IC Engines and Gas Turbines
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Lecture – 22
Combustion in SI and CI Engines, Pressure Crank Angle Diagram (Contd.)

A normal combustion is that, that we have seen that Combustion SI Engine can be classified into 2 categories, one is normal combustion another is abnormal combustion.

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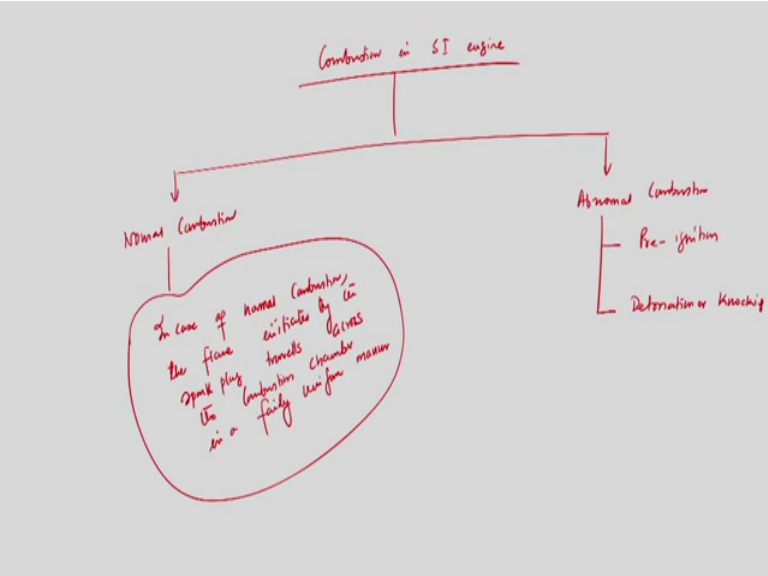

We have discussed that in case of a normal combustion, a flame which is being initiated because of the spark plug that will you know travel across this you know combustion chamber in a fairly uniform manner whereas, we will discuss now that, in case of a in case of an abnormal combustion again it can be sub classified into 2 categories, preignition rather it is abnormal combustion has 2 different parts, one is preignition another is detonation knocking where flame which is do we know existence of visible flame essentially an indicate indication of combustion.

So, in case of a in case of abnormal combustion that flame which is being you know developed because of the spark plug switching on the spark plug, that flame will not be able to travel in a fairly uniform manner rather that flame will be disturbed by the other flames in the combustion chamber. So, we need to know maybe you are telling that the

main flame front will be disturbed by the presence of other flames in the combustion chamber.

So, we need to know what are the sources rather origin of the other flames in the combustion chamber and or other flames are of; obviously, there because of which the main flame will get disturbed rather the dis travel of the main flame front will be disturbed so, knowing that fine, there are other sources from which the secondary flames are being developed then we need to know how can be prevent the formation of secondary flame and even we cannot stop completely the formation of secondary flames in the combustion chamber how we can mitigate the you know travel of the secondary flames. So, that there should not be any problems which will essentially give rise to a abnormal combustion in the combustion chamber.

So, before I go to discuss about this let us quickly recapitulate what we have learnt from the beginning of this; from the beginning of this course that what are the different strokes in a SI engine. So, if we can recall that in case of a spark ignition engine we ha have we have 4 different strokes of course, if it is a four stroke engine whether it is four stroke or two stroke. In case of a four stroke engine we have intake compression power and exhaust, in case of a two stroke engine we have power stroke and intake compression and ignition intake compression and exhaust stroke are occurring in a same stroke.

So, during the compression stroke if I try to write de know that is very important that we have discussed how that in a compression stroke we are; we are rising the tempera ra rising the pressure of the charge which is being introduced in intake stroke to a limit. So, that at the end of the compression stroke in case of SI engine we need to switch on the spark plug to ignite the entire com entire charge or in case of a CI engine, we have seen that we need not to use we do not have any spark plug or external agent like spark plug.

