Fundamentals of Automatic Systems
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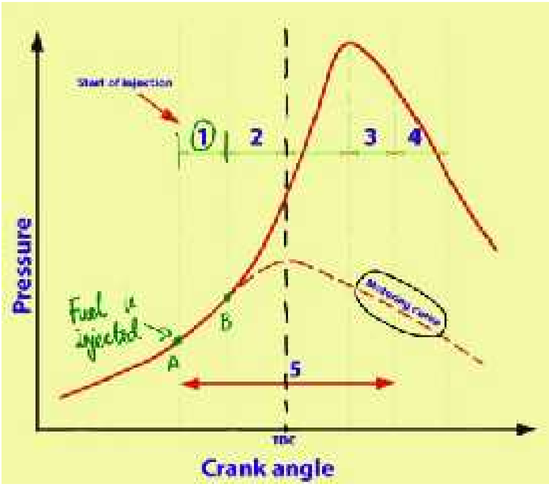
Module No # 04
Lecture No # 19
Combustion in CI Engine and Carburetion – Part 01

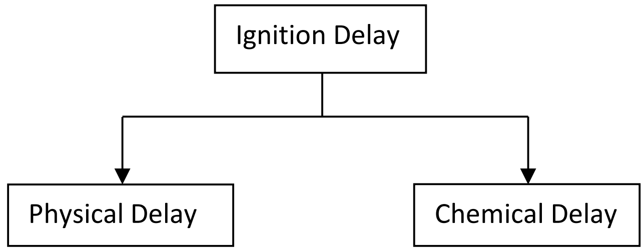
Greetings welcome to today's class so quick recap of what we did in the last class so in a previous class we looked at the factors influencing knocking in spark ignition engine's right. So we have discussed what was the influence of various factors like compression ratio mass of inducted charge inlet temperature and flame speed etc., right on knocking and we also looked at how knocking is quantified or anti knock properties of a fuel are quantified using octane number.

And we just started the actual combustion process in compression ignition engines if we recall the main difference in the compression ignition engine is that the fuel self-ignites. So once the fuel reaches its self-ignition temperature so 2 points are important particularly CI engines because the fuel is sprayed into the combustion chamber towards the end of the compression stroke okay. So the fuel needs to be introduced into the combustion chamber there are two attributes that are important first one is atomization of fuel which essentially involves breaking down the fuel particles into smaller particles and essentially enable the vaporization so that the fuel vapors mixed well with air to form a combustible mixture.

Please note that as oppose to as spark ignition engine the time available for the fuel to combust in a CI engine is typically smaller because of the process by which the fuel introduction takes place right. So a few more factors where the introduction of a proper air swirl so that like the fuel is also spread throughout the combustion chamber and not localized so that we get a near homogenous mixture of fuel and air in a short interval of time in a compression ignition engine.

And in order to prevent the presence of significance amount of unburned fuel in the exhaust diesel engines are also typically operated with the leaner mixture to avoid unburned hydrocarbons okay the engine exhaust we will look at emissions later on okay as we proceed and to enable the atomization of fuel and also the dispersion of fuel in inside the combustion chamber the fuel is typically injected at very pressures in a diesel engines.





Stages of combustion in CI Engines:

So we look at these injection systems also later on okay to continue from this point so today we will start with a discussion on what are the different stages of combustion in CI engine. So once again we would look at a P theta diagram for the combustion in a CI engine close to the top dead center. So this would essentially convey to us you know like what happens when the compression stroke is almost getting completed and fuel is introduced into the combustion chamber.

So this is the P theta curve for the actual combustion process in a combustion ignition engine once again this is the top dead center so we can see that this vertical line indicates the phase where the piston is at the top dead center and we can observe the motoring curve as we recall the motoring curve is the trace of the P theta diagram which is obtained when there is no combustion in the cylinder.

So the pressure is the peak pressure is reached at the top dead center so now when the fuel is injected into the combustion chamber in a compression ignition engine once again there are different phases of combustion so what are these? So the first phase which is labeled as 1 here okay which takes place from here to here so this is the point where the fuel is injected okay at this point at the start of the first phase.

So the first phase is what is called as the ignition delay period so we can observe that the first phase last between these 2 points okay. So let us say we call this points A and B okay the fuel is injected into the combustion chamber at point A and we can observe that at point B the pressure in the actual theta P theta diagram starts to move away from the motoring curve that means that the fuel as started burning right.

So A to B is what is called as the ignition delay period so how is that defined? This is the time interval between the instant at which the first drop of fuel is injected into the combustion chamber and the instant at which the combustion starts. So this is the definition of the ignition delay period so if we look at diagram you know like the instant at which the first drop of fuel is injected in the combustion chamber we called it as labeled as point A right in the P theta diagram and point B is the instant at which the combustion process starts.

