Applied Thermodynamics
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Module - 03
Internal Combustion Engines
Lecture - 23
Basic Engine Cycle and Engine Kinematic Analysis

Welcome to this course, Applied Thermodynamics. We are in the module 3, that is Internal Combustion Engine.

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So, in this module we had 9 lectures. In the first lecture, we discussed about the internal engine, its components, nomenclature, and classifications.

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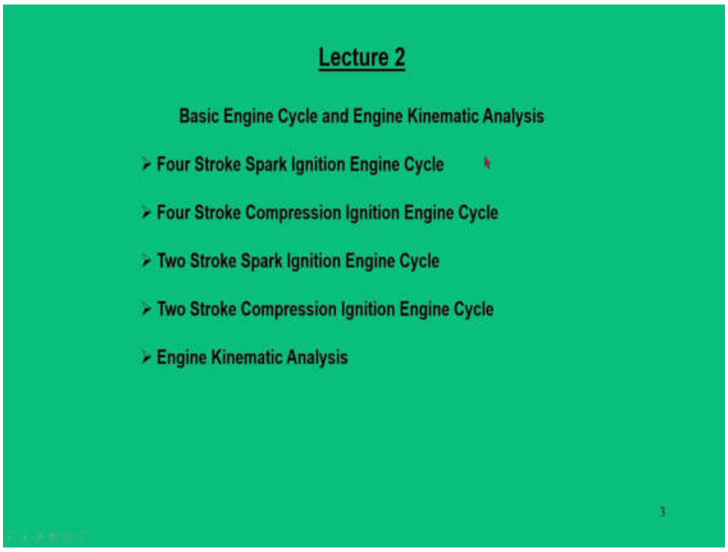

Now, we are in lecture number 2, and for this we are going to discuss the following contents, that is the basic engine cycle and engine kinematic analysis. And in this lecture, we will be focusing on four-stroke spark ignition engine cycle, four-stroke compression ignition engine cycles, two-stroke spark ignition engine cycles, two-stroke compression ignition engine cycle, and towards the end of this lecture we will discuss about engine kinematic analysis.

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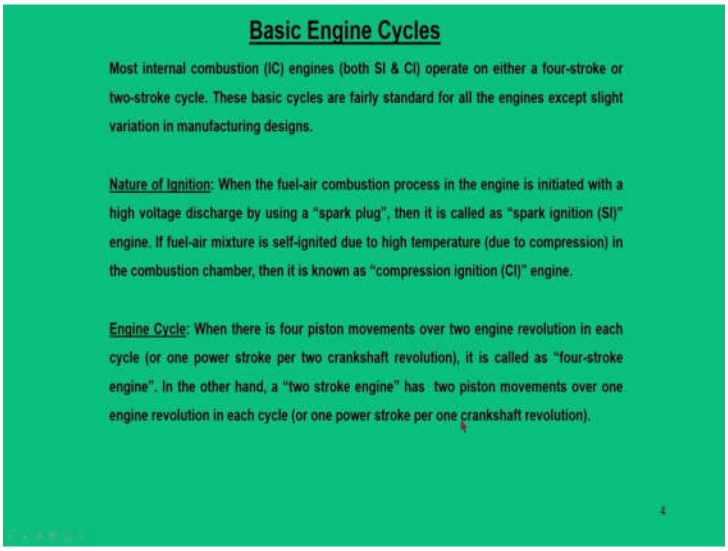

Now, let me go through these some of the basic things that we discussed in our last class that one of our important method of classification of IC engines is on SI mode or CI mode. And both the engines, they can either operate on four-stroke cycle or two-stroke cycles.

Of course, although there are some basic insights about the four-stroke cycles which is very common nowadays, but we will also try to discuss about something two-stroke engine cycles which were already in existence for decades. But nowadays, those two-stroke engine cycles in the manufacturing industries they are obsolete now. But the basic design between these two are almost similar, but there are some mechanisms which are different for SI engine and CI engines.

So, when you do this engine classification we do in two ways, one is nature of ignition and in this nature of ignition what we say is that the fuel and air mixture in the combustion process is ignited through a high voltage spark and mechanically you use a spark plug that gives an electric discharge. So, in this method, what we do is typically for air fuel mixture is that we forcibly ignite the charge. So, that is what it is called spark ignition engine.

But if the fuel and air mixture is self-ignited by itself due to high temperature during compression stroke, then it becomes a compression ignition engines that means, fuel air charge is self-ignited.

