal components within the injector can allow internal leakage, bypassing the metering process.
- **Effect:** This disrupts the intended fuel delivery and pressure within the injector.
- **Symptoms:** The symptoms can be similar to those mentioned above, but the severity might vary depending on the extent of the internal leakage.

4. **Faulty Solenoid Valve (if applicable):**

- **Description:** In electronically controlled injectors, a faulty solenoid valve might not properly actuate the needle valve.
- **Effect:** This disrupts the precise timing of the fuel injection process as controlled by the engine management system.
- **Symptoms:** Depending on the nature of the solenoid valve malfunction, it could lead to:
  - **Engine Starting Issues:** In severe cases, a faulty solenoid valve might prevent the injector from opening entirely, leading to difficulty starting the engine.
  - **Erratic Engine Operation:** Improper injection timing due to the solenoid valve malfunction can cause erratic engine behavior and performance issues.

5. **Degraded Spray Pattern:**

- **Description:** Over time, wear on the injector nozzle tip or internal components can cause the fuel spray pattern to deteriorate.
- **Effect:** This can lead to uneven fuel distribution within the cylinder, hindering optimal combustion.
- **Symptoms:** The symptoms might be similar to those mentioned previously, such as reduced power, increased fuel consumption, and potentially rough engine running. However, they might be less pronounced compared to other injector defects.

These injector defects highlight the importance of regular maintenance practices, including cleaning or replacing injectors as per manufacturer's recommendations. This helps ensure optimal engine performance, prevent further damage from occurring, and maintain efficient and clean operation.

April 2022

April 2022 MDE

6. (a) Sketch a section through the nozzle of a fuel injector, labelling the MAIN components. (6)

(b) Explain what is meant by EACH of the following terms:

(i) atomisation; (2)

(ii) penetration. (2)

(a) Fuel Injector Nozzle Cross-Section and Main Components:

A typical diesel fuel injector nozzle has several key components arranged in a precise manner to achieve optimal fuel atomization and delivery. Here's a breakdown of a cross-section and the main components:

1. **Body:** The main housing of the injector nozzle, typically made from high-pressure resistant steel.
2. **Sac (Optional):** A small chamber within the body that can hold a reserve of fuel for improved injection response. Not all injectors have a sac design.
3. **Needle Valve:** A spring-loaded valve that controls the opening and closing of the injector, allowing pressurized fuel to flow through.
4. **Nozzle Seat:** A precisely machined surface within the body that forms a tight seal with the needle valve when closed.
5. **Spring:** A spring that applies pressure to the needle valve, keeping it closed until the fuel pressure overcomes the spring force.
6. **Nozzle Tip:** The tip of the injector where the fuel exits. It contains several tiny orifices (holes) arranged in a specific pattern.

Fuel Flow Path:

- Fuel under high pressure enters the injector body.
- When the pressure overcomes the spring force, the needle valve lifts, allowing fuel to flow through the sac (if present) and past the nozzle seat.
- The fuel exits the injector through the tiny orifices at the tip, where it's broken up into a fine mist (atomization) due to the high pressure and the design of the orifices.

(b) Explanation of Terms:

(i) Atomization:

In the context of fuel injection, atomization refers to the process of breaking up a liquid fuel into a fine mist of tiny droplets. This is crucial for efficient combustion in diesel engines. Here's why:

- **Increased Surface Area:** By breaking the fuel into a fine mist, the total surface area of the fuel is significantly increased. This allows for better mixing with the air within the engine cylinder, promoting more complete combustion.
- **Improved Combustion Efficiency:** Better air-fuel mixing due to proper atomization leads to more efficient combustion, resulting in higher power output and lower emissions.
- **Controlled Spray Pattern:** The design of the injector nozzle tip and orifices determines the spray pattern of the atomized fuel. This pattern ensures proper distribution of fuel within the cylinder for optimal combustion throughout the power stroke.

