Internal Combustion Engine 1

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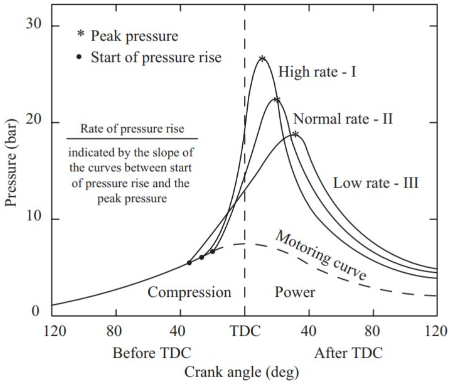
Rate of Pressure Rise

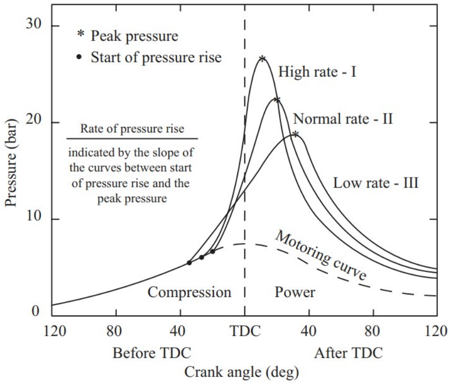
Rate of Pressure Rise

- The rate of pressure rise influences:
  - Peak pressure developed
  - Power output
  - Smoothness of force transmission to the piston
- Mainly dependent on the mass rate of combustion.



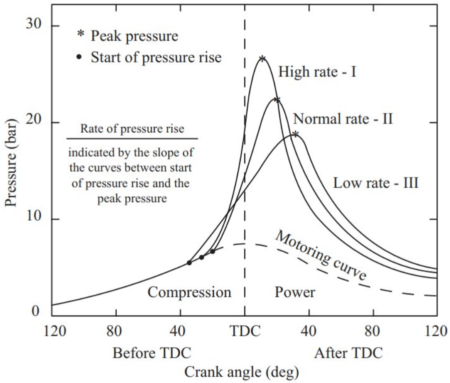
Effects of Combustion Rate

- Curve I: High rate of combustion, leading to:
  - Higher rate of pressure rise
  - Higher peak pressure closer to TDC
  - Increased power output



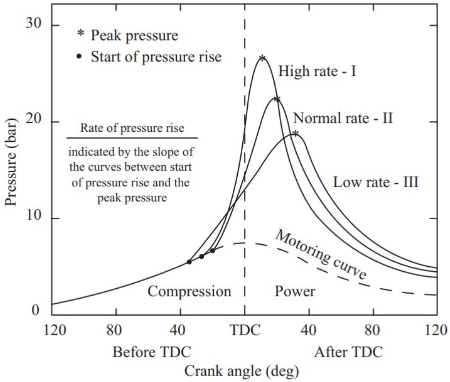
Effects of Combustion Rate

- Curve II: Normal rate of combustion
- Curve III: Low rate of combustion, leading to:
  - Longer combustion time
  - Lower peak pressure
  - Possible rough engine operation



Compromise in Engine Design

- Optimal design targets achieving:
  - Approximately half of the maximum pressure by TDC
  - Balancing peak pressure with power stroke effectiveness
  - Minimizing roughness and knocking
- This balance ensures smooth engine operation while maintaining power output.



Abnormal Combustion

Abnormal Combustion

- Normal Combustion:
  - Flame travels uniformly across the combustion chamber
  - Spark initiates combustion in a controlled manner
- Abnormal Combustion:
  - Deviations from normal combustion conditions
  - May result in knocking or preignition
  - Causes loss of performance and possible engine damage

Phenomenon of Knock in SI Engines

Combustion Process in SI Engines

- In a spark-ignition engine, combustion is initiated between the spark plug electrodes and spreads across the combustible mixture.
- A definite flame front, which separates the fresh mixture from the products of combustion, travels from the spark plug to the other end of the combustion chamber.
- Heat-release due to combustion increases the temperature and consequently the pressure of the burned part of the mixture above those of the unburned mixture.

