COMBUSTION PROCESS IN SPARK IGNITION AND COMPRESSION IGNITION ENGINES

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Abstract

The process of normal and abnormal combustion in SI and CI engines has been explained in the present paper. In case of SI engine, the air-fuel mixture is prepared in the intake system and then the mixture is inducted into the cylinder through the intake valve and the compression takes place. Then, the flame is generated in a turbulent manner. The high speed motion of flame development has been illustrated. The travelling of Flame has been explained and the engine flame-trace has been shown. The detonation and pre-ignition in spark-ignition engine have also been described. In case of CI engine, high-pressure fuel is injected at the end of the compression stroke into the cylinder. The injected fuel first evaporates and then mixed with the compressed hot air and then finally the ignition takes place. The combustion process in diesel engine has been illustrated. The detonation in compressed-ignition engine has also been given. The comparison between detonation in spark-ignition and compression-ignition engines has been done. Finally, the paper gives the clear view of the combustion process in SI and CI engines.

Keywords: *Flame Propagation, Engine Flame Trace, Detonation, Pre-Ignition, Flame High Speed Motion*

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1. INTRODUCTION

Engine efficiency emissions and power are controlled by the process of combustion of the air-fuel mixture inside the engine cylinder. It is the intake system of the engine where the fuel is generally mixed with air. Electric discharge initiates the compression process after the compression of air-fuel mixture and the residual gas, a flame created by the spark discharge, develops and propagates across the cylinder to the combustion chamber walls.

First of all, combustion takes place at the spark plug and the flame front begins to travel from spark plug. The flame is quenched or extinguished at the walls due to the transfer of heat. In the case of spark-ignition engine, combustion has an exothermic sussonic flame which progresses through a premixed homogeneous air-fuel. It is remarkable here that the spread period of the flame front is highly increased by induced turbulence swirl and squish across the cylinder.

2. NORMAL COMBUSTION IN SI ENGINE

A homogeneous mixture of air and fuel is supplied to SI engine and this mixture remains in gaseous form during ignition time. The mixing of air and fuel takes place in the intake system of a conventional spark-ignition engine. This mixture is inducted through the intake valve into the cylinder, where residual gases mix with this mixture and then compression takes place. The combustion initiates at the spark plug due to the electric discharge produced by it at the end of the compression stroke. The flame is generated in the turbulent manner and it propagates through the charge till it reached the walls of combustion chamber and then the flame ends.

2.1 Flame Propagation

In normal combustion, the forward boundary of the reacting zone is called the flame front.[1] The flame front, as well as the burnt products which are behind the flame front, is remarkably luminous and can be used for photographic observation. In case, when flame front is not sufficiently luminous, a small portion of sodium compound is used to make it luminous.

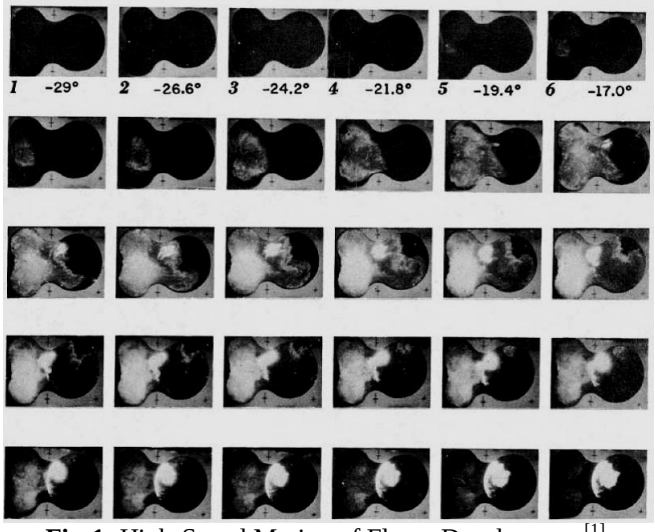

Fig-1: High-Speed Motion of Flame Development[1]

It is better to consider first the combustion of gaseous mixtures under simple conditions, as the combustion process in engine is complicated due to the motion of piston, due to the presence of residual gases and due to turbulent motion of the gases.

2.2 Travelling of Flame and Development of Pressure

Time and position of the flame front have been represented by the horizontal axis and vertical axis in Figure 2. As the shape of the flame front is irregular, the observed flame front velocity through a narrow slot does not represent the average velocity. Trends in the average velocity of the front have been indicated by measurements of flame velocity from photographs of type of Fig-2. It is possible only if there is no appreciable swirl of the gases and also if there is no systematic changes in flame front shape with the variables.