(ii) Penetration:

Penetration refers to the ability of the atomized fuel spray to travel a specific distance within the engine cylinder after injection. Here's its importance:

- **Reaching Combustion Chamber:** The fuel spray needs to penetrate adequately to reach all areas of the combustion chamber, ensuring proper mixing with air throughout the cylinder volume.
- **Optimum Mixing:** Good penetration allows for better air-fuel mixing even in larger cylinders, promoting efficient combustion.
- **Impact on Power Output:** Proper penetration helps ensure all the injected fuel participates in the combustion process, leading to optimal power output from the engine.

The design of the injector nozzle, particularly the size and arrangement of the orifices, plays a crucial role in achieving both proper atomization and desired penetration characteristics for efficient fuel delivery and combustion.

Oct 2021

October 2021 MDE

4. With reference to Bosch or jerk type fuel injection pumps:

(a) describe how the delivered quantity of fuel oil may be controlled; (6)

(b) explain the purpose of the delivery valve. (4)

Bosch (Jerk Type) Fuel Injection Pump: Fuel Delivery Control and Delivery Valve

(a) Controlling Fuel Delivery Quantity:

In Bosch or jerk-type fuel injection pumps, the delivered quantity of fuel oil is controlled by the interplay of three main components:

1. **Plunger and Helical Groove:**
- The pump has a plunger that moves reciprocally within a barrel.
- The key element for fuel metering is a helical groove machined on the plunger's surface.
2. **Spill Port and Control Rack:**
- The barrel has a spill port that allows pressurized fuel to return to the suction side of the pump when uncovered.
- A control rack, connected to the engine governor or electronic control unit, positions a sleeve around the plunger.
3. **Operating Principle:**
- During the upward stroke of the plunger, fuel gets drawn into the pump chamber through an inlet port.
- As the plunger continues to move up, the helical groove on its surface progressively covers the spill port.
- The duration for which the spill port remains covered determines the amount of fuel trapped in the pump chamber for injection.
- The control rack position influences the orientation of the plunger and the helical groove relative to the spill port.
  - By moving the rack, the governor or ECU can adjust the position of the helical groove, thereby controlling how long the spill port remains covered during the plunger's stroke.
  - A shorter coverage time (less fuel trapped) corresponds to a lower fuel delivery. Conversely, a longer coverage time results in a higher fuel delivery.

(b) Purpose of the Delivery Valve:

The delivery valve, also known as the discharge valve or pressure relief valve, plays a critical role in ensuring proper fuel injection pressure and preventing internal damage:

- **Location:** The delivery valve is typically located at the outlet of the pump chamber, directly connected to the high-pressure fuel line leading to the injectors.
- **Function:** The valve remains closed by a spring until the pressure within the pump chamber exceeds a predetermined level.
- **Operation:** As the plunger moves upwards and the spill port closes, the fuel pressure within the chamber builds up.
- **Opening and Injection:** Once the pressure reaches the set limit, the delivery valve opens, allowing the high-pressure fuel to flow through the line and reach the injectors for fuel injection.
- **Safety Function:** The delivery valve acts as a safety mechanism by preventing excessive pressure buildup within the pump and fuel lines that could lead to component damage.
- **Closing and Cycle Repeat:** After fuel injection occurs and the pressure drops, the delivery valve closes again, and the cycle repeats for the next injection event.

The delivery valve ensures that the fuel injection pump operates within the designated pressure range, delivering pressurized fuel to the injectors for efficient engine operation while safeguarding the system from excessive pressure.

Oct 2020

October 2020 MDE

4. With reference to scroll type fuel injection pumps:

(a) describe how the delivered quantity of fuel may be varied; (5)

(b) explain the purpose of the delivery valve; (3)

(c) describe how fuel oil is prevented from spraying out if the high pressure pipe fails in service. (2)

Scroll Type Fuel Injection Pump:

(a) Varying Delivered Fuel Quantity:

Unlike jerk-type pumps, scroll type pumps achieve fuel metering through a fundamentally different mechanism. Here's how the delivered fuel quantity is varied:

- **Scroll Design:** The core of the pump is a spiral-shaped scroll housed within a cylindrical body.
- **Inner Rotor:** An eccentrically positioned inner rotor with blades rotates within the scroll.
- **Fuel Chambers:** As the rotor rotates, crescent-shaped cavities are formed between the rotor blades and the scroll wall, acting as fuel chambers.