Now, when you talk about engine cycle there are two ways we define or classify the engines. One way is that the there is four piston movements over two engine revolutions in each cycle; that means, we are going to get one power stroke per two crankshaft revolution. So, we call this as a four-stroke engines. On the other hand, in a two-stroke engine there are only two piston movements over one engine revolution in each cycle; that means, we are going to get one power stroke per one crankshaft revolutions.

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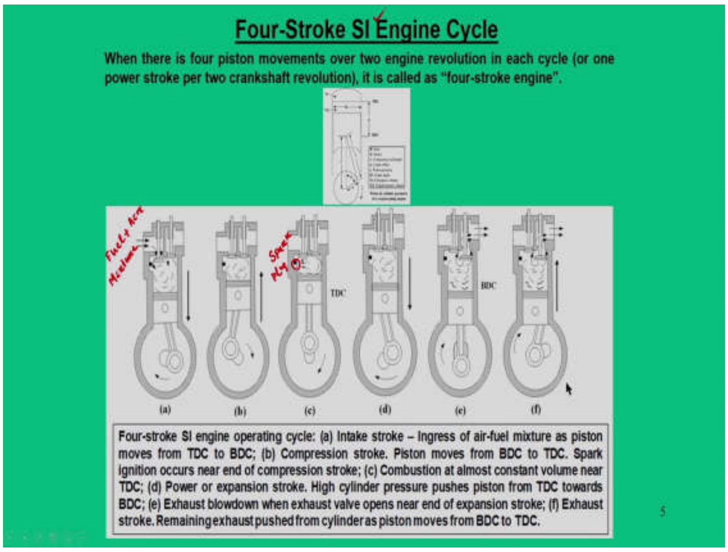

Now, let us start the first classification that is four-stroke spark ignition engine cycle. So, remember one thing here that we are talking about spark ignition modes; that means, here we will have air fuel mixture as a charge. And they are forced to be ignited through spark plug. And what we are going to get is that one power stroke per two crankshaft revolutions. And there are typically four-strokes. What are they; we are going to explain now. And we call this as a four-stroke spark ignition engine cycles.

So, to do this analysis first recall our classical figure this engine terminology in which we said that piston has to extreme locations that is top dead centre and bottom dead centre. And the piston moves between these two locations, that is the topmost location we call it as a top dead centre and the bottom most location is the bottom dead centre.

When the piston is at TDC entire charge is compressed fully. When the piston is at BDC entire charge is expanded fully. And at any instantaneous positions we can represent the piston, its crank, connecting rod, the crank pin and the crank shaft in this manner as you see here. But at the outset what I can say is that just remember that there are two extreme locations TDC and BDC.

Now, with this philosophy let us try to explain that how a four-stroke SI engine cycle work. So, if you look at this particular figure there are 6 particular instantaneous positions that has been represented here. And all of them represents a complete four-stroke cycle and the cycle happens or starts with ‘a’ and ends with ‘f’, and again after ‘f’ then it goes to same original position ‘a’. So, next cycle starts.

So, what are they? So, the first figure a, represents the intake stroke, and this is what we called as a first stroke. So, what happens in this stroke? Ingress of air fuel mixture as the piston moves from TDC to BDC. So, in this process what happens? Piston moves from TDC to BDC, the inlet valve opens, the charge comes in, and when the charge comes in, this charge we call as fuel air mixture, and remember it is a SI engine cycle.

Next, we move to compression stroke. Now, this intake process ends, when the piston comes to the BDC position, and for the compression stroke piston moves from BDC to TDC. So, when the piston moves from BDC to TDC, both the valves were closed and entire charge gets compressed.

And exactly when the piston is at TDC in figure c; that means, entire charge is fully compressed and here we have a spark plug. So, this spark plug gives adequate voltage to this charge. So, that they can be ignited. And during this situations both the valves are also closed.

Once the charge gets ignited, the pressure and temperature also switches up. And in the process of increasing the pressure the piston receives force in which the piston has to travel its path in backward direction that is piston starts from moving from to TDC to BDC. And that is what we call this as a expansion or power strokes.

So, in this process high cylinder pressure pushes the piston from TDC towards BDC. So, this process keeps on continuing till the piston reaches BDC. And as power stroke ends, the piston is exactly at BDC.

