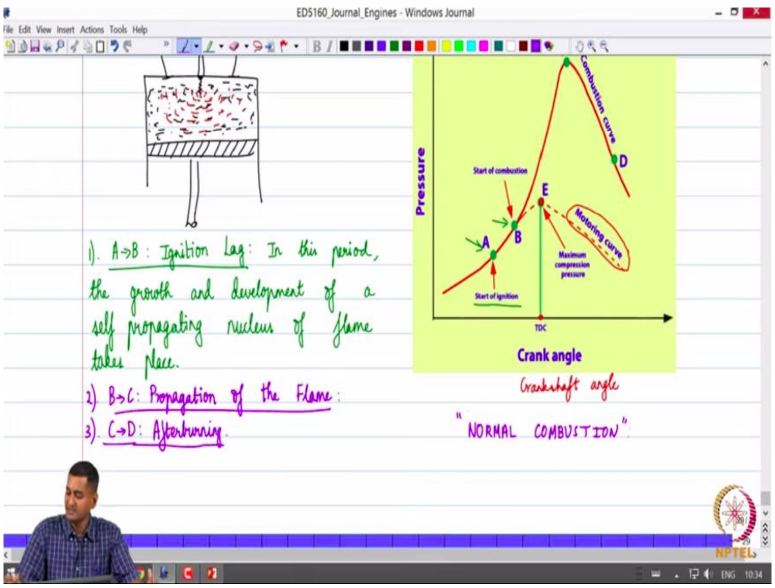
Fundamentals of Automotive Systems

Prof. C. S. Shankar Ram
Department of Engineering Design
Indian Institute of Technology – Madras

Module No # 04
Lecture No # 16
Supercharging and Combustion in SI Engines -Part 02

(Refer Slide Time 00:16)



Having discussed supercharging and turbochargers you know like we are going to the next topic of stages of combustion in spark ignition engines ok. So we would also look at how the actual combustion process takes place in spark ignition engines of petrol engines and what factors affect them. And some critical points you know which we will ultimately associates with you know whether super charging is possible or what limit super charging in a spark ignition engine ok.

So we are going to discuss all those concepts now ok. So if you look at the typical stages of combustion in a spark ignition engine we are going to look at the phase where the air as been taken in during the suction stroke and air fuel mixture has been compressed during the compression stroke and the spark is given to the fuel air mixture towards the end of the compression stroke.

So we are going to focus on that phase of the engines operation near about the end of the compression stroke ok to discuss this process of the combustion right. So please know that this is the crank angle or the crankshaft angle ok. So we can say crank angle or crankshaft angle right. So now this is the top dead center ok. So we in this diagram we have plotted pressure versus crankshaft angle.

Suppose let us say there is no ignition process in the engine right. So we are just maybe you know manually rotating the crankshaft without giving any fuel or we do not have a spark in the spark plug. We do not excite the spark plug to give a spark and so on. What would happen? I take an air I compress a in the compression stroke and the pressure of air keeps on increasing. And obviously the pressure of air would become maximum at the TDC towards the end of the compression stroke and then it will start decreasing.

So the resulting curve is what is called as a motoring curve. So motoring curve means you know no combustion ok. So we are just using that curve to help us understand the actual combustion process and the motoring curve serves as a reference curve ok. So in other words motoring curve is a curve but obtained when we plot pressure versus crankshaft angle if we do not have combustion process in the engine.

Obviously the pressure will become maximum when the piston is at the top dead center right and the two valves are closed. So that is the motoring curve. So now what happens let us say we consider the actual combustion process. So now what we have done is that we have introduced the fuel air mixture. The fuel air mixture is compressed and we provide a spark close to the top dead center a few degrees before the top dead center.

At let us say point A, so point A is the point at which we start the ignition process that is we provide a spark. Now you can see that during this phase from A to B there is hardly any difference between the actual combustion curve and the motoring curve. The reason being that although we give a spark through the spark plug, there is a delay from the instant at which a spark is given to the instant at which a flame is formed.

You know like which will just travel along the combustion chamber and burn the fuel air mixture. So please recall how the combustion chamber can be visualized in this process. So I am just drawing a simple schematic so let us say this is the piston. The piston is close to the top dead center so my intake valve exhaust valve both are closed and then there is a spark plug which provides this spark ok to the fuel air mixture ok.

So the fuel air mixture is spread throughout the combustion chamber is nice homogeneous mixture. So it has mixed very well and then it has spread ok. So please recall once again for the process of combustion we need fuel, we need air or the oxygen in a correct proportion right and then we also need a mechanism to initiate the combustion process. We have taken in fuel air mixture during the suction stroke you know.

The fuel air mixture has been nicely mixed and a homogeneous mixture has been formed towards the end of the compression stroke. Towards the end of the compression stroke we are providing the mechanism to initiate the combustion process by providing a spark through the spark plug ok. So that is what we have the combustion process taking place in the SI engine ok. So we give a spark then what we need is that we need a small flame to form and then the flame will sweep across the entire combustion chamber ok like this.