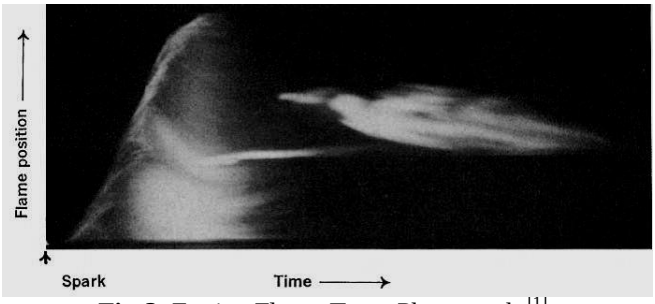

Fig-2: Engine Flame-Trace Photograph.[1]

The shape of the curve in an engine plotted between flame position and time has been shown in Fig-2. As, there is a small change in volume while the flame travels in an engine. So, in an engine, the mixture is very turbulent in nature.

The unburned part of the charge is compressed by the expansion of the burned gases, so the motion of a flame in a mixture contained in a chamber of constant volume is complicated. Consequently, the boundary of the unburned charge moves with the reference to the chamber. As such, the observed flame motion is the sum total of two movements namely, the rate of movement of the flame into the unburned portion of the charge, which is called the burning velocity and the rate of the push forward of the flame front by the expansion of the burned gases, which is called the transport velocity.

Generally, the whole of the pressure rise in a constant volume combustion process is found during the later portion of the flame travel in the chamber.

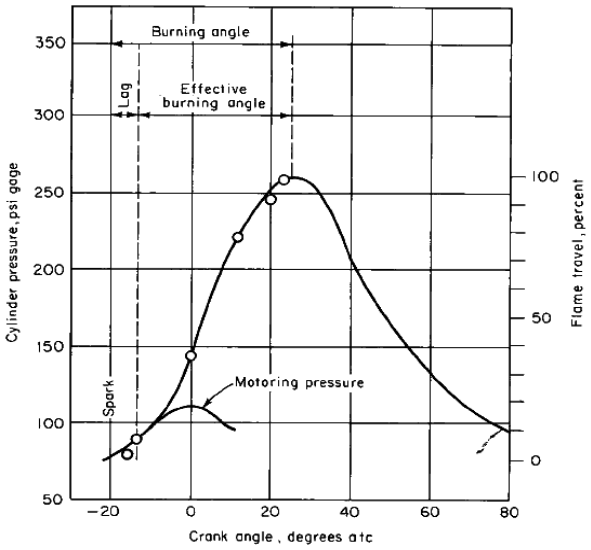

Fig-3: Pressure development and flame travel in an engine cylinder [1]

Pressure development and flame travel in an engine cylinder has been shown in Fig-3. It is found here that the pressure rise is consistent with flame position due to piston motion and attenuated form of the L-head chamber. In the case of compact combustion chambers, the relation between pressure and flame position must be large.

3. ABNORMAL COMBUSTION IN SI ENGINE

If the flame initiated by a spark travels uniformly over the combustion chamber then the combustion is said to be normal. But, in some cases, it is deviated from the normal which results loss of performance and change to the engine. The phenomena of abnormal combustion is called as knocking or detonation, in SI engines. The consequences of abnormal combustion are loss of engine power, recurring pre-ignition and increased wear of the engine.[1]

3.1 Detonation

In detonation state of the engine, six series of flame photographs, which have been taken through a transparent cylinder head, are shown in Fig-4.

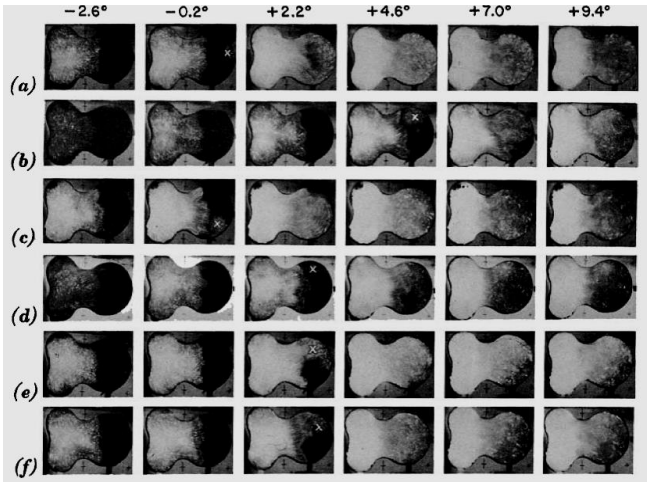

Fig-4: Six series of photographs of the flame in a glass-topped cylinder, showing detonation.[1]

The development of a nucleus of flame, in each case, ahead of the flame front is evident at a moment when the flame has travelled nearly two third to three fourth of the chamber. Complete inflammation has been shown in Fig-5. It is remarkable here that the charge of this portion burns rapidly.