But still we are utilizing the high pressure and temperature of the you know compressed substance itself to ignite the fuel because we need to supply fuel through fuel injector or fuel pump in a finer spray pattern. So, the moment when which fuel is being injected into the combustion chamber during the end of the compression stroke the pressure and temperature of the compressed air will itself allow the air the fuel to be ignite. So, if I try to now write the you know the very important at crank angle and pressure diagram.

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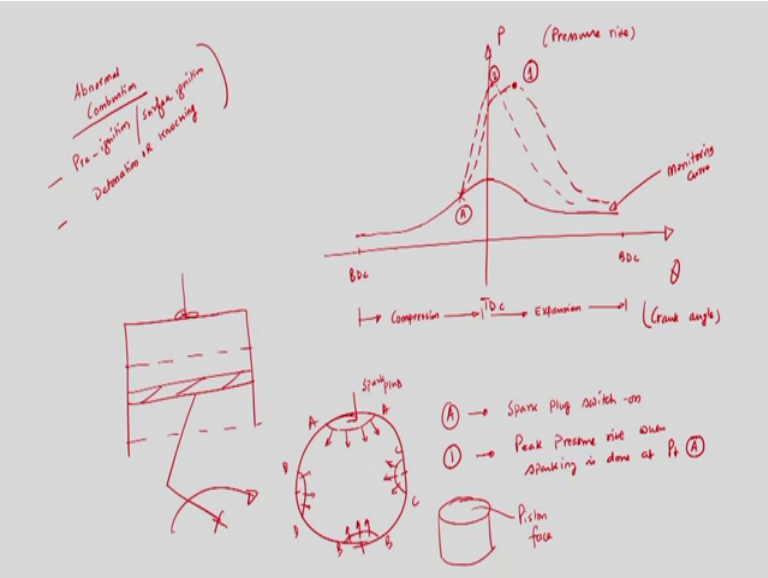

So, if I try to write that if I try to draw this is theta this is crank angle and this is of course, pressure rise P so this is pressure rise; pressure rise. So, maybe we need to know. So, this is the location of the TDC and may be this is BDC bottom dead center and this is also bottom dead center. So, this is compression stroke, this is compression and it will last up to this point, then this is again expansion stroke and it will last up to this point.

So, this compression and expansion so piston is coming from BDC to TDC compression stroke and again it is coming from TDC to BDC during power stroke and during that stroke what is happening in terms of pressure inside the cylinder that is what is now our objective. So, just if we have a curve, this one is a monitoring monitor curve. So, if we do not have any combustion rather we have a compression stroke then so this is known as monitoring curve.

So, if we just move the piston using an electric motor we will get curve like this. So, we have air inside the cylinder we have taken air during in during intake stroke and then we have closed valves that is intake both the valves intake and exhaust and just I am moving piston using an electric motor.

So, then it will during the compression stroke pressure will increase that is reflected in this diagram and again during expansion stroke pressure of the air will decrease. So, what is done at the end of the compression stroke maybe we are switch on the spark plug when if I try to recall when piston close to that that point. So, here we having spark loc

location. So, this is point A. So, point A is the spark plug switch on. So, if I switch on the spark plug at the end of the compression stroke when piston is very close to TDC then this spark plug we will switch on, we will try to initiate allow the combustion to be initiated and there will be a rise in pressure peak pressure, then it will follow the same curve. So, peak pressure is happening over here let us say point 1. So, 1 is the peak pressure rise when sparking is done at point A.

So, when we switch on the spark plug at point A, then there is a rise in peak pressure at 1 to 1 because of the combustion the pressure will be high temperature will be also high. This diagram is very important and we have we will keep this diagram as it is and we will now again superimpose another curve after sometime. So, now, we will discuss about that we have seen that normal combustion is fine because there is no aerotic movement of the flame and flame moves almost in a fairly accurate manner in a fairly uniform manner in the combustion chamber.

