Internal Combustion Engine 1

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Combustion and Combustion Chambers

Combustion

- Combustion is a chemical reaction in which certain elements of the fuel, like hydrogen and carbon, combine with oxygen, liberating heat energy and causing an increase in the temperature of the gases.
- Conditions necessary for combustion:
  - Presence of a combustible mixture.
  - Some means of initiating the process.

Combustion - cont.

- The theory of combustion is a very complex subject and has been a topic of intensive research for many years.
- Despite this, not much knowledge is available concerning the phenomenon of combustion.
- The process of combustion in engines generally takes place in:
  - Homogeneous fuel vapor-air mixture.
  - Heterogeneous fuel vapor-air mixture.

Homogeneous Mixture

Homogeneous Mixture in Spark-Ignition Engines

- In spark-ignition engines, a nearly homogeneous mixture of air and fuel is formed in the carburetor.
- This mixture is formed outside the engine cylinder.
- Combustion is initiated inside the cylinder at a particular instant towards the end of the compression stroke.
- The flame front spreads over a combustible mixture with a certain velocity.
- In a homogeneous gas mixture, the fuel and oxygen molecules are more or less uniformly distributed.

Flame Front and Propagation

- Once the fuel vapor-air mixture is ignited, a flame front appears and rapidly spreads through the mixture.
- Flame propagation is caused by heat transfer and diffusion of burning fuel molecules from the combustion zone to the adjacent layers of unburnt mixture.
- The flame front is a narrow zone separating the fresh mixture from the combustion products.
- The velocity with which the flame front moves with respect to the unburned mixture, in a direction normal to its surface, is called the normal flame velocity.

Flame Speed and Equivalence Ratio

- In a homogeneous mixture with an equivalence ratio, ϕ (the ratio of the actual fuel-air ratio to the stoichiometric fuel-air ratio) close to 1.0, the flame speed is normally of the order of 40 cm/s.
- In a spark-ignition engine, the maximum flame speed is obtained when ϕ is between 1.1 and 1.2, i.e., when the mixture is slightly richer than stoichiometric.
- If the equivalence ratio is outside this range, the flame speed drops rapidly to a low value.

Effects of Low Flame Speed

- When the flame speed drops to a very low value, the heat loss from the combustion zone becomes equal to the amount of heat released due to combustion, and the flame gets extinguished.
- It is preferable to operate the engine within an equivalence ratio of 1.1 to 1.2 for proper combustion.
- By introducing turbulence and incorporating proper air movement, the flame speed can be increased in mixtures outside the optimal equivalence ratio range.

Heterogeneous Mixture

Combustion in Heterogeneous Gas Mixtures

- In a heterogeneous gas mixture, the rate of combustion is determined by the velocity of mutual diffusion of fuel vapors and air.
- The rate of chemical reaction is of minor importance.
- Self-ignition or spontaneous ignition of the fuel-air mixture, at high temperatures developed due to higher compression ratios, is crucial in determining combustion characteristics.

Ignition in Heterogeneous Mixtures

- Combustion can occur in an overall lean mixture in heterogeneous mixtures.
- Local zones exist where the equivalence ratio ϕ varies between 1.0 and 1.2, corresponding to the maximum rate of chemical reaction.
- Ignition starts in these zones, and the flame helps burn fuel in adjoining zones with a leaner mixture.

Combustion in Rich Zones

- In zones where the mixture is rich, combustion occurs due to the high temperature produced by combustion initiated in zones where ϕ is 1.0 to 1.2.
- This process ensures that even in a heterogeneous mixture, efficient combustion can be achieved across different mixture zones.

Combustion in Spark-Ignition Engines

Combustion in Spark-Ignition Engines

- In a conventional spark-ignition engine:
  - Fuel and air are homogeneously mixed in the intake system.
  - The mixture is inducted through the intake valve into the cylinder.
  - It mixes with residual gases and is then compressed.
- Combustion is initiated towards the end of the compression stroke by an electric discharge at the spark plug.

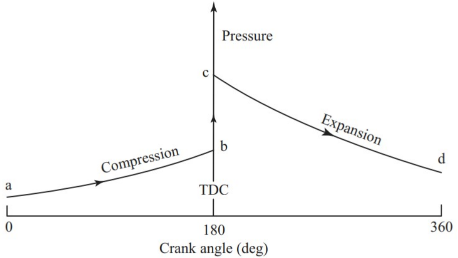
Propagation of Combustion

- A turbulent flame develops following ignition and propagates through:
  - The premixed charge of fuel and air.
  - The residual gas in the clearance volume.
  - Until it reaches the combustion chamber walls.
- Combustion in the SI engine may be broadly divided into two general types:
  - Normal combustion.
  - Abnormal combustion.

