Chapter 9: Combustion in SI Engines

The normal sequence of processes in SI engines is as follows:

(i) Fuel and air mix and are inducted into the cylinder through the intake valve.
(ii) Compression of the fuel-air-residual exhaust gas mixture occurs after IVC.
(iii) Towards the end of the compression stroke, the in-cylinder mixture is ignited by an electric discharge at the spark plug.
(iv) Following ignition, a turbulent (premixed) flame propagates through the cylinder consuming the internal mixture until it reaches close to the cylinder walls where it extinguishes.

The sequence of flame propagation photographs shown in Fig 9.1 (key word) "throws more light" on the basic SI engine combustion process.

A very important engine combustion diagnostic measurement is the in-cylinder pressure trace. Based on this pressure measurement, considerable information about the nature of the combustion process at any operating condition can be gleaned.
Perhaps, the most important information can be obtained by performing a so-called "heat release analysis" of engine pressure data. We will discuss more about how this is done later.

As discussed before, the point of ignition and significant energy release can be observed by comparing the "motoring" (no combustion) and "firing" (combustion) pressure curves. It is important to note that just after the spark discharge, the pressure does not rise immediately; there is a short period in which the flame energy release is too small to give rise to any sharp pressure rise.

As the flame grows from near the location of the spark, the pressure increases rapidly and attains its maximum value just after TDC. At this point, it is not necessary (which means, usually) that all mass should have been burned. There is still some unburned mass left when peak pressure occurs and this mass burns during the expansion stroke when pressure decreases due to increasing volume. The "heat release analysis" also yields rate of mass burned and volume fraction engulfed by the flame as functions of crankangle.
There are considerable cycle-by-cycle and cylinder-to-cylinder variations in the combustion process which are usually reflected as variations in the shape of the pressure curves as well as their phasing with respect to TDC. These variations affect the performance (power and efficiency) and emissions of the engine.

The gas composition and motion near the spark plug (between the electrodes) and cyclic variations therein are crucial for the ignition and subsequent flame development in each cycle. These variations should be limited by proper design of components and choice of operating conditions.

It is also interesting to note that the fraction of volume engulfed by the flame \( \frac{\text{Volume}}{\text{Initial Volume}} \) increases faster (is more rapid) than the apparent normalised mass burning rate. This is due to the fact that the enflamed gases (burned products) are much hotter than the unburned mixture and hence, less dense, so they expand faster. When the whole cylinder is fully enflamed, there is still considerable unburned mass surrounding the flame which is compressed and hence occupies a very small volume.
The overall SI engine combustion process may be divided into four distinct phases:

(i) Spark ignition.
(ii) Early flame development.
(iii) Flame propagation.
(iv) Flame termination (or extinguishment or quenching).

The phasing of the combustion process is extremely important since it affects the power output, fuel conversion efficiency, and the pollutant emissions. In an SI engine, the parameter that yields maximum control over the combustion phasing is spark timing. When spark timing (also called spark advance) is varied (w.r.t. TDC), the power or torque output (at a fixed engine speed) changes accordingly.

**Spark timing:** If the spark is advanced before TDC, the combustion event is advanced and the compression stroke work requirement increases (because the expanding burned products need to be compressed). On the other hand, if the spark is progressively retarded, the peak firing pressure is reduced and it occurs later in the expansion stroke; therefore the work output or torque is decreased.
**MBT timing**: There is an optimum spark advance (timing) at which the maximum brake torque is obtained. This is called maximum brake torque (MBT) timing.

NOTE: There is a unique MBT for each set of operating conditions such as speed, load, etc. So MBT is not a single constant for an engine.

**MBT timing depends on the rate of flame propagation, length of flame travel, and flame termination.**

And MBT timing changes with the duration of the combustion process (which is usually 30° - 90° crankangle).

**The four stages of SI engine combustion (especially the first three) are particularly affected by turbulence inside the cylinder. Turbulence is affected by "initial conditions"; (i.e.) the velocities and their fluctuations in the intake manifold.**

As engine speed increases, the velocity of gas flow in the intake manifold increases thereby increasing the turbulence intensity in the intake manifold. This increased intake manifold turbulence leads to increased in-cylinder turbulence at higher engine speeds.