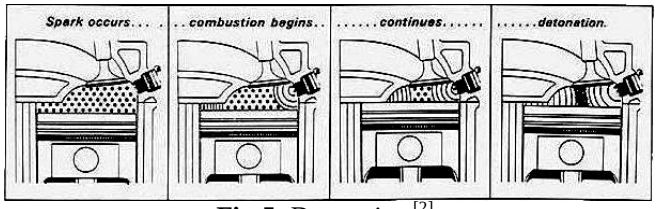

Fig-5: Detonation [2]

3.2 Pre-Ignition

The ignition of the homogeneous mixture, when it comes in contact with hot surfaces without spark is called pre-ignition. Spark plug and exhaust valve are overheated due to auto ignition and it becomes so hot that its temperature can ignite the charge in next cycle in compression stroke before spark plug takes place which results the pre-ignition of the charge.

The following overheated projecting parts can cause pre-ignition:

1) Exhaust Valve Head
2) Metal Corners in th Combustion Chamber
3) The Spark Plug Electrodes
4) Carbon Deposites

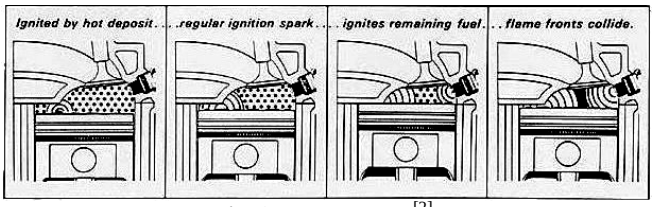

Fig-6: Pre-ignition[2]

It is found that persistent detonation pressure shockwaves can cause pre-ignition. The surface temperature of any protruding poorly cooled part of the chamber is increased by the heat flow through the walls, which creates situation for further pre-ignition.

4. NORMAL COMBUSTION IN CI ENGINE

In the diesel engine, high pressure is necessary to inject the fuel at the end of the compression stroke, generally before top dead centre into the main combustion chamber. Normally, the following systems are used:

1. Distributor injection pumps with injection pressure of the order of 1450 bar.
2. Pump-nozzle with pressure over 2000 bar.
3. Common rail injection system with pressure of nearly 1650 bar.

The injected fuel firstly evaporates then it mixes with the compressed hot air and after that it ignites. If CI engine is compared with the SI engine, a short duration is available for the mixture formation with the diesel engine. An intensive mixture formation is necessary, which can be attained by fast injection and best possible atomization.

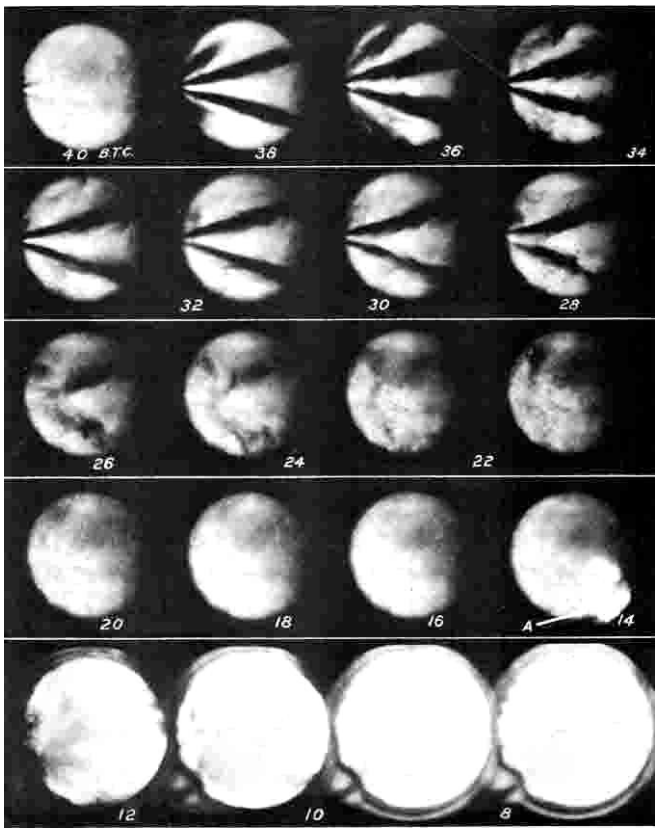

Fig-7: Delay period is longer than injection period. Numbers indicate degrees before top center[1]

4.1 Period of Rapid Combustion

Uncontrolled combustion is the period of rapid combustion. Pressure rise is rapid in the phase of uncontrolled combustion. The combustion of air-fuel mixture is formed during delay period. The pre-flame reactions are overcome. The period of rapid combustion is counted from the end of delay period or the beginning of combustion to the point of maximum pressure on the indicator diagram. The rate of heat release is also maximum during this period.[1]

It is to be noted here that for longer delay period , there is more rapid and the pressure rise is also higher due to higher fuel quantity accumulated before ignition.