Now, once the piston is at BDC, what happens? By the time your exhaust valve starts opening or as the piston is about to make its path reversal, the exhaust valve starts opening. When it starts opening this entire charge has a tremendous pressure and momentum that forces them or drives them out on its own through the opening passage of this exhaust valve.

Now, what happens? But there are some charge still remains then piston has to travel backward, again, from BDC to TDC to push all unwanted exhaust product out of the cylinders, and during this process your intake valve is closed. So, in this continuous process, what happens?

There are four-strokes, one is intake, compression, power stroke, and exhaust stroke. That is the region we call this as a four-stroke. And why we say? In this entire cycle there is only one power stroke, and through this process by the piston reversal of two motion, the crankshaft has made two crankshaft revolution in this process.

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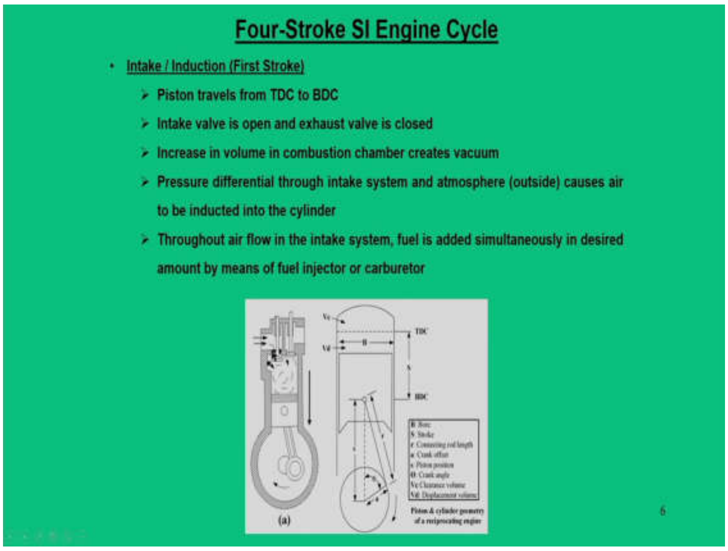

Now, we will go step by step. So, whatever I have explained, it is explained in the step by step, but in addition to that there are some other concepts which were introduced here. So, when you recall this figure ‘a’ first, so piston moves from TDC to BDC, that is the first or intake stroke.

And in this process, only intake valve is open and exhaust valve is closed. So, during the injection of the charge into the cylinder, there is a increase in the volume in the combustion chamber because it is done through this piston movement from BDC to TDC.

Now, when during this process also how this charge enters? That is a pressure differential that gets created at the intake system. And throughout this air flow in the intake system, fuel is added continuously by desired amounts by fuel injector or carburetor. So, there are ways that we can directly inject the fuel. We can use the fuel and air mixture together into combustion chamber or fuel can be injected through fuel injector or mixture can be prepared through carburetor and they can directly enter through this intake system.

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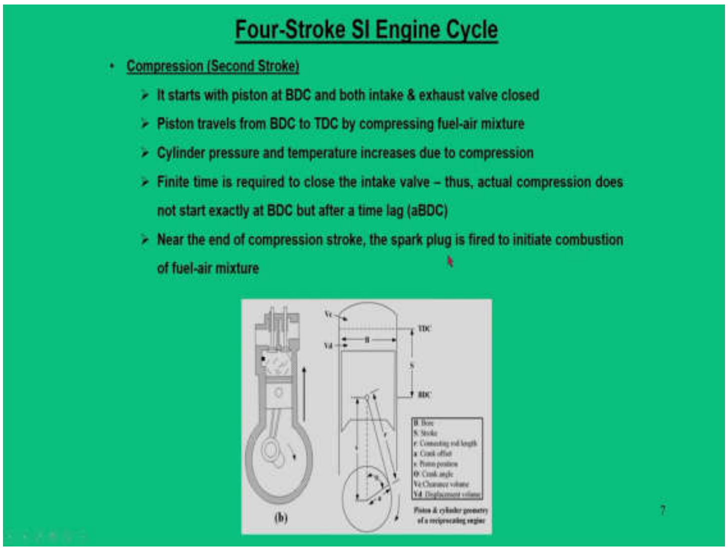

Now, in the compression stroke the piston moves from BDC to TDC, and during that point of time both intake and exhaust valves are closed. So, air fuel charge gets compressed. The cylinder pressure and temperature is increased it because the process is typically adiabatic in nature.