But now I will discuss about the abnormal combustion. So, abnormal combustion I am writing, abnormal combustion that is having another 2 different parts one is preignition sometimes it is known as surface ignition; surface ignition and another is detonation or knocking. So, these 2 are very important. I can tell you that whenever we start internal combustion particularly spark ignition engine then if I draw the schematic again maybe. So, this is the piston and we have spark plug over here.

So, if I draw; if I draw the, if I take a top view of the cylinder and then maybe here we are having spark plug. So, now, when you switch on the spark plug there will be a initiation of combustion and as I said that the indication of combustion being initiated is the appearance of visible flame. So, indication of app initiation of combustion is the appearance of a visible plane inside the combustion chamber. So, maybe this is the location of the spark plug. So, when combustion is initiated, a visible flame that will appear and not only that this the flame will try to expand and it will try to expand in a inside the combustion chamber and the charge which is very close to that flame again will take part in the combustion and in this way the entire charge will be will take part in the combustion.

So, during the first whenever we start the engine then there is no problem, but after a few cycle then because of the continuous combustion then, the cylinder phase cylinder wall

as well as surface of the piston will be having higher temperature. So, when we start our engine there will be no problem, but because of this continuous combustion there will be a time maybe at the later half later part of the cycle that is engine is running continuously.

So, piston phase so if I draw the piston then piston phase also will be having higher temperature. So, this is piston. So, this piston phase also will; also will be having higher temperature of the temperature of the piston phase as well as the cylinder wall will be higher because of the continuous combustion because, this walls solid walls are sustaining the combustion temperature.

Now, what will happen a time will come this is the actual spark plug there will be location inside the combustion chamber which will be acting, there will be different locations within the combustion chamber those locations will be acting as a you know artificial spark plug so that means, there will be a situation because when we have compressed the air maybe always we are the this four strokes are you know continuous.

So, maybe after certain cycles whenever we are com taking fresh air where fresh air rather air fuel mixture whenever you are compressing because of this hot spot that means, those which are acting like a like an artificial spark plug; that means, face of the piston as well as the cylinder walls, the temperature will be so high that the charge which are in contact with those locations will be able to there the combustion may take part combustion will initiate.

So that means, this hot spot like piston phase and cylinder walls are the location of the exhaust manifold also there where temperature is excessively high those locations will be acting like an artificial spark plug and whenever a fresh charge under whenever a fresh charge during compression stroke is coming in contact with those hot spot, then those hot spot will allow the charge which are in contact with those spots to you know initiate combustion.

So that means, there might be situation when maybe the charge at the remote locations from here, from here so here we may have another flame front, here we may have another flame front, here we may have another flame front. So, these flame fronts again will try to proceeds in the from that location to the surroundings places. So, main flame front is coming because of the spark plug, but because of the continuous rising or

excessive rise in temperature because of the continuous process there will be hot spot from where this hot spot temperature is so high that the temperature will allow the combust the fresh charge, the compressed charge to be compressed charge to be ignited in from those locations.

As a result of which the main flame front is proceeding towards the for the downstream not only that the another flame front also will try to proceed further and as a result of which there will be a excessive rise in the pressure. So, excessive rise in pressure and temperature again we will try to increase the temperature and this excessive rise in pressure and temperature will not only will you know this is continuous process this is cumulative effect; that means, the this flame is coming so again it will keep on increasing temperature and pressure.

So, this rise in the pressure and temperatures cumulative effect not only will tend to raise the temperature and pressure and which make the rate another problem about problem detonation and knocking, but also it may creates the peak pressure to be occur even further before that I will be now write at the draw in the schematic and that will even try to reduce the efficiency of the engine.

So, now before I go to discuss that aspect, let us see that when main flame front is coming from the actual spark plug location and because of the secondary flame being developed because of this artificial spark plug then, now this flame the secondary flames maybe this is BD, this is AA, this is BB, this is CC and this is DD.