So those are the 2 instants right so ignition delay is broadly classified into physical delay and chemical delay so what comes under physical delay so when the fuel is injected into the combustion chamber right. So it requires sometime to atomize, vaporize, mix with the air and form a combustible fuel air mixture so there are some time taken for all these processes is to happen okay.

Okay so that is those are the processes that constitute what is called as physical delay so physical delay includes the time taken for the fuel to vaporize to atomize vaporize and mix with air and ultimately rise to the self-ignition temperature okay so that comes under physical delay.

So typically this physical delay can be reduced with higher injection pressures so if the injection pressures are higher you know like obviously when the fuel is sprayed in okay so it is going to essentially atomize and mix faster okay because it is going to come as a very fine spray right. So with higher injection pressures and also higher cylinder temperatures the start of the injection right.

So that means at if we increase the compression ratio right so then we are going to have higher temperatures at the end of the combustion sorry compression and that is going to promote better atomization and vaporization you know faster ones right. So what comes under chemical delay, chemical delay includes the time taken by the chemical reactions required to result in ignition or result in combustion right.

So that comes under chemical delay of course that depends on the chemical constitution of the fuel right of course also the operating condition but it is mainly influenced by the chemical composition of the fuel okay so those are broadly the physical delay and chemical delay. So the period AB or region 1 is the region where there is a significant ignition delay okay so that is the first phase of actual combustion process in a compression ignition engine.

So now let us come to the second phase so the second phase typically starts from this point B and goes till this point okay point C let us call this as point C okay so this is the phase where ignition starts and there is a rapid release of heat energy and the cylinder pressure increases rapidly okay so we can see that the cylinder pressure increases from point B okay moves away from the motoring curve as a tremendous rate of increase and then pressures reaches it is maximum at point C okay.

So the phase of the what we call as the phase 2 which is typically referred to as a period of rapid combustion phase 2 which is what is called as period of rapid combustion okay is the phase at which the heat released due to ignition right of the fuel you know like results in tremendous increase in pressures okay. So this is typically characterize and also like visualized as a period from the end of the ignition delay period which is point B okay to the point of maximum pressure okay.

So this is what typically called as the period of rapid combustion okay so after the peak pressure is reached even though fuel is injected into the combustion chamber and even through it ignites and burns the piston as moved past the moved away from the top dead center towards the bottom dead center. So what happens is that all through heat energy is now released it is not sufficiently high to sustain the same increase in pressure okay there is heat energy which is released due to the injection of the fuel and it is combustion.

However you know like the heat energy may not be sufficiently high to increase the pressure however the temperature will increase although the volume as started increasing okay there is heat energy which is released the temperature would still go and increase. So that phase is what is called as phase number 3 in this curve okay. So the process 3 takes place from let us say C to D okay in this curve okay.

So what is this phase C to D? C to D is the phase wherein there is drop in pressure but the fuel is still injected see fuel injection takes place in the time interval which is labeled as 5 so what is this time interval 5 okay? So this 5 is the period over which the fuel is injected in the combustion chamber okay. So you can see that this time period is spilt into 3 regions the first what we call as region 1 which is the ignition delay region 2 which is called as period of rapid combustion and region 3 where the pressure stops decreasing but still since the fuel is being injected and combusted you know we still have temperature increase okay and this phase is what is called as the period of controlled combustion okay.

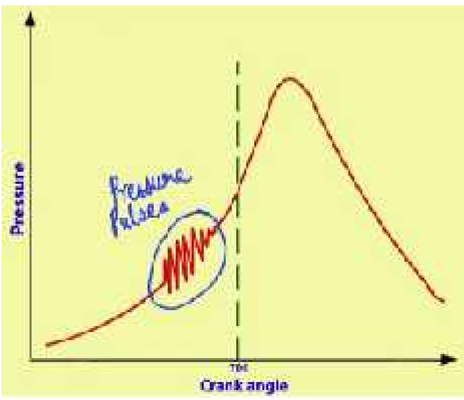
So essentially this is characterized as a region from the point of maximum cylinder pressure okay to the point of maximum temperature okay so that is the period of controlled combustion and of course in this process you know whatever fuel is injected also vaporizes faster and combust faster because there is lot of already heat energy which is being released right. So the combustion process also faster okay so if we go back to this P theta diagram so we can see that the injection process happens from let us say point A to D okay so that is the entire injection process.

