Internal Combustion Engine 1

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Combustion in Compression-Ignition Engines

Combustion in CI Engines: Overview

In CI engines, air is compressed to a high temperature and pressure, and fuel is injected into this compressed air. Key differences from SI engines:

- SI engines use a homogeneous air-fuel mixture ignited by a spark.
- CI engines use only air, with fuel injected into highly compressed air.

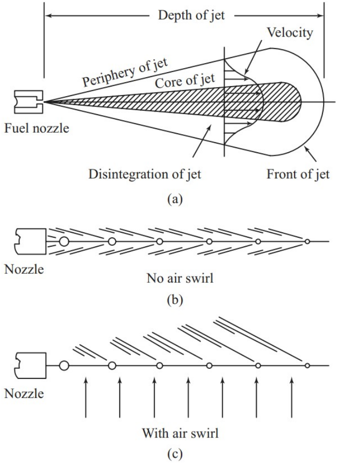
Fuel Injection and Atomization

CI Engine Combustion Process:

- Fuel is injected through one or more jets.
- Disintegration of fuel jet into core and spray envelope.

Schematic Representation:

- (a) Disintegration of fuel jet
- (b) No air swirl nozzle
- (c) With air swirl nozzle



Evaporation and Ignition

Fuel Droplet Behavior:

- Liquid fuel droplets absorb latent heat of vaporization.
- Delay before vapor reaches autoignition temperature.

Ignition Delay:

- Mixture must reach autoignition temperature.
- A delay occurs before ignition takes place.

Air Swirl and Combustion

Importance of Air Swirl:

- Provides orderly movement of air with a specific direction.
- Assists in breaking up fuel jet and intermixing burned and unburned portions.

Comparison with SI Engines:

- SI engines have disorderly turbulence.
- CI engines require controlled swirl for efficient combustion.

Combustion Characteristics

Combustion Differences:

- SI engines: Single flame front, slow pressure rise.
- CI engines: Multiple ignition points, rapid pressure rise.

Air-Fuel Ratio (A/F Ratio):

- SI engines: Stoichiometric A/F ratio from no load to full load.
- CI engines: Variable A/F ratio depending on load.

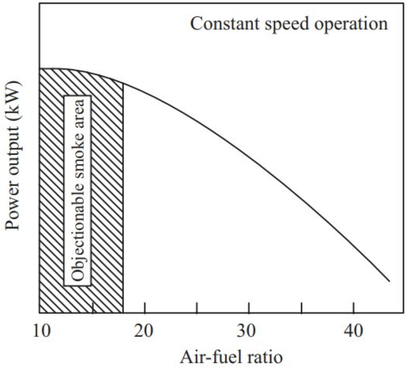
Effect of A/F Ratio on CI Engine Performance

A/F Ratio Variations:

- CI engines operate with excess air (15-40%).
- The A/F ratio affects power output and smoke production.

Power Output and Smoke:

- Lean mixtures improve thermal efficiency but reduce power.
- Rich mixtures can produce black smoke.



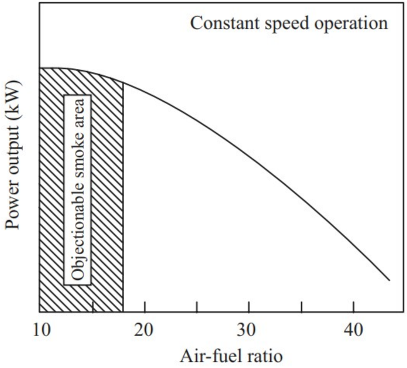
Impact of A/F Ratio on Power Output

Power Output Curve:

- Power output varies with A/F ratio.
- Optimal A/F ratio provides maximum power output.

Graph Analysis:

- Shaded area represents objectionable smoke region.
- A/F ratio affects engine efficiency and smoke production.



CI Engine Design Considerations

Design Objectives:

- Achieve a balance between thermal efficiency and power output.
- Maintain a manageable level of exhaust smoke.

Design Strategies:

- Use excess air to avoid black smoke.
- Optimize A/F ratio for different operating conditions.

Summary

Key Points:

- CI engines rely on high compression and fuel injection for combustion.
- Air swirl and proper A/F ratio are crucial for efficient combustion.
- Engine performance is affected by the A/F ratio and excess air levels.