Pressure and Temperature Effects

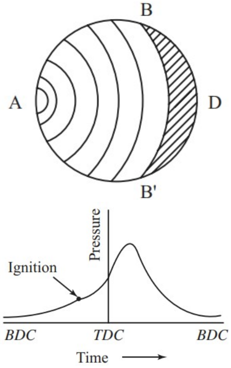
- To effect pressure equalization, the burned part of the mixture expands, compressing the unburned mixture adiabatically, thereby increasing its pressure and temperature.
- This process continues as the flame front advances through the mixture, further increasing the temperature and pressure of the unburned mixture.

Phenomenon of Knock

- If the temperature of the unburnt mixture exceeds the self-ignition temperature of the fuel and remains at or above this temperature during the period of preflame reactions (ignition lag), spontaneous ignition or autoignition occurs at various pinpoint locations.
- This phenomenon is called knocking.
- The process of autoignition leads towards engine knock.

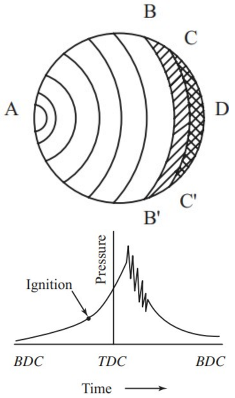
Normal Combustion Process

- In normal combustion, the flame travels from point A (spark plug) towards point D.
- The advancing flame compresses the end charge BB' D, raising its temperature.
- Temperature rises due to compression and heat transfer from the flame front.
- If end charge doesn't reach self-ignition temperature, it burns normally.



Abnormal Combustion (Knocking)

- If end charge reaches autoignition temperature, it leads to knocking.
- Flame advances partially, and autoignition occurs in the remaining charge.
- Collision of flame fronts generates severe pressure pulses.
- Pressure pulses cause vibrations in the gas and chamber walls (frequency of about 5000 Hz).



Types of Vibrations Due to Autoignition

- When autoignition occurs, two types of vibrations may be produced.
- In one case, a large amount of mixture may autoignite, leading to a rapid increase in pressure throughout the combustion chamber, causing a direct blow on the engine structure.
- The human ear can detect the resulting thudding sound and noise from free vibrations of the engine parts.
- In the other case, large pressure differences in the combustion chamber cause gas vibrations, which can force the walls of the chamber to vibrate at the same frequency as the gas, producing an audible sound.

Impact of Knocking

- Knocking impacts engine performance, causing noise and potential damage.
- Pressure differences due to knocking cause vibrations in the engine components.
- These vibrations can lead to increased heat loss and engine wear.
- Knocking is detectable by pressure transducers connected to oscilloscopes.

Detection of Knocking

- Knocking is often judged by audible sound (thudding) and engine vibration.
- Scientific detection involves using a pressure transducer to measure pressure changes.
- The output is analyzed using an oscilloscope to observe pressure-time traces.
- Typical traces include variations from normal combustion to knocking combustion.

Knock Limited Parameters

Knock Limited Parameters

- The aim of the engine designer should be to reduce the tendency of knocking in the engine.
- In this context, certain knock limited parameters are important to consider.
  - **Knock Limited Compression Ratio**
  - **Knock Limited Inlet Pressure**
  - **Knock Limited Indicated Mean Effective Pressure (Klimep)**

Knock Limited Compression Ratio

- **Knock Limited Compression Ratio:**
  - Obtained by increasing the compression ratio on a variable compression ratio engine until incipient knocking is observed.
  - Any change in operating conditions, such as fuel-air ratio or engine design, that increases the knock limited compression ratio reduces the tendency towards knocking.

Knock Limited Inlet Pressure

- **Knock Limited Inlet Pressure:**
  - Inlet pressure can be increased by opening the throttle or increasing supercharger delivery pressure until incipient knock is observed.
  - An increase in knock limited inlet pressure indicates a reduction in knocking tendency.