And at point D injection stops and then the unburned fuel is burnt in the phase what is labeled as phase 4 okay. So this phase 4 in this P theta diagram is what is called as the period of after burning. So in the period of after burning the unburned fuel burns and it is starts from the point of maximum temperature and unburned fuel particles are ignited or combust in this process okay so that is what happens in period of after burning.

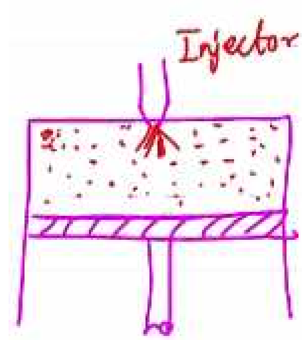
So broadly these are the 4 processes that had happen during the actual combustion process in a compression ignition engine okay. So the first phase is ignition delay phase second phase is period of rapid combustion third phase is period of control combustion and then the period of after burning right okay. So this is how the actual combustion process takes place in a compression ignition engine this is normal combustion.

Please note that in a compression ignition engine the normal combustion is already due to self-ignition or auto ignition. Now the question becomes you know like as what is abnormal right in a compression ignition engine in a spark ignition when we discussed about knocking we observed that in spark ignition engines we have normal combustion if the primary flame front reaches and burns any unburned fuel air mixture right.

We have abnormal combustion or knocking only when a part of the unburned fuel air mixture combust by itself and then that result in pressure pulsations. So then if knocking is associated with self-ignition in SI engines how can we qualify or characterize knocking in CI engines where anyway the normal combustion process itself is by self-ignition. So let us look at that part okay.



Knocking of CI Engines



So how is abnormal combustion or knocking in CI engines can be characterized so as oppose to an SI engine knocking in CI engine happens at the initial stages itself okay of the combustion process so what do I mean by that let us look at this P theta diagram once again right. So if we look at the P theta diagram here okay so consider a scenario where the ignition delay in a compression ignition engine is significantly high then what happens?

We inject fuel into the combustion chamber and if the ignition delay were to be high unburned fuel will start accumulating in the combustion chamber. So let us say I consider the combustion chamber okay I am not I am just drawing a simple schematic to just discuss this point let us say we have this cylinder and piston. Let us neglect all the other component right now okay for this discussion the valves and so on.

So suppose I start injecting fuel okay so through the injector okay and if the ignition delay were to be high what will happen I will have lot of unburned fuel pockets droplets which are going to be accumulating in the combustion chamber because there is what to say higher time period right time interval for them to spread out. Now when these unburned fuel particles self-ignite what is going to happens is that it is going to release lot of heat energy even higher heat energy which will result in pressure pulses okay because each fuel particle itself if you localize them it is going to self-ignite and there are going to be some pressure waves okay which are going to be generated.

If the ignition delay were to be high what is going to be happen is that the number of such self-ignition is going to only increase right because we are going to have more amount of unburned fuel in the combustion chamber and that is going to create some pressure pulses but at the start of the combustion process okay. So if you recall in the SI engine the knocking happened close the peak region right because that is how the phenomenon was right but here knocking if at all it happens right it would happen would occur in the initial stages of combustion okay in a CI engine if it were to happen okay.

So the main parameter which characterizes or which affects this phenomenon of knocking in CI engines is only the ignition delay so larger the ignition delay implies larger amount of un-burnt fuel particles injected fuel particles or the commencement of ignitions which would in turn imply higher pressure oscillations right. So the pressure pulses if they are to be significant would be felt towards the start of the combustion process okay in a CI engines.

So the main factor is the ignition delay so of course lowering the ignition delay would lower the chances of knocking in CI engines lowering the ignition delay would reduce the tendency for knocking in CI engines okay so that is what happens in CI engines okay. So this is the normal combustion and abnormal combustion process in compression ignitions okay. So now once again how do we characterize this ability of the fuel to prevent knocking in CI engines right in SI engines we quantify the anti-knock characteristics of gasoline using octane number.

Similarly in diesel engines the ability of the fuel to prevent knocking right is quantify by what is called as Cetane number. So once again is going to be a ratio of two base fuels that we will take and figure out which what is the composition of that mixture which will give me the same ignition delay right as the diesel fuel which have been provided okay. So what is that definition so it is the percentage by volume of normal Cetane is chemical composition is $C_{16}H_{34}$ and a mixture of normal Cetane and alpha methyl naphthalene which is $C_{11}H_{10}$ okay which has the same ignition characteristics.

So for diesel this is essentially quantified by the ignition delay of the fuel under consideration when combustion is carried out in a standard engine under a set of standard operating conditions okay so that is the definitions of Cetane number okay. So this is the concepts of combustion process in a CI engine and what is normal and how is knocking characterize in CI engine.