4.2 Mixing-Controlled Combustion

The third stage of combustion in CI engine is the controlled combustion. The temperature and pressure of air-fuel mixture is high in controlled combustion. Therefore, injected fuel droplets burn rapidly when these droplets come in contact with the available oxygen. Increased pressure may be controlled by the injected rate. The period of controlled combustion starts from maximum pressure condition and it ends at maximum temperature condition.

4.3 Photographs of the Combustion Process

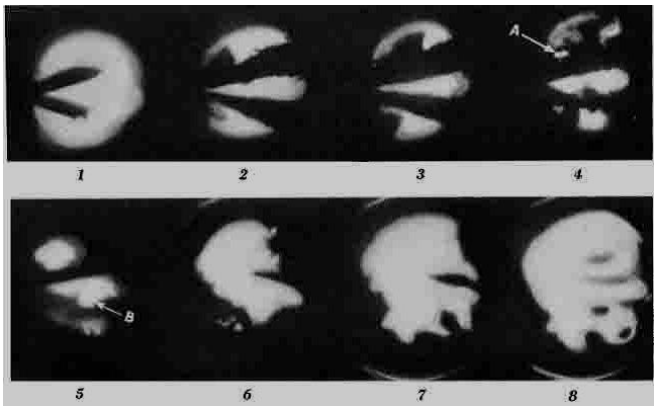

Fig-8: High-speed motion pictures taken through the glass-sided combustion chamber of the NACA compression-ignition apparatus.[1]

5. ABNORMAL COMBUSTION IN CI ENGINE

If the ignition delay is longer, the actual burning of the first droplets gets delayed, and a large quantity of fuel gets accumulated in the combustion chamber. When combustion initiates the rate of pressure rise is too rapid, resulting in jamming of forces on the piston and rough engine operates. If the ignition delay is still longer, then a higher quantity of fuel is accumulated. In that case, pressure rise during combustion is instantaneous and violent. The extreme pressure differential causes violent gas vibrations known as knocking and this type of combustion is called abnormal combustion.

5.1 Detonation

In practice, most Diesel engines have a rate of pressure rise sufficiently high to cause audible noise. When such noise becomes excessive in the opinion of the observer, the engine is said to "detonate" or " knock". It is evident that personal judgment is here involved. Thus, in the compression-ignition engine there is no definite distinction between normal and "knocking" combustion.

6. COMPARISON BETWEEN DETONATION IN SI AND CI ENGINES

Compression ignition follows by a sudden pressure rise and in this way both have same basic cause. It is found that the cause is same in both cases. The reaction is in the last part of the charge to burn in the case of SI engine but in the CI engine, reaction takes place in the first part. If detonation in spark-ignition engine is to be avoided then compression-ignition should be stopped. Earlier possible ignition is required in the compression-ignition engine so that favourable conditions should not have appreciable time to form knocking during the delay period.

Table -1: Characteristics Tending to Reduce Detonation or Knock [1]

Characteristic	Spark-Ignition Engines	Compression-Ignition Engines
Ignition temperature of fuel	High	Low
Time lag of fuel	Long	Short
Compression ratio	Low	High
Inlet temperature	Low	High
Inlet pressure	Low	High
Combustion-chamber wall temperature	Low	High
Revolutions per minute	High	Low
Cylinder size	Small	Large

In order to avoid detonation in the spark-ignition engine, it is necessary to prevent compression ignition from taking place at all. In the compression-ignition engine the earliest possible ignition is necessary, so that conditions favourable to knocking will not have time to form during the delay period.

7. CONCLUSION

The present paper tries to explain the normal combustion of SI engine in which it gives the overview of flame propagation in its high speed motion and the flame-trace of the engine has also been represented. The detonation and pre-ignition occurred during abnormal combustion has been explained. The paper also explains the normal combustion in CI engine and provides the better view of period of rapid combustion and mixing-controlled combustion. The abnormal combustion in CI engine has been explained. The paper also elaborates the combustion process in spark-ignition and compression-ignition engines. Finally, the paper describes the actual combustion process in both spark-ignition as well as compression-ignition engines.

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