So, the main flame front is coming from location A and another flame front which is going from location BB, there might be a situation when that main flame front before main flame front the main flame reaches at the at that the those locations BB or CC or DD the secondary flames are coming forward and there might be a situation when these two flames or the flames are colliding each other.

So, this collision of the flames will not only will create you know you know high pressure and temperature, but this collision will create a you know violent vibration with result in noise which is known as detonation and knocking. So that means, we understood what we understood that now we need to know how we can control how we can suppress the speed of the secondary flames being developed or we cannot completely stop it, but we can mitigate it.

What we can do? We can take some preventive measure by which we can mitigate or we can suppress the movement of the secondary flame that is being developed. So, for the time being you should know the main flame front is coming because of the spark plug original spark plug, but because of the continuous rise in temperature there will be locations where temperature will be so high and those places will be acting like an artificial spark plug. So, whenever a compressed charge is coming in contact with those place then, those the compressed charge will be ignited because of the high temperature and because of this ignition combustion will also start from those locations and secondary flame will be developed.

Now, secondary flame will after develop after that after the development of the secondary flame; after the development of a secondary flame, the flames will propagate rather the flames will travel then if we cannot create a situation that whenever main flame the time required to proceed main flame front up to the remote location may let us say BB another flame front the secondary flame BB is coming further and these two flames will collide each other and eventually result you know that a violent vibration and that will result a noise which is known as detonation or knocking.

That means we now need to know that this is so this is the collision of the flames maybe main flames main flame as well as the secondary flames. So, we should know that somehow we cannot stop because we cannot you know reduce the rise in temperature in the combustion chamber if we if we reduce then efficiency will further drop so, that we cannot do beyond a particular point, but what you can do? We can take some preventive measures so that although the secondary flames are generated, but we somehow can suppress their movement. So, that by the time when say main frame will be reaching there that secondary flame will not be able to propagate. So, my and in this way we can stop detonation and knocking that we will discuss.

So, what is surfacing ignition preignition? That means, we told that what is preignition the very important that some of the boundaries of the combustion chamber such as spark plug location, exhaust manifold, drop of a piston phase and walls if the cylinder becomes overheated under certain operating condition and because they are keep on because these places are always you know surfacing you know high pressure and temperature high temperature. So, their temperature is gradually increase that is quite obvious. So, and this surfaces are acting like a like an artificial spark plug.

So, when whenever is as it artificial spark plug and whenever a compressed charge is coming in contact with those surfaces then, the those you know comb again compressed gas, compressed charge will be ignited and as if we are igniting before the main flame main flame reaching over there so, we are preigniting combustion product. So, that is why it is known as preignition. So, the process is known as preignition.

Why it is preignition? Because the farthest this charge which is loc which are located; the farthest compressed charged which are located maybe in CC, DD or BB from there even we can see that the flame the charge is getting charge is getting initiated because of the highest temperature not only that secondary flames having developed; that means, even without reaching the main flame front over there actually in we are expecting that whenever main flame is developed from the spark plug regime, that flame will try to propagates in the with the across the combustion chamber. So, the charge very adjacent to that flame will again the temperature of the charge which adjacent to the main flame will be higher and their charge will be ignited and in this way the entire combustion product entire com entire compressed charge will take part in the combustion.

But what we can see that it is not the case even up the before that main flame reaching the locations like BB, CC and DD there might be a situation from there we can get flames; that means, their compressed charger charges are getting ignited. So there, there are locations in the combustion chamber where we even we get ignition a priory that is a preignition. So, this is why it is known as the process is known as preignition.

So, what we can see this preignition also increases the temperature and pressure. So, preignition tends to there is a temperature and pressure in the process that is what we can see because we will have a several flames. So, it will increase the temperature and pressure and because of this higher flame pressure and pressure the temperature in these locations and also in the surrounding cylinder will increase again further in the and the succeeding cylinder will be increased further.