Fuel Metering Principle:

1. **Fuel Intake:** During rotation, the expanding volume of the fuel chambers on the suction side draws fuel in through an inlet port.
2. **Fuel Trapping and Compression:** As the rotor continues to rotate, the scroll's shape progressively reduces the volume of the fuel chambers, trapping and compressing the fuel.
3. **Delivery Valve and Outlet Port:** A delivery valve is located at the outlet of the pump, connected to the high-pressure fuel line.

4. **Fuel Delivery:** When the pressure in a chamber exceeds the delivery valve's opening pressure, the valve opens, allowing the high-pressure fuel to flow through the line to the injector.
5. **Fuel Delivery Control:** The amount of fuel delivered per cycle is primarily determined by the geometry of the scroll and the rotor. However, some designs might incorporate a bypass valve or variable control sleeve to influence the filling and discharge processes, allowing for limited adjustment of the delivered quantity.

(b) Purpose of the Delivery Valve:

Similar to jerk-type pumps, the delivery valve in a scroll type pump serves a crucial purpose:

- **Location:** The delivery valve is positioned at the outlet of the pump, separating the high-pressure fuel section from the discharge line.
- **Function:** The valve remains closed by a spring until the pressure within the pump chamber reaches a predetermined level.
- **Operation:** As the trapped fuel gets compressed during rotor rotation, the pressure within the chamber builds up.
- **Opening and Injection:** Once the pressure reaches the set limit, the delivery valve opens, allowing the high-pressure fuel to flow through the line towards the injectors for fuel injection.
- **Safety Function:** The delivery valve acts as a safety mechanism by preventing excessive pressure buildup within the pump and fuel lines that could lead to component damage.
- **Closing and Cycle Repeat:** After fuel injection occurs and the pressure drops below the set point, the delivery valve closes again, and the cycle repeats for the next injection event.

(c) Preventing Fuel Spray in Case of High-Pressure Pipe Failure:

Scroll type pumps typically incorporate a safety feature to prevent uncontrolled fuel spraying in case of a high-pressure pipe failure:

- **Overflow Valve or Bypass Port:** Some designs might use an overflow valve or bypass port located within the pump housing.
- **Operation:** In case of a high-pressure pipe rupture, the sudden pressure drop would cause the overflow valve to open or fuel to bypass an internal passage.
- **Fuel Return:** This allows the pressurized fuel to return back to the pump's low-pressure side (suction side) through this overflow or bypass mechanism.
- **Preventing Spray:** By redirecting the fuel back to the low-pressure side, the system prevents uncontrolled spraying of high-pressure fuel, minimizing the risk of fire or injury.

Additional Notes:

- Scroll type pumps are generally simpler in design compared to jerk-type pumps.
- Their flow rate is typically less sensitive to variations in engine speed compared to jerk pumps.
- However, their fuel metering capabilities might be less precise than those of jerk-type pumps.

FUEL COMBUSTION

Oct 2023

October 2023 MDE

1. (a) With reference to the combustion of fuel, explain EACH of the following terms:

   (i) atomisation; (3)

   (ii) penetration; (2)

   (iii) compression ratio. (1)

   (b) State the factors which influence the terms explained in part (a). (4)

april 2022

April 2022 MDE

1. (a) With reference to the combustion of fuel, explain EACH of the following terms:

   (i) atomisation; (3)

   (ii) penetration; (2)

   (iii) compression ratio. (1)

   (b) State the factors which influence the terms explained in part (a). (4)

feb 2020

February 2020 MDE

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   (i) atomisation; (3)

   (ii) penetration; (2)

   (iii) compression ratio. (1)