So from the time if spark is provided to the time a small nucleus of flame that propagates itself is form is what is called as a ignition lag. And during this phase we can observe that the pressure does not deviate too much from the motoring cave ok. So ignition lag is the period in which the growth and development of a self-propagating nucleus of flame takes place ok. So that is the ignition lag.

Now we can immediately observe that once we have this flame combustion starts right that means that the chemical energy the fuel is converted to thermal energy ok. So point B combustion starts heat energy is released. So we can immediately see the pressure curve starts moving away from the motoring curve there is a huge pressure increase from point B to point C where point C is a point just after the top dead center where the maximum cycle pressure is reached ok.

Point C is a point where we get the maximum pressure in this operating cycle ok. So this is the phase through which the flame propagates through the combustion chamber and generates lot of energy thermal energy which leads to significant increase in the cylinder pressure. So we can immediately observe that this flame propagation phase starts from the point where the nucleus of flame is formed to the point where the cycle pressure is the maximum ok so that is the second phase ok.

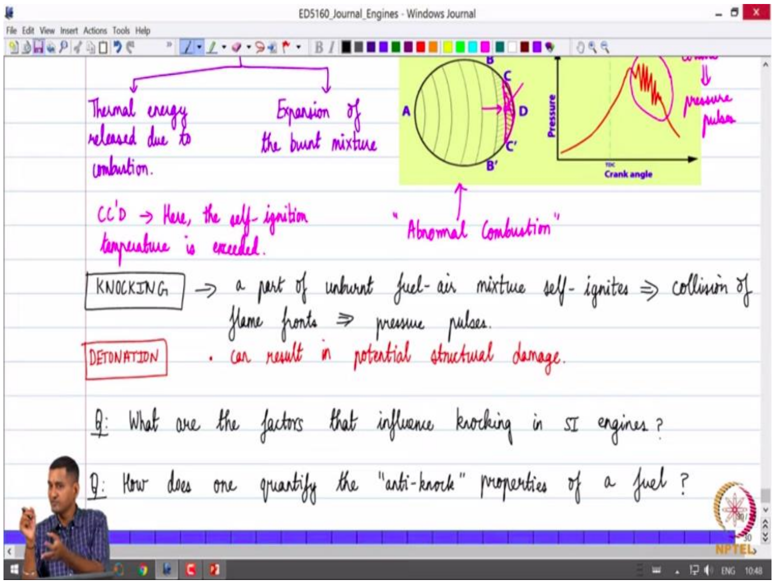
Then once majority of the fuel air is mixture burnt in the combustion chamber right what happens there may be few pockets of fuel air mixture which are still unburn and the flames goes and burns them. But by that stage you know the piston is already started moving downwards. So, the volume is increasing so all the thermal energy is still released. The rate at which the thermal energy is released essentially is not high enough to ensure the pressure still rises with the volume increase.

So with the volume increases even if I release thermal energy the pressure may start dropping. If the thermal energy which is released is it is not significantly high. That is what happens in the third stage which we call as after burning. So after burning is typically referred to as the stage once the maximum cycle pressure is reached and where the remaining of fuel air mixture is burned by the flame front ok.

So that stage is what is called as a after burning phase. So broadly these are the 3 phases in a spark ignition engine ok. As far as the combustion is concerned A to B is what is called as a ignition lag. B to c is the propagation of the flame front and C to D is the after burning stage ok. So these are the three processes in the combustion phase ok of a petrol or gasoline or spark ignition engine.

So this is how the engine should normally operate. What happens if something goes wrong ok. So that is the next concept we are going to look at. So this during the normal combustion process. You know like this is how we would picturize the P Theta curve or the P pressure and crank angle or crankshaft angle curve during normal combustion ok.

(Refer Slide Time 11:19)



So what happens if something does not work properly ok so let us look at what happens in abnormal combustion which lead to the important phenomena called knocking ok. So let us look at knocking in spark ignition ok so to understand this better let us look at this simple schematic and discuss. So let us say we consider these 2 graphs 2 schematics ok. So first let us look at normal combustion what we discussed just now so I am just drawing an arbitrary shape for the combustion chamber ok.

So let us say this what is drawn here is the combustion chambers snap shot ok. When the combustion process is ongoing ok in the cylinder ok. So the spark originates from the point A and we can see that this is the flame front ok. So the curve lines indicate the flame front and the flame front is currently at BB prime let say ok. And this region BB prime D is the unburned fuel air mixture ok that is BB prime D ok very simple schematic.

So what is this oval you know just a what to say a representative cross section of the combustion chamber as the combustion process on going right. My spark originates at point A and then a flame front travels ok. The arcs indicate the previous position of the flame front at some discrete instants of time and currently the flame front is at BB prime ok and what is upstream or a sorry ahead of the flame front is what is un-burnt ok. So that region BB prime D is the unburnt fuel air mixture ok. That indicates the un-burnt fuel air mixture.