Stages of Combustion in SI Engines

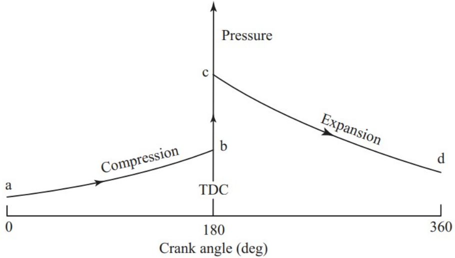
Stages of Combustion in SI Engines

- A typical theoretical pressure-crank angle diagram during:
  - Compression (a $\rightarrow$ b)
  - Combustion (b $\rightarrow$ c)
  - Expansion (c $\rightarrow$ d)
- In an ideal engine:
  - The entire pressure rise during combustion takes place at constant volume, i.e., at TDC.



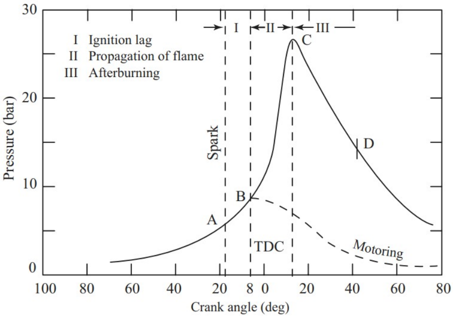
Combustion Stages According to Sir Ricardo

- In an actual engine, this ideal scenario does not occur.
- Sir Ricardo describes the combustion process in an SI engine as consisting of three stages.



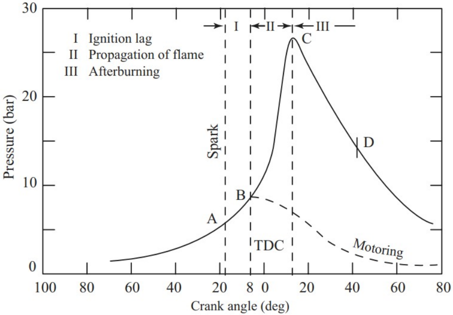
Details of Combustion Stages

- The pressure variation due to combustion in a practical engine is shown in the diagram.
- In the pressure variation diagram:
  - Point A: Passage of spark (say 20° bTDC)
  - Point B: Beginning of pressure rise (say 8° bTDC)
  - Point C: Attainment of peak pressure



Details of Combustion Stages

- Thus:
  - AB represents the first stage of combustion.
  - BC represents the second stage.
  - CD represents the third stage.



First Stage of Combustion (A$\rightarrow$B)

- The first stage is known as the ignition lag or preparation phase.
- In this phase, a self-propagating nucleus of flame grows and develops.
- This is a chemical process influenced by:
  - Temperature and pressure.
  - Nature of the fuel.
  - Proportion of exhaust residual gas.
- It also depends on the relationship between temperature and the rate of reaction.

Details of the First Stage (A→B)

- The process is dependent on the chemical nature of the fuel and the mixture conditions.
- This stage sets up the conditions for the flame to propagate in the next phase.
- Important factors include:
  - Temperature and pressure dynamics.
  - Fuel characteristics.
  - Residual gases' impact.

Second Stage of Combustion (B→C)

- The second stage is a physical phase involving the spread of the flame.
- It begins where the first measurable rise of pressure is observed (point B).
- During this stage:
  - Flame propagates at a nearly constant velocity.
  - Heat transfer to the cylinder wall is minimal.
  - The rate of heat release depends on turbulence intensity and mixture composition.

Details of the Second Stage (B→C)

- The rate of pressure rise is proportional to the rate of heat release.
- Combustion chamber volume remains nearly constant.
- Key factors include:
  - Turbulence intensity.
  - Reaction rate.
  - Mixture composition.

Third Stage of Combustion (C→D)

- The third stage starts at the maximum pressure (point C).
- During this stage:
  - Flame velocity decreases.
  - Rate of combustion becomes lower due to reduced flame velocity and flame front surface.

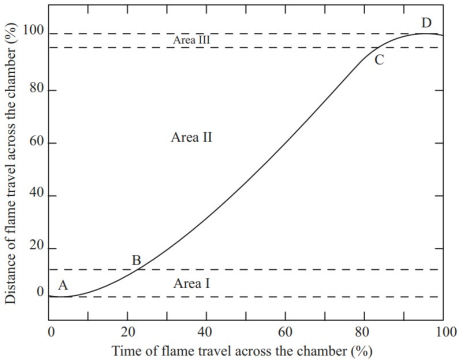
Details of the Third Stage (C→D)

- The expansion stroke begins before the end of this stage.
- The piston moves away from TDC, preventing pressure rise during this stage.
- Key points:
  - Reduced flame velocity.
  - Lower combustion rate.
  - No pressure rise due to piston movement.