Now, the this cumulative effect. So, temperature was temperature at the location BB are automatically higher was already higher now, because of this you now artificial combustion over there, because of this artificial you know existence of spark plug I mean because of the hot spot the temperature will even be even will be higher in the succeeding stroke. So, the cumulative effect of these not only will tend to raise the

pressure and encouraging the detonation to occur, but also it allow the peak pressure that is the 0.1 to go even beyond the closure to TDC.

That means there might be situation when this peak pressure might go even closer to TDC and so maybe 2. So, now, because of this cumulative effect preignition or surface ignition, peak pressure this surface ignition will keep on increasing the temperature of those hot spotted hot hot spot not only that and am in this hot spot or in the succeeding cylinder not only that so the rise in pressure and temperature this cumulative effect not only in not only increase the det pro probability of having detonation and also the temperature it also will try to you know it also will try to create peak pressure inside the cylinder during the compressions during the; during the combustion which is very closer to the TDC at 0.2 what we can see.

Now, if the peak pressure even be occurs before the TDC so piston has not reached at TDC; that means, before reaching piston TDC peak pressure occurs, that pressure will create resistance for the upward travel of the piston and we will get we will; we will we need to sacrifice the overall efficiency of the engine.

So, this preignition may also cause damage through burning of this engine so what we can see, because of the surface ignition temperature a few temperature at certain locations that is what we have discussed spark plug, exhaust manifold, piston face will go high that may leads to damage of that locations damage of thus those parts through burning of course, not only that this peak pressure rise will again the rise in peak pressure we will try to it will enhance of undesirable phenomena like detonation or knocking, not only that the cumulative in fact, will allow peak pressure to occur even very close to TDC and piston sometimes it may occur even when piston has not reached at TDC.

So, during that case piston will face resistance and we need to sacrifice the efficiency not only that it will make a very jerky operation of the piston. So, as if piston has not moves moved at TDC, but there peak pressure is rising so, piston with resistance so we will have a jerky movement jerky motion of the piston.

So, and so this is a very undesirable phenomenon and this is one part of the abnormal combustion. So, I will write now that what are the you know consequence of having this abnormal phenomenon we have discussed.

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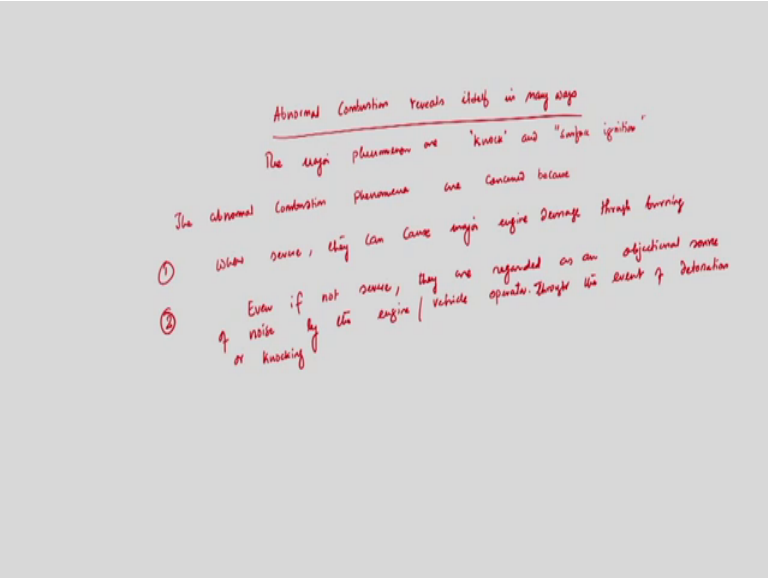

So we can we can write this abnormal combustion; abnormal combustion revels itself in many ways; in many ways right. So, the major; the major phenomenon are knock and surface ignition or preignition that is what we have discured discussed; that is what we have discussed. So, the measure phenomenon are knock and surface ignition.

So, the abnormal combustion phenomenon phenomena are of concerned because so the abnormal phenomenon abnormal phenomena; the abnormal combustion phenomena are concerned concerned because number one very important when severe they can cause major engine damage through burning that is what we have discussed that, cumulative rise in temperature in those places may you know leads to permanent damage through burning. So, when severe they can cause major engine damage through burning.