So now when we have combustion this un-burnt fuel air mixtures pressure increases due to two reasons. What do you think are the two reasons through it do it to the you know like the pressure of unburned fuel air mixture increase. The first one is a thermal energy or the heat energy released due to combustion. Obviously that is going to increase the pressure and temperature of the un-burnt fuel air mixture. Of course, pressure and temperature of the un-burnt fuel air mixture increase due to these two first reason being the thermal energy which is released due to combustion.

And the second reason is and if you look at behind the flame front we have burned gases right and those gases are going to expand right so they are hot right. And they are going to expand right they also are a high pressure and temperatures. So if the gases expand what are they going to do? They are going to compress the un-burnt fuel air mixture even further right. So the expansion of the burnt mixture are the combusted mixture is also going to increase the pressure and temperature of the unburned fuel air mixture.

If the temperature of the un-burnt fuel of mixture does not exceed the self-ignition temperature of the fuel. Then the flame front will travel through the combustion chamber burn even the unburn fuel air mixture and the combustion would be normal. So what do you mean by that? Let us say in the first figure the flame front is that BB prime right. So this is the un-burnt fuel air mixture if this temperature is less than the self-ignition temperature of the fuel. What is self-ignition temperature?

The self-ignition temperature of a fuel is a temperature at which the fuel will ignite on its own. It does not require external mechanism to ignite like a sparkler ok. So that is what is called self-ignition or auto ignition ok. So if the gasoline fuel or the petrol fuel that we use in the engine is such that the temperature of this BB prime D is lower than the self-ignition temperature of the fuel then the flame front will proceed it will burn the fuel air mixture which is remaining and then the combustion process will happen normally and we will have the P theta curve as we have already studied ok it will be smooth curve.

However, let us say you know there is a scenario where things do not work out the way we plan right. So this is what we call as abnormal combustion ok. So now things do not work the way we want to be right. So what happens is that let us there is a small sub region ok. This is just a without loss of generality ok. So it need not be here all the time let us say some chunk ok CC prime D ok.

CC prime D here the auto ignition or self-ignition temperature is reached. So let us say in this region the self-ignition temperature is exceeded right. Now I am considering a scenario where the combustion process does not work normally due to whatever reason. We will see what reason can basically create this self-ignition in petrol engines. So let us say CC prime D in the region the fuel ignited on its own.

Then what is going to happen there is going to be another flame front which is going to be originating in this region. The primary flame front comes like this the secondary flame front let say it comes from some other direction what is going to happen at some place at some instance there are going to collide with each other because these are like flame fronts ok. And they carry tremendous amount of energy with them right.

So when these 2 flame fronts collide what is going to happen is a? there are going to be significant pressure pulsations that is going to be reflector in the P theta diagram as shown here ok. So towards the end of combustion or in the phase C to D right. So due to this self-ignition the pressure pulses may be formed and if at all this process happens it happens near the place of maximum cycle pressure.

And pressure pulses are the location where we encounter the maximum cycle pressure is detrimental to the engine obviously right because you know that is going to create structural damage potential structural damage to the engine components right. So this phenomena is what is called as knocking. So what is knocking? Knocking is the phenomena in which the part of the un-burnt fuel air mixture self-ignites before the primary flame front will primary flame front reaches there right self-ignites this leads to collision of flame fronts ok which in turn leads to pressure pulses ok.

So that phenomena is what is called as knocking ok. Some people also will call it as detonation in SI engines ok why because it produces the loud noise ok. So since it take place at near about the peak cycle pressure significant pressure pulses near the peak pressure means you hear a loud noise right. So some people will call it as detonation ok in spark ignition engine. But we will use a term knocking right. So knocking in SI engine is this phenomena.

So one knocking is undesirable because it is not how the combustion process is expected to work or expected to happen in a spark ignition engine and second due to these pressure pulses knocking also can creates significant transient mechanical loads on the engine components on the engine structure and this can result in potential structural damage ok in addition to vibration right.

So the engine going to vibrate right due to the pressure pulses can also result in potential structural damage ok to the engine components and the engine structure ok. So that is why it is undesirable ok in spark ignitions ok. So now the question that arises and what we will start answering one by one is what are the factors that influence knocking in SI engines and consequently how they are what to say they restrict or affect the operation and design of the SI engine itself ok.

So that is the question we will answer. Another question is that how does one quantify the so called antiknock properties of a fuel ok used in SI engines ok. So these are important questions to ask right. We need to figure out what factors affect knocking. How they affect and correspondingly what restrictions they place on the design and operation of petrol or gasoline or SI engines.

And the second question is when we want to look at knocking, we can evenly observe that it is closely related to a fuel property right because if boils down to whether the fuel will self-ignite or not. So the important property from the perspective of fuel that we are interested in is the self-ignition temperature of fuel that we use in the SI engines. So question becomes how do we quantity that antiknock properties of a fuel ok used in SI engines.

So we would discuss the answers to these questions in the next class and then we would continue with how combustion process happens in diesel or compression ignition engines ok. So we would end here and then like we will continue in the next class, thank you.