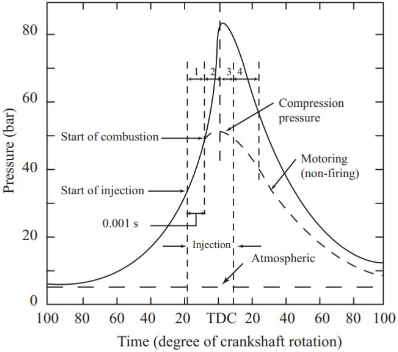
Combustion Stages in CI Engines

Stages of Combustion in CI Engines

- The combustion in a CI engine occurs in four main stages:
  - Ignition Delay Period
  - Period of Rapid Combustion
  - Period of Controlled Combustion
  - Period of After-Burning
- Each stage plays a crucial role in the overall combustion process and impacts engine performance.

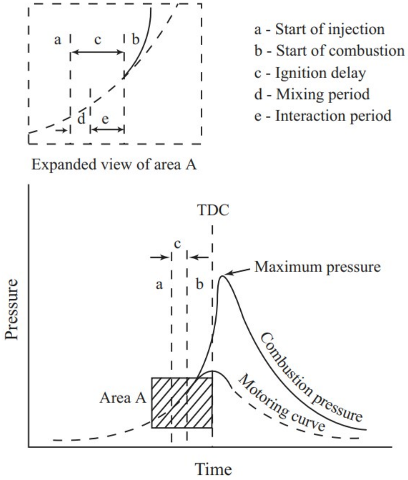
Ignition Delay Period

- The ignition delay period, also called the preparatory phase, is the time between the start of fuel injection and the point where the pressure-time curve separates from the motoring curve.
- During this period, some fuel has already been admitted but has not yet ignited.
- This period greatly influences engine design and performance, including combustion rate, knocking, starting ability, and exhaust smoke.



Pressure-Time Diagram

- The pressure-time diagram illustrates the ignition delay period.
- Key points include:
  - **Start of Injection**: Beginning of fuel injection.
  - **Start of Combustion**: Point where the pressure curve separates from the motoring curve.



Physical Delay

- Physical delay is the time between the start of fuel injection and the attainment of chemical reaction conditions.
- During this period:
  - Fuel atomizes and vaporizes.
  - It mixes with air and reaches its self-ignition temperature.
- Factors affecting physical delay include fuel type, injection pressure, combustion chamber temperature, and turbulence.

Chemical Delay

- Chemical delay is the time during which the chemical reactions start and accelerate until ignition occurs.
- This delay is generally longer than physical delay and is influenced by the surrounding temperature.
- At higher temperatures, chemical reactions are faster, making the physical delay longer than the chemical delay.
- In CI engines, ignition lag is usually shorter than the duration of injection.

Summary

- Ignition delay in CI engines involves both physical and chemical delays.
- Physical delay covers atomization, vaporization, and temperature rise.
- Chemical delay is influenced by temperature and affects the overall ignition process.
- Understanding these delays is crucial for improving engine performance and design.

Period of Rapid Combustion

- Rapid combustion occurs immediately after the ignition delay period with a significant rise in pressure.
- The rate of heat release is maximum during this phase.
- The pressure achieved depends on the duration of the delay period.

Period of Controlled Combustion

- The controlled combustion phase follows rapid combustion.
- Fuel droplets burn faster due to high temperature and pressure, with any further pressure rise controlled by the injection rate.

Period of After-Burning

- After-burning involves the combustion of unburnt and partially burnt fuel particles.
- This phase starts from the maximum cycle temperature and continues during the expansion stroke.
- Duration typically corresponds to 70-80 degrees of crank travel from TDC.