Number two, even if not severe; even if not severe they are regarded as an; they are regarded as an objectional source of noise objectional source of noise by the engine or vehicle operated through the through the event detonation or knock. So, even if not severe they are regarded as an objectional source of noise by the engine or vehicle operators through the event of detonation or knocking.

So, these are the very important consequences. So, abnormal combustion is not desirable at all. If severe that is what we have discussed the rise in temperature pressure will be so high that it may leads to damage of a permanent damage of the engine parts through burning of course, even if they are not severe they are considered they are; they are

regarded as an objectional source of noise by the engine or vehicle operated through the event of detonation or knocking.

So, now we have discussed that what is preignition in detail, we have discussed what is knock of course, and preignition occur only because of the continual rise of the temperature of you know some; you know some parts of the or some of the boundaries of the combustion chamber like piston phase, valve and exhaust manifold and they these spots can be considered as a the exist as if the artificial spark plug so, whenever compressed charge is coming in contact with those locations we may have combustion from there also and of course, combustion means we can get existence we can get the visible flame.

So, whenever flame is being developed that this planes will try to propagate and there might be a situation when the main flame front will not be able to reach before the secondary flame front start propagating they will collide each other and eventually there will be a violent vibration and we may get a noise and which is known as detonation or knocking.

So, now you should know that by how we can control the detonation or knocking; that means, detonation or knocking we are having.

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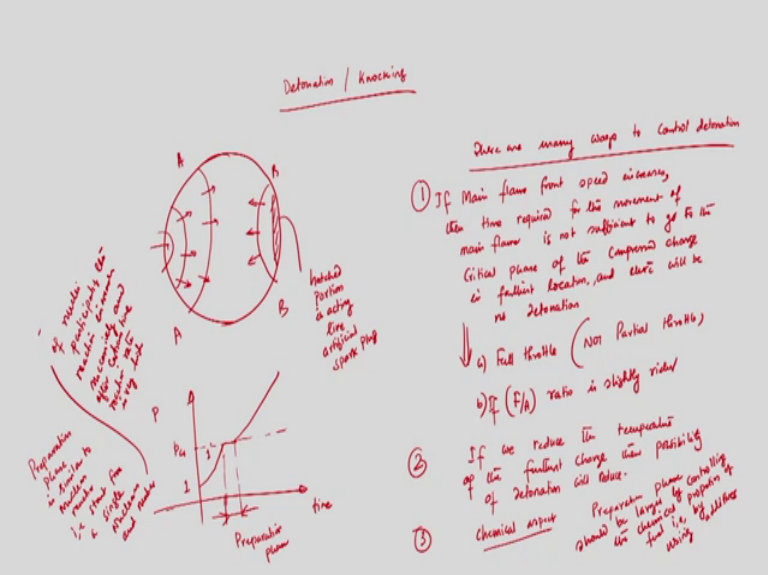

Detonation or knock knocking this is very important that if I try to draw again a schematic. So, maybe we are having one spark plug over here. So, main flame front is moving in this direction, now if this hatched portion maybe acting like a so this hatched portion is acting like artificial spark plug.

So, whenever combustion compressed charge will come another secondary flame will developed. So, maybe this is A and this is BB and this secondary flame will try to move in this direction. So, if I somehow can mitigate suppress the propagation of the secondary flame there is no chance of having cavitation is chance of there is no chance of having detonation, but if we cannot suppress or prevent the propagation of the secondary flame maybe that depends upon so many factors we will discuss now. So, there will be a movement when these two flames A and BB will collide each other and will results a violent vibration with an audible noise and that is known as detonation.

So, now there are so what how we can control, first let me now discuss that if we can control the; control the detonation if you would like to control the detonation what we have to do we have to control the movement of the secondary flame if you can by how?