So, you can call this an adiabatic compressions. Now, what happen that when the piston is about to reach towards the end of compression stroke, we want to ignite this charge. So, a finite time is required to close this intake valve. So, the actual compression does not exactly starts at BDC, but it starts after a time lag that is after BDC.

So, basically, the actual compression does not starts at BDC which is supposed to be in ideal in nature, but it starts after a time lag in actual scenario. And towards the end of this compression stroke, the spark plug is fired to initiate the combustion of fuel air mixture.

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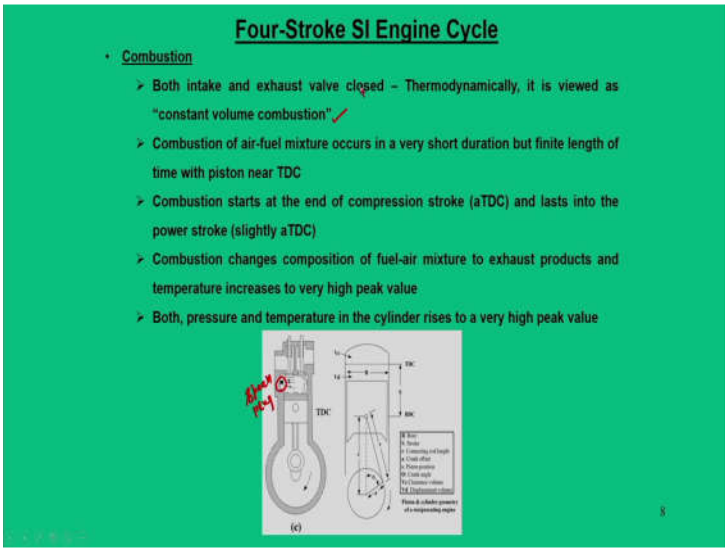

Next we call this as a combustion. So, during the combustion process, the piston is already at TDC and it is about to make its path reversal. That mean for the next subsequent stroke it has to travel from TDC to BDC, but to do that we need some force from the charge. How that force from the charge comes in? Because once it is fully compressed the charge is ignited through a spark plug.

So, the spark plug creates a high voltage spark that ignites the charge and through this ignition process we get a rise in the pressure and temperature, and this rise in the pressure adds to force on the piston phase that allows the piston to start the next cycle. And here, one of the important thing that we say that this combustion process is treated as a constant volume combustion.

This is most important thing that you do in this spark ignition engine because if you look at the combustion that happens at the end of the compression stroke, we can see that it is a closed volume, and this closed volume we have air fuel mixture charge, which is typically a constant quantity and we create the combustion through this charge. Since, the volume is kept constant, so we call this as a constant volume combustion. So, this is how the combustion that is viewed thermodynamically for a spark ignition engine cycle.

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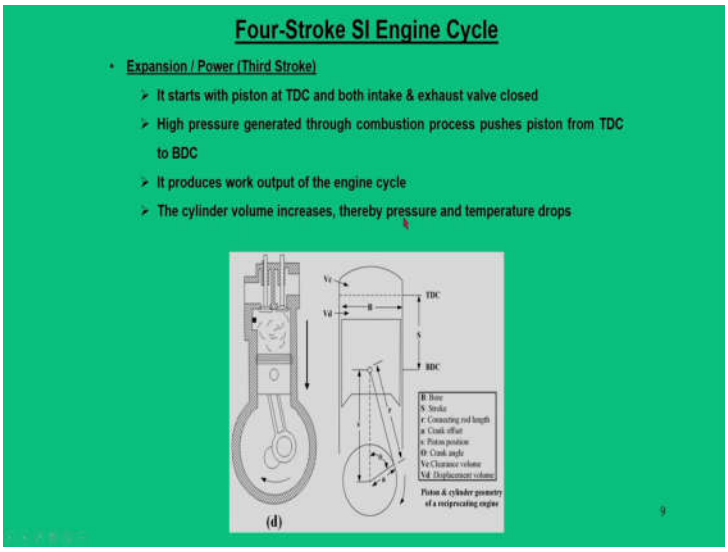

Then we moved to third stroke. So, by the end of combustion piston had received sufficient force on its face, so it is about to move from TDC to BDC. And this is happened because high pressure generated in the combustion process pushes the piston down. And this is the only one stroke in which work output we get in the form of crankshaft revolutions. And in this process of expansion process, the cylinder volume increases, thereby the pressure and temperature drops.