   (b) State the factors which influence the terms explained in part (a). (4)

oct 2018

October 2018 MDE

1. (a) With reference to the combustion of fuel, explain EACH of the following terms:

   (i) atomisation; (3)

   (ii) penetration; (2)

   (iii) compression ratio. (1)

   (b) State the factors which influence the terms explained in part (a). (4)

(a) Combustion Terms Explained:

In the context of diesel engine combustion, several key terms play a crucial role in optimizing the process:

(i) Atomization:

- **Definition:** Atomization refers to the process of breaking up a liquid fuel into a fine mist of tiny droplets.
- **Importance:** Proper atomization increases the surface area of the fuel significantly. This allows for better mixing with the compressed air within the engine cylinder, promoting more complete and efficient combustion.
- **Benefits:**
  - Increased Power Output: Better air-fuel mixing leads to more efficient combustion, resulting in higher power output from the engine.
  - Reduced Emissions: Proper atomization contributes to lower emissions of pollutants like soot and NOx by ensuring complete combustion of the fuel.

(ii) Penetration:

- **Definition:** Penetration refers to the ability of the atomized fuel spray to travel a specific distance within the engine cylinder after injection.
- **Importance:** The fuel spray needs to penetrate adequately to reach all areas of the combustion chamber, ensuring proper mixing with air throughout the cylinder volume.
- **Impact:**
  - Efficient Mixing: Good penetration allows for better air-fuel mixing even in larger cylinders, promoting efficient combustion.
  - Power Output: Proper penetration helps ensure all the injected fuel participates in the combustion process, leading to optimal power output.
  - Incomplete Combustion: Insufficient penetration can lead to some fuel droplets not mixing well with air, resulting in incomplete combustion and potentially higher emissions.

(iii) Compression Ratio:

- **Definition:** The compression ratio is a dimensionless parameter that compares the volume of the cylinder with the air-fuel mixture at the bottom of the intake stroke (maximum volume) to the volume of the compressed air-fuel mixture at the top of the compression stroke (minimum volume).

- **Importance:** A higher compression ratio signifies a greater compression of the air-fuel mixture, leading to a higher temperature and pressure within the cylinder.
- **Impact on Combustion:**
  - Improved Efficiency: Higher compression temperatures promote more efficient ignition and combustion of the fuel, leading to better fuel economy.
  - Increased Power Output: The higher pressure in the cylinder during the power stroke translates to greater force acting on the piston, resulting in increased engine power output.
  - Trade-offs: While beneficial, excessively high compression ratios can lead to problems like engine knocking and the need for higher quality fuels to avoid pre-ignition.

(b) Factors Influencing the Combustion Terms:

(i) Atomization:

- **Injector Nozzle Design:** The size and arrangement of orifices in the injector nozzle tip significantly influence how finely the fuel is atomized.
- **Fuel Injection Pressure:** Higher injection pressure generally leads to finer atomization due to the increased force breaking up the fuel droplets.
- **Fuel Properties:** The viscosity and volatility of the fuel can affect its atomization characteristics.

(ii) Penetration:

- **Injector Nozzle Design:** The spray pattern and angle of the injector nozzle can influence how far the fuel spray penetrates within the cylinder.
- **Injection Timing:** The timing of fuel injection relative to the piston position can affect the available space for the spray to penetrate before combustion starts.
- **Engine Speed:** Higher engine speeds can lead to turbulence within the cylinder, potentially affecting the penetration of the fuel spray.

(iii) Compression Ratio:

- **Engine Design:** The engine's physical design, particularly the cylinder head and piston crown shapes, determines the maximum achievable compression ratio.
- **Clearance Volume:** The volume remaining above the piston at top dead center (TDC) of the compression stroke is called the clearance volume. A smaller clearance volume contributes to a higher compression ratio.
- **Fuel Characteristics:** The octane rating of the fuel determines its resistance to autoignition. Higher compression ratios typically require fuels with higher octane ratings to avoid pre-ignition.