Factors Affecting the Delay Period

Factors Affecting the Delay Period

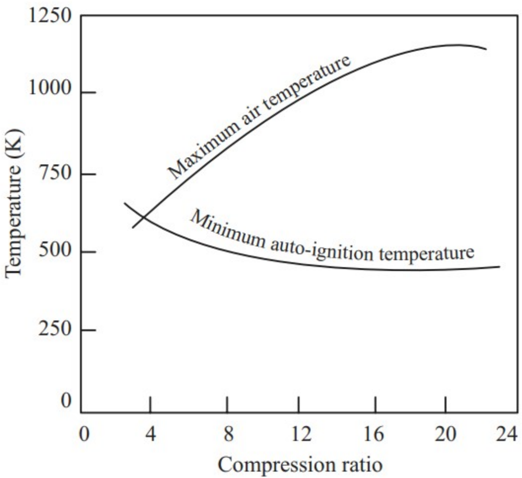
- The delay period in CI engines is influenced by several factors:

- Compression Ratio
- Engine Speed
- Output
- Atomization of Fuel and Duration of Injection
- Injection Timing
- Quality of the Fuel
- Intake Temperature
- Intake Pressure

- Each of these factors impacts the delay period and the overall combustion process.

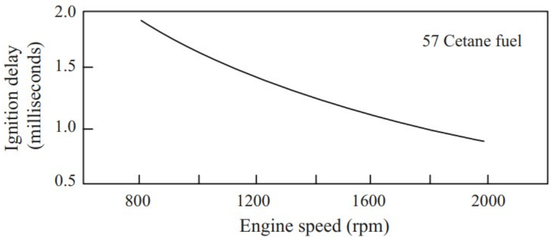
Compression Ratio

- Increasing the compression ratio raises the compression temperature of the air.
- Higher compression ratios decrease the minimum auto-ignition temperature of the fuel.
- This results in a shorter delay period and improved combustion efficiency.



Engine Speed

- Increasing engine speed decreases the delay period in milliseconds due to reduced heat loss.
- However, the delay period in degrees of crank travel increases at higher speeds.
- More fuel is present at high speeds, resulting in a higher rate of pressure rise.



Output

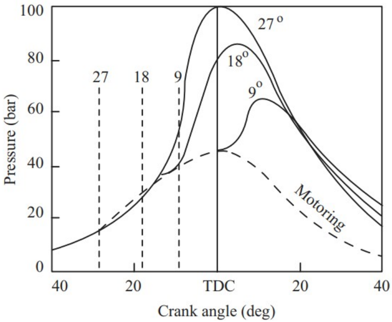
- Increased engine output decreases the air-fuel ratio and operating temperatures.
- This results in a reduced delay period.
- While the rate of pressure rise remains unaffected, the peak pressure may be higher.

Atomization and Duration of Injection

- Higher fuel-injection pressures improve atomization, reducing ignition delay.
- Smaller droplet sizes increase the surface area for ignition, potentially increasing pressure rise.
- Optimal droplet size and fuel delivery law are crucial for effective combustion.

Injection Timing

- Early injection timing increases the delay period due to lower pressure and temperature at injection.
- Optimal injection advance generally ranges around 20° before TDC.
- Proper timing is critical for efficient combustion and engine performance.
    - The figure illustrates the effect of injection timing on pressure variation.



Quality of Fuel

- Fuel properties such as self-ignition temperature, cetane number, volatility, latent heat, viscosity, and surface tension affect the delay period.
- Fuels with lower self-ignition temperatures and higher cetane numbers reduce the delay period.
- Fuel quality impacts engine smoothness and overall performance.

Intake Temperature

- Higher intake temperatures increase the compressed air temperature, reducing the delay period.
- Preheating the intake air could reduce volumetric efficiency and power output.
- Managing intake temperature is a balance between reducing delay and maintaining engine efficiency.

Intake Pressure

- Increasing intake pressure or supercharging lowers the auto-ignition temperature.
- This reduces the delay period but increases peak pressure due to higher compression pressure.
- Optimizing intake pressure enhances engine performance without causing excessive peak pressures.

Summary of Factors

- Compression Ratio: Increases temperature, decreases delay period.
- Engine Speed: Reduces delay period in milliseconds, affects delay in crank degrees.
- Output: Reduces delay period, may increase peak pressure.
- Atomization and Injection Timing: Affects delay and pressure rise.
- Fuel Quality, Intake Temperature, and Pressure: Influence delay period and combustion efficiency.

Impact on Engine Performance

- Optimizing the factors affecting the delay period leads to improved engine performance and efficiency.
- Understanding and managing these factors is crucial for designing efficient and reliable CI engines.
- Balancing various parameters helps achieve desired combustion characteristics and overall engine performance.

End of Lecture 19

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