There are ways many ways if we can increase the speed of the main flame if we can suppress the speed of the secondary flame that is possible, now if we increase the speed of the main flame or if we if we suppress the speed of the secondary flame there is no chance of having detonation, but if we can increase the although the secondary flame is being developed and it will try to propagate. Now if we somehow increase the speed of the main flame then what will happen the time the main flame will take to reach at section BB by that time secondary flame has not being developed at all or although it is developed it has not you know; you know started its journey.

So by that time the secondary main flame will try to restrict the propagation of secondary flame itself so we can prevent detonation. The hatched portion is acting like a artificial flag not only that sometimes maybe the temperature of that hatched portion is not high to initiate combustion, but whenever main flame front is progressing and this main flame will acting like a piston. So, the movement of the main flame will be you know will be as if a piston is now putting pressure on the for discharge which is there in section BB.

So, I am assuming now the temperature of the section BB we can somehow able to control beyond a particular limit now, the temperature is not high enough to initiate

combustion over there, but the main flame front movement main flame is the movement of the main flame is just like a piston is moving and a piston is putting pressure on the furthest charge that is there in section BB.

So, because of these pressure, the pressure will increase over there at section on the you know pressure will increase in the in section BB. So, because of this raise in pressure again whatever maybe the temperature may temperature is not so less, but temperature is not enough itself to initiate combustion, but rise in pressure because of this movement or because of travel of the main frame; main flame the pressure at of the compressor you know of the compressed charge in section BB is will increase will be increased and that pressure will allow the compressed charge to take part in the to initiate combustion with that temperature what is there in section BB.

So, what I can say, that there are so many ways there are many ways to control detonation. What are the ways? So, number one is you know flames front speed decreases if the flame front. So, I can see now if the main flame front speed decreases detonation will be there this is obvious. So, increase main flame front so main flame front speed increases if main flame front speed increases then, time required; time required for the movement of the main flame.

For the movement of main flame will be if main flame front speed increases then time required for the movement of the main flame front main flame front is not sufficient; is not sufficient to go to the critical phase; to go to the critical phase of the; to go to the critical phase of the compressed charge in a you know for you know in a in a you know farthest location so location and then there will be no detonation.

That means what is the critical phase. So, whenever it is very important what is the critical phase of the compressed charge? Now as I said you that the main flame front is acting like a piston. So, it is putting continuous pressure on the compressed charge that is there in section BB. So, you now if I now plot that pressure at section BB will increase temperature I am not somehow if I can somehow if you can able to maintain temperature of section BB to a limit which is not sufficient to initiate combustion of the compressed charge ah; of the compressed charge that is there now, but because of the movement of the main flame, the pressure of the furthest charge will increase and pressure is increasing let us say from 1 to 1 prime and this is critical pressure.

So, this is critical pressure P critical or critical phase then the compressed charge we require certain amount of time and if I plot with time versus pressure; time versus pressure then this critic this is known as this time is known as you know preparation phase. So, preparation phase just like a this is known as preparation phase and then the high a pressure rise will be high so DP rate will be high.

So, this preparation phase which his similar to the nuclear reaction. So, maybe compressed charge that is there in section BB if the travel of the main frame the travel of the; travel of the main flame will try to rise try to increase the pressure of the furthest charge that is there in section BB. So, there will be a movement when the pressure of the compressed charge in section BB will be critical pressure.

Now, we recall certain amount of time finite time that is known as preparation phase that is; that is essentially the which is similar to nuclear reaction the chain reaction, but up if I allows that certain time period then there will be huge pressurize because of the combustion. So, then after this preparation phase only the entire combustion of the combustion from the combustion from the farthest charge that is combustion section DB will start.

So, now if I somehow can increase the speed of the main flame in such a way that, that the time required up to the preparation phase the movement the time required to travels the main flame up to the location BB is always is very less and even it is lesser than the time required up to the preparation phase of the furthest charge then there is no possibility of having detonation. So, this is true by how we can increase and to increase the main flamefront speed what you have to increase we have to increase the we need to how full throttle.