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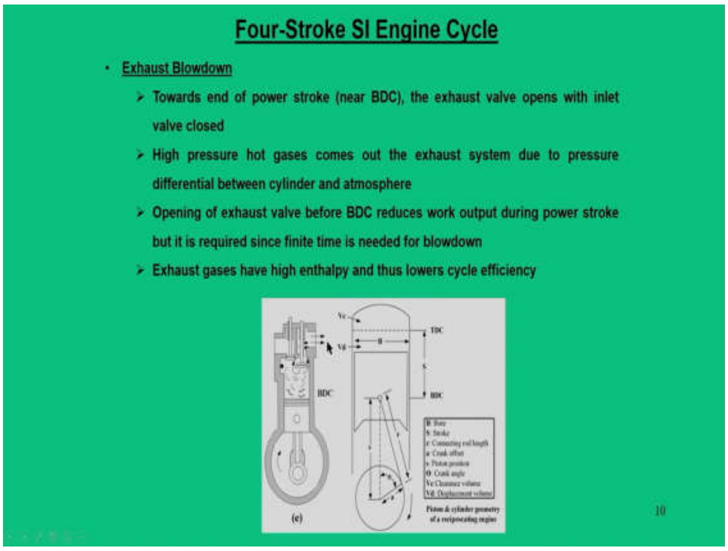

So, once the exhaust stroke is about to complete, then the entire charge in this cylinder is mostly the combustion products; that means, we say it is a unwanted products. But they have very high pressure and temperatures; of course, this high pressure gives necessary momentum for the charge to go out through this passage.

So, towards the end of power stroke the exhaust valve opens, so this entire momentum of the charge on its own gets out of the through the exhaust passage. But as and when it goes out its pressures drops, after that they cannot go on its own. So, the piston has to do a backward motion from BDC to TDC to push them out. So, we call this as a exhaust blow down. Of course, it is not a stroke, but it is a just blow down, because the charge on its way gets out from the cylinder.

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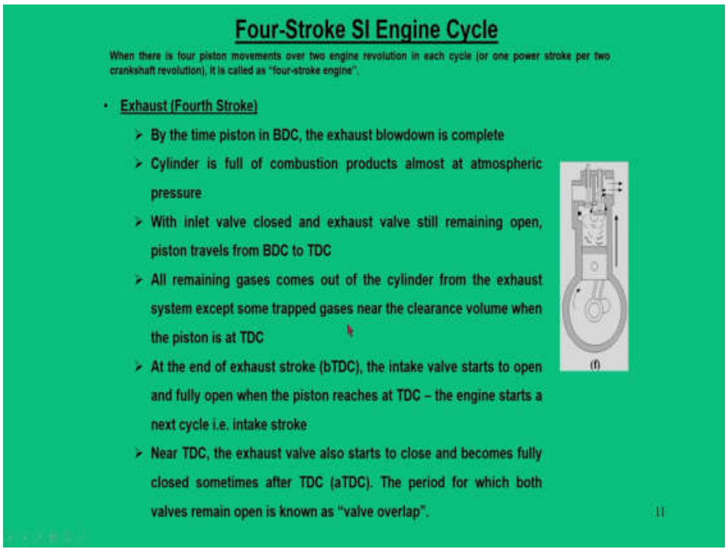

The next stroke is the four-stroke that is exhaust stroke. So, as I mentioned that by the time the exhaust blow down is over the charge does not have sufficient momentum. So, the piston has to push them out through this exhaust valve. So, this particular stroke we call this as a exhaust stroke or and this is the four-strokes. And during the process the intake valve or inlet valve is closed and exhaust valve remains open.

Now, by the time what happens? The piston travels from BDC to TDC, what happens, the intake valve starts opening because these exhaust charge comes out and intake valve starts opening. Because there are some finite time lag, these valves needs to open and close.

So, there is a synchronization between these inlet valve and exhaust valve. So, by the time exhaust valve slowly closes, inlet intake valve starts opening. So, in this process also, for some period both the valves remains open, so that we call this as a concept of valve overlap that is the period for which both the valves remain open is known as valve overlap.

So, in this process of valve overlap analysis, we will be using the concept of reference line of TDC and BDC, then we use the terms like bTDC; that means, before TDC or aTDC means after TDC. Similarly, we can say before BDC and after BDC. So, all this terminology which we will be using frequently in this reference. And with our main ref concept is that we have reference as TDC and BDC.