Knock Limited Indicated Mean Effective Pressure (Klimep)

- **Knock Limited Indicated Mean Effective Pressure (Klimep):**
  - Klimep is the indicated mean effective pressure measured at incipient knock.
  - This parameter, along with the corresponding fuel consumption, is of great practical interest.
- A useful measure of knocking tendency, called the **performance number**, is developed from Klimep.

Performance Number

- **Performance Number:**
  - Defined as the ratio of Klimep with the fuel in question to Klimep with iso-octane at constant inlet pressure.
  - This number relates to octane number and extends the octane scale beyond 100 for fuels superior to iso-octane.

Relative Performance Number

- **Relative Performance Number (rpn):**
  - Defined as:

$$rpn = \frac{\text{Actual Performance number}}{\text{Performance number corresponding to the imep of 100}}$$

  - Provides a simplified measure of performance.

Effect of Engine Varaibles on Knock

Effect of Engine Variables on Knock

- Four major factors are involved in either producing or preventing knock:
  - Temperature
  - Pressure
  - Density of the unburned charge
  - Time factors
- Temperature, pressure, and density are closely interrelated and are grouped together.
- Time factors are considered in a separate group.

Density Factors

Density Factors

- Reducing the temperature of the unburned charge reduces the possibility of knocking by lowering the temperature of the end charge for autoignition.
- Reducing the density of the charge tends to reduce knocking by providing lower energy release.
- The following parameters, connected with temperature, pressure, and density factors, affect the possibility of knocking:

Compression Ratio

- Compression ratio determines the pressure and temperature at the beginning of the combustion process.
- Increasing compression ratio:
    - Increases pressure and temperature at the end of the compression stroke.
    - Decreases ignition lag of the end gas, increasing the tendency for knocking.
    - Increases the density of the charge, enhancing preflame reactions and knocking tendency.
    - This increase in knocking tendency limits the compression ratio to a lower value.

Mass of Inducted Charge & Inlet Temperature of the Mixture

- **Mass of Inducted Charge:**
  - Reduction in the mass of inducted charge by throttling or reducing supercharging decreases temperature and density at ignition, reducing knocking.
- **Inlet Temperature of the Mixture:**
  - Increase in inlet temperature raises compression temperature, increasing knocking tendency.
  - Lower inlet temperature is preferable to reduce knocking but should not be too low to cause starting and vaporization issues.

Combustion Chamber Wall Temperature

- **Temperature of Combustion Chamber Walls:**
  - Hot spots in the combustion chamber, particularly around the spark plug and exhaust valve, increase knocking.
  - Avoid compressing the end gas against the hottest parts to prevent knocking.

Retarding Spark Timing & Power Output of the Engine

- **Retarding Spark Timing:**
  - Retarding the spark timing moves peak pressure farther down the power stroke, reducing knocking.
  - This may affect brake torque and power output as it differs from MBT timing.
- **Decreasing the engine's power output:**
  - Lowers the temperature of the cylinder and combustion chamber walls.
  - Decreases the pressure of the charge, thereby lowering mixture and end gas temperatures.
  - This reduction in temperature and pressure lowers the tendency to knock.

Time Factors

Time Factors in Knock Reduction

- Increasing the flame speed, extending the ignition lag duration, or reducing the exposure time of the unburned mixture to autoignition conditions tends to reduce knocking.
- Several factors contribute to reducing the possibility of knocking by influencing time factors.

Turbulence

- Turbulence depends on the combustion chamber design and engine speed.
- Increasing turbulence:
    - Increases flame speed.
    - Reduces time available for the end charge to reach autoignition conditions.
    - Decreases the tendency to knock.

Engine Speed

- Increasing engine speed:
  - Increases the turbulence of the mixture.
  - Results in increased flame speed.
  - Reduces the time available for preflame reactions.
  - Hence, knocking tendency is reduced at higher speeds.