Flame Front Propagation

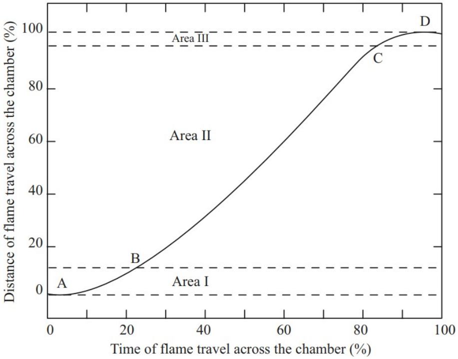
Flame Front Propagation

- For efficient combustion, the rate of flame front propagation within the cylinder is critical.
- Two main factors:
  - Reaction Rate: Chemical combination where the flame advances into the unburned charge.
  - Transposition Rate: Movement of the flame front relative to the cylinder wall, influenced by pressure differentials.



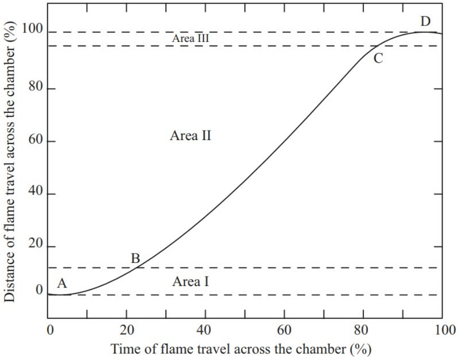
Flame Front Propagation (A→B)

- Area I (A→B):
  - Slow flame progression due to low transposition rate and turbulence.
  - Limited charge burned initially, resulting in slow flame advance.
  - Spark plug placement in a quiescent gas layer reduces turbulence and flame speed.



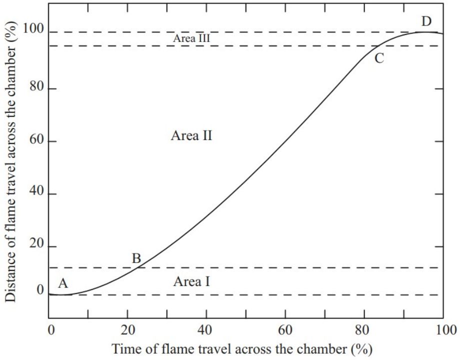
Flame Front Propagation (B→C)

- Area II (B→C):
  - Flame progresses rapidly in turbulent areas with more mixture.
  - Constant rate of progress due to increased turbulence.



Flame Front Propagation (C→D)

- Area III (C→D):
  - Flame speed decreases as the volume of unburned charge is low.
  - Reaction rate drops in lower turbulence zones.



Factors Influencing Flame Speed

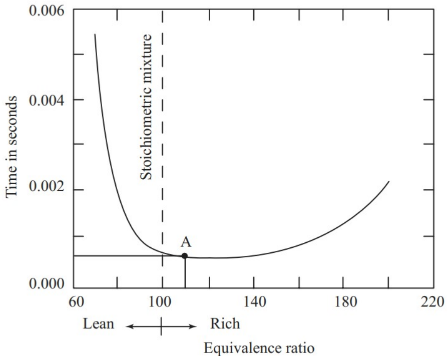
- Flame speed affects the rate of pressure rise and abnormal combustion.
- Key factors:
  - Turbulence
  - Fuel-Air Ratio
  - Temperature and Pressure
  - Compression Ratio
  - Engine Output
  - Engine Speed
  - Engine Size

Turbulence

- Low flame speed in non-turbulent mixtures.
- Increases with turbulence due to better mixing of particles.
- Turbulence is generated during intake and affects flame speed.
- Excessive turbulence can lead to rough operation and flame extinction.
- Suitable design of combustion chamber geometry increases turbulence.
- Higher turbulence can reduce combustion duration and minimize abnormal combustion.
- Fine turbulence (small swirls) is more effective than large swirls.

Fuel-Air Ratio

- Highest flame velocities are with slightly richer mixtures.
- Leaner or richer mixtures decrease flame speed.
- Lean mixtures release less thermal energy; rich mixtures cause incomplete combustion.



Temperature and Pressure

- Flame speed increases with higher intake temperature and pressure.
- Higher initial pressure and temperature improve mixture homogeneity.
- Increased density aids faster combustion.

Compression Ratio

- Higher compression ratios increase flame speed.
- Results in reduced ignition advance and enhanced combustion phases.
- Increased cylinder gas density raises peak pressure and temperature.

Engine Output

- Increased output raises flame speed due to higher cylinder density.
- Higher throttle opening results in increased density and flame speed.
- Reduced output leads to lower pressures and increased mixture dilution.

Engine Speed

- Flame speed increases with engine speed due to increased turbulence.
- Time for flame to traverse the combustion space decreases with higher speed.
- Crank angle for flame propagation remains nearly constant.

Engine Size

- Size affects combustion duration but not flame speed directly.
- Larger engines require more time for combustion due to longer flame travel distance.
- Larger engines are generally designed for lower speeds.

End of Lecture 16

End of Lecture 16