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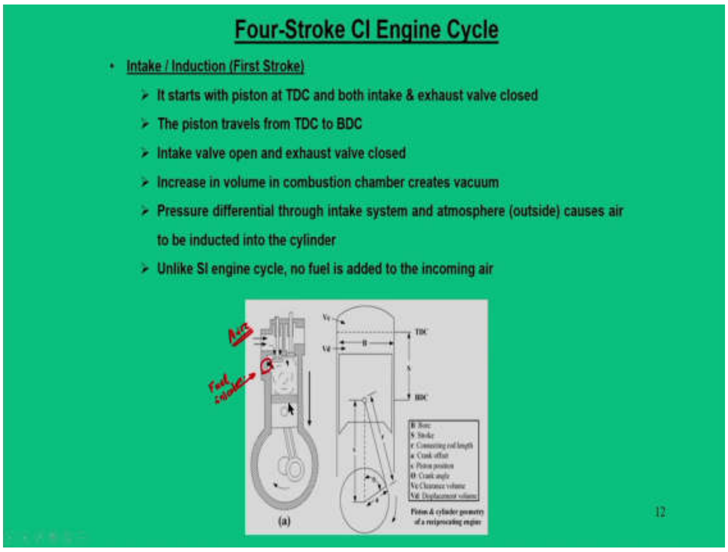

Now, we will move to the next engine cycle that is four-stroke CI engine cycles. So, remember we have same four-stroke cycle, but it is in CI mode. So, CI mode means here we are going to see that we do not have fuel air mixture. So, in this SI engine cycle the fuel and air charge does not self-ignite, but in CI engine cycle we will see that the compression will make the air and fuel charge to ignites on its own.

So, in this case what we have is, in intake stroke we have only air and somewhere here we will have fuel injector. So, what happens? So, in the first stroke that is intake stroke, it starts with piston at TDC and that point of time both intake and exhaust valves are closed. Pistons travel from TDC to BDC, and through this motion a pressure differential is created. So, only air enters through this intake valve, and simultaneously air gets injected through this intake valve. So, entire cylinder volume is now filled with air.

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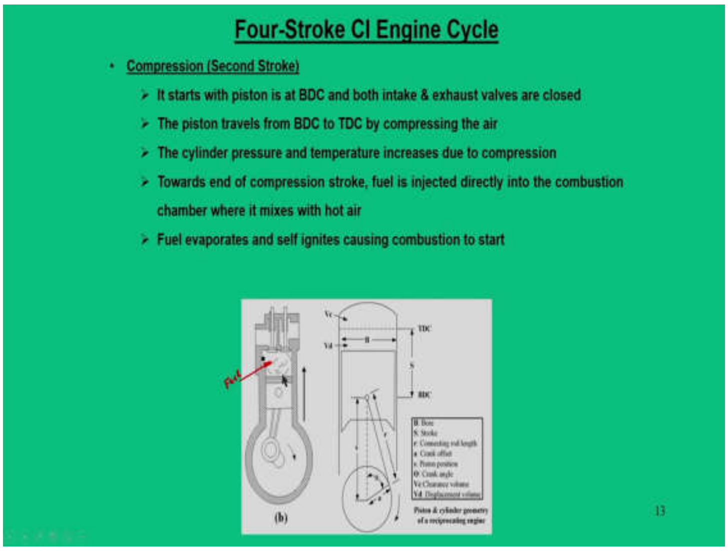

So, next stroke is the compression stroke. So, during the compression stroke, the piston moves from BDC to TDC, and in this compression stroke the air gets compressed. And through this compression process the pressure and temperature inside the cylinder increases. Now, towards the end of compression stroke fuel is injected directly into this combustion chamber.

So, basically towards the end of compression stroke, we starts injecting fuel. So, when the fuel gets injected into this what it sees is a high temperature air. So, when it sees this high temperature air, this fuel self-ignites, when it self-ignites, the combustion happens, and this combustion process pushes the piston back. So, after this compression stroke we have this combustion process, so here it is not called as a stroke, but simple a combustion process.