Flame Travel Distance & Engine Size

- **Flame Travel Distance:**
  - Shortening the flame travel distance reduces knocking tendency.
  - Factors: Engine size, combustion chamber size, and spark plug position.
- **Engine Size:**
  - Larger engines have a longer flame travel time, increasing knocking tendency.
  - Spark-ignition engines are generally limited to a bore size of about 150 mm to minimize knocking.

Combustion Chamber Shape

- More compact combustion chambers have shorter flame travel distances and combustion times.
- Compactness leads to better antiknock characteristics.
- Shaping the chamber to promote turbulence can further reduce knocking tendency.

Location of Spark Plug

- Central location of the spark plug minimizes flame travel and reduces knocking tendency.
- Large engines may use two or more spark plugs to further reduce flame travel and knocking.

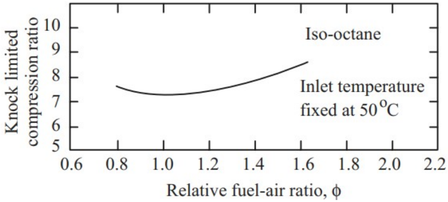
Composition Factors

Composition Factors

- Once the engine design is finalized, the fuel-air ratio and the properties of the fuel, particularly the octane rating, play a crucial role in controlling knock.

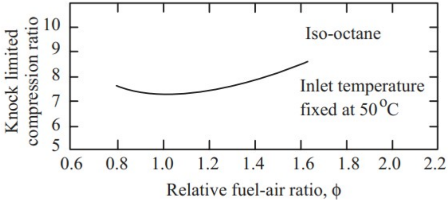
Fuel-Air Ratio

- The flame speeds are affected by the fuel-air ratio.
- Flame temperature and reaction time differ for different fuel-air ratios.
- Maximum flame temperature is obtained when $\phi \approx 1.1$ to 1.2 whereas $\phi = 1$ gives minimum reaction time for autoignition.



Knock Limited Compression Ratio

- The maximum tendency to knock occurs at the fuel-air ratio that gives minimum reaction time.
- The reaction time of the mixture is a predominant factor in knocking.
- Except at the rich end, the engine behavior follows the same pattern as the fuel-air ratio versus reaction time.



Octane Value of the Fuel

- Higher self-ignition temperature and low preflame reactivity reduce knocking tendency.
- Paraffin hydrocarbons have the maximum, and aromatic hydrocarbons the minimum tendency to knock.
- Naphthene series hydrocarbons fall between paraffins and aromatics.
- Compounds with more compact molecular structures are less prone to knock.
- Unsaturated aliphatic hydrocarbons generally have a lower knocking tendency than saturated hydrocarbons, with exceptions like ethylene, acetylene, and propylene.

Summary of Variables Affecting Knock

- The following table provides a summary of variables affecting knock in an SI engine.
- It indicates whether the various factors can be controlled by the operator.

Effect of Various Variables on Knock in SI Engines (1/3)

Increase in Variable	Major Effect on Unburned Charge	Action to Reduce Knocking	Can Operator Usually Control?
Compression Ratio	Increases temperature & pressure	Reduce	No
Mass of Charge Inducted	Increases pressure	Reduce	Yes
Inlet Temperature	Increases temperature	Reduce	In some cases

Effect of Various Variables on Knock in SI Engines (2/3)

Increase in Variable	Major Effect on Unburned Charge	Action to Reduce Knocking	Can Operator Usually Control?
Chamber Wall Temperature	Increases temperature	Reduce	Not ordinarily
Spark Advance	Increases temperature & pressure	Retard	In some cases
A/F Ratio	Increases temperature & pressure	Make very rich	In some cases

Effect of Various Variables on Knock in SI Engines (3/3)

Increase in Variable	Major Effect on Unburned Charge	Action to Reduce Knocking	Can Operator Usually Control?
Turbulence	Decreases time factor	Increase (through engine speed)	Somewhat
Engine Speed	Decreases time factor	Increase	Yes
Distance of Flame Travel	Increases time factor	Reduce	No

End of Lecture 17