So, we require full throttle not partial throttle so not partial throttling. So, this is full throttling. Number two is or a number one is full and A is full throttle, B is if we increase fuel air ratio. So, fuel air ratio is slightly richer. So, if fuel air ratio is slightly richer then also main flame front that will be will increase. So, these are the two, number three is that is very this is obvious that if we reduce the temperature of the farthest charge.

So, if we reduce the temperature of the farthest charge then possibility of detonation will be reduced this is very this is quite obvious. So, if we if we supply more coolant we need to know that if we keep on increasing coolant then it will reduce the temperature in such

a way that again it will drop current efficiency, but if you can maintain the temperature up to a limit which will not allow the secondary flame development of the secondary flame then perhaps we can you know reduce the possible you know detonation possibility of detonation.

And number three; number three is very important that chemical aspect; chemical aspect that is as I said you that preparation phase. So, preparation phase which is similar to this preparation phase is similar to nuclear reaction it start it is it similar to nuclear reaction; similar to nuclear reaction start from a single nucle that is start from a single nucleus; start from a single nucleus and number of nuclei and number of; and number of nuclei participate participating ; participating the you know chain reaction participating participating in the reaction in the participating the reaction increases successively and after certain time after certain time this reaction rate is very high.

So, this is this preparation phase similar to that temperature of the section BB is not so high, but somehow the movement of the piston it just like just is acting like a piston and it is increasing the pressure of the farthest charge. So, now, we require certain time that is preparation phase all the pressure has these are the critical value, but we require certain time which is known as preparation phase that just like a chain reaction. So, initially there will be a one nuclei, but and one nuclei and slowly the number of nuclei participating in the reaction will be increasing and after certain time the entire there will be huge rate of the rate of reaction will be high and the entire combustion will be completed and then that combustion will start.

So, the chemical aspect is chemical aspect of the fuel is that preparation phase should be larger by controlling the chemical property of the fuel. So, if we can control the preparation time, preparation phase should be larger; preparation phase should be larger by controlling the chemical property of the fuel by controlling the chemical properties of fuel that is by adding; that is by adding; that is by using in a additives or using additives that is why using additives.

That means somehow if I can increase the preparation phase by altering the chemical composition of the fuel by using additives, we can see that by that time main flame will be reaching at section BB. So, we can suppress the formation of the secondary flame at

rather formation of the secondary flame in section BB. So, there is no chances of having detonation.

So, these are the ways by how we can control the detonation, also there might be situation that if we have the by altering the spark plug location. So, if we can somehow cylindri the pist is pist a engine cylinder is a cylindric cylindrical shape. So, instead of putting spark plug in a particular location bringing close to the one bounded we close to the boundary if we can place at the middle and then perhaps the formation of the travel of the main flame will try to proceed in a fairly uniform manner in the combustion chamber. So, might be there might be a the chances of detonation might be reduced. So, what we can see from this is the overall aspect of the SI engine combustion.

So, we have seen that somehow we cannot prevent formation of secondary flame because the temperature and pressure a temperature of the temperature of some boundaries in the combustion chamber will go high because of the cumulative effect, but although the compressed charged when you are coming into con coming in contact with those locations we there might be initiation of the combustion since they are acting like a like artificial spark plug, but what we can do the farthest charge may take part in the combustion, but we should not allow the formation of this you we should not allow the propagation of the secondary flame and for that if we do some if you if we take some preventive steps like whatever we have discussed then perhaps we can reduce the detonation.

So, from this today's discussion from the, to from the today's discussion what we can conclude that, somehow we need to know what are the factors that affects the main flame speed. So, if you can somehow increase the speed of the main flame probably we can reduce the chances of having detonation in the context of operation of spark ignition engine. So, what are the factors increases the main flame front again I will discuss in detail and that part I will discuss in the next class.

So, with this I stop here today and I will continue my discussion in the next class.

Thank you.