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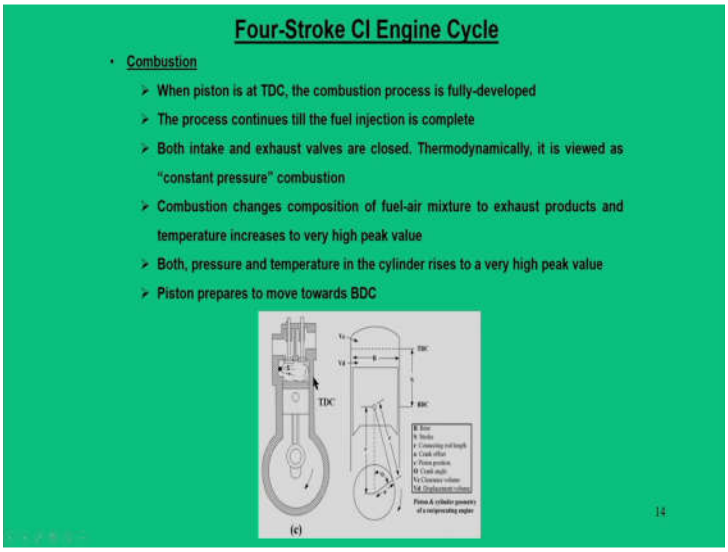

So, during this combustion process, we still have the situation when the piston at TDC, combustion process is fully developed fuel injection is complete and when the fuel self-ignites. So, basically, we cannot assume it to be a constant volume process as you did in the SI engine cycle because fuel is continuously added into the air. So, volume cannot be treated as a constant.

So, thermodynamically, an ideal approach would be to treat this process as a constant pressure combustion. So, we call this as a constant pressure combustions. So, once this combustion is over, so, it changes the composition of the fuel air mixture to exhaust product and temperature also increases to a very high value. So, when pressure and temperature increases, it keeps necessary force on the piston face and the cycle continues. So, piston starts moving in the expansion stroke.

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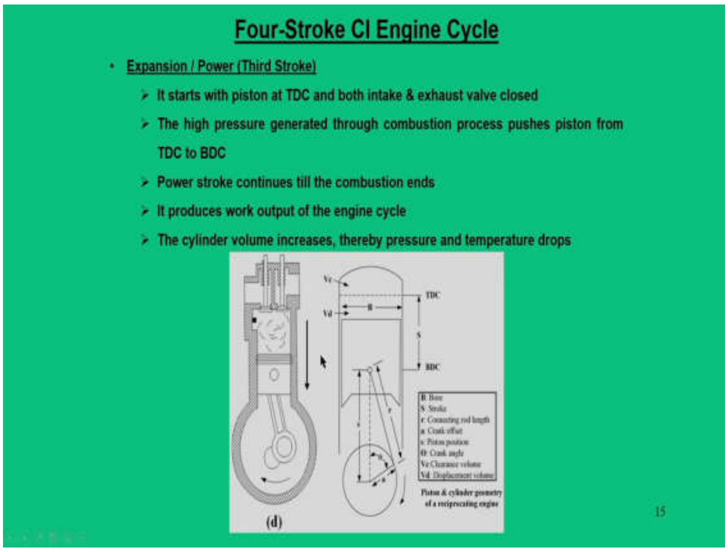

So, here we have this expansion stroke. This happens exactly in similar manner as you view in a SI engine cycles. Piston starts at TDC and ends at BDC. So, the power stroke continues till the combustion ends. And this is the only power cycle or power output in this continuous four-stroke cycle.

In similar way, when the combustion is complete, by that time the exhaust valve opens, the exhaust blow down starts and the piston is about to reverse its path from BDC to TDC. So, in the first process, the entire charge has necessary momentum that goes on its own to this exhaust port or exhaust valve. So, this is similar to what we see in a SI engine cycle.

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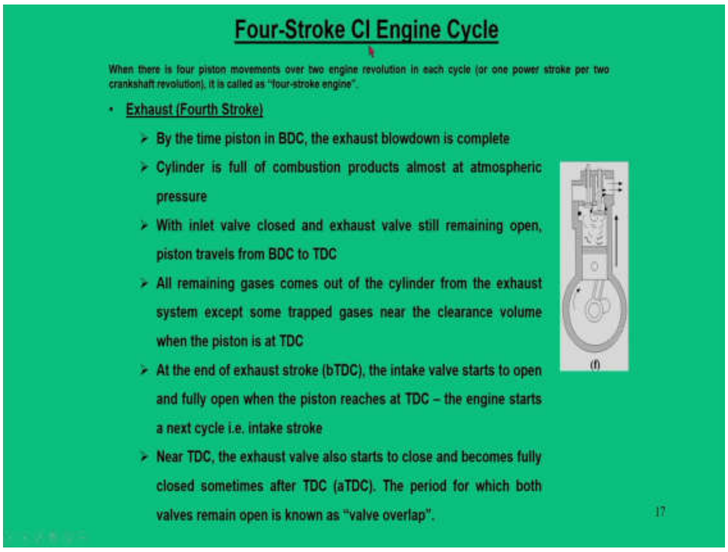

And the last stroke, what we see is the four-stroke in which the piston pushes all unwanted exhaust product out of the cylinder and by the time the exhaust valve slowly closes and inlet valve starts opening. And the same concept of valve overlap also applies here. So, again, here we see that still there are four-strokes, but one power stroke per two crankshaft revolutions. So, this is called as four-stroke CI engine cycle.

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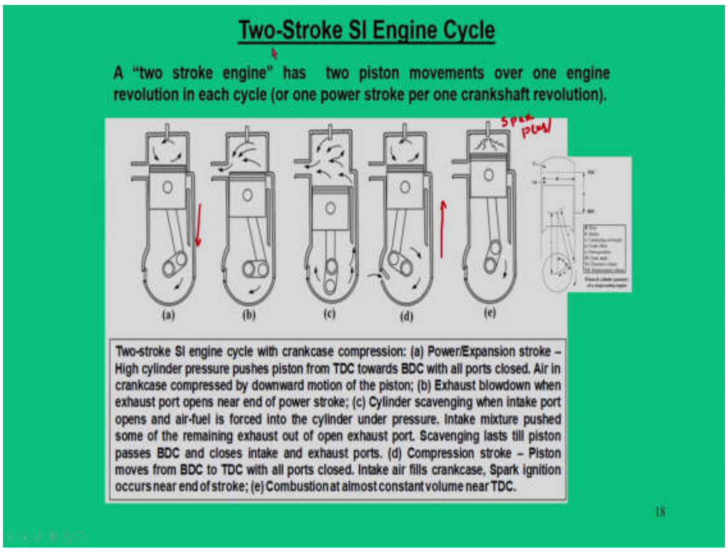

Now, we will move to the next engine cycle that is two-stroke SI engine cycle. So, here the concept of SI and CI remains same, but the number of stroke drops to two. Two means we are going to get one power stroke per one crankshaft revolution. So, we will see how we get it.

So, this particular sequence of events is shown in this figure and we call this as a two-stroke SI engine cycle with crankcase compression. The cycle starts with figure ‘a’. So, what we call this as a power or expansion strokes. So, remember, we have same notations TDC and BDC for this engine cylinder. So, the cycle starts with power or expansion strokes.

So, in this power or expansion stroke, high cylinder pressure pushes the piston from TDC to BDC. So, the piston has this downward movement. So, it goes from TDC to BDC. And with all ports closed, we do not have separate exhaust valve or intake valve as we see in the four-stroke cycle, but we have only one valve and there is a port here.

So, through this valve the charge can enter or charge can go out. And also there is a port, in this port only charge can enter. There is no out outlet of it. And the top portion what we see? Either it can be a spark plug or it can be a fuel injector depending on whether it is a CI or SI.

So, in the first stroke when the piston moves the backward as the high pressure on the cylinder pushes the piston in the backward motion that is from TDC to BDC. Now, when the piston is at BDC, the exhaust blow down starts.

So, in this exhaust blow down what happens? There are unwanted combustion products, so they have sufficient pressure and that pressure allows them to go out because by the time piston crosses this valve, this space is now empty, so the charge goes out on its own.

So, we call this as a exhaust blow down when the exhaust port opens near the end of power stroke. And the most important segment in this two-stroke cycle is that cylinder scavenging. Cylinder scavenging is a process in which the intake port opens and air fuel is forced into the cylinder under pressure. And simultaneously, the intake mixture pushes some of the exhaust product out of the exhaust port. So, this complete scavenging process, lasts till the piston passes the BDC and closes the intake and exhaust port.

So, this complete process is a very critical feature in SI engine cycle. In which, what it does? It does few important things. It creates or prepares a fuel air mixture, at the same time it pushes some of the exhaust product out, so we call this as a scavenging. And if you look see that point here, only the exhaust space is open, so that pushes the product out.

Next cycle happens the compression stroke. Now, during the compression stroke already it has prepared the charge and at the same time there are also fresh air or fresh fuel air mixture that comes in, and the piston moves from BDC to TDC.

So, this we call this as a compression stroke. And in this compression stroke all the ports are closed. So, intake air fill the crankcase and spark ignition occurs at rear end of the compression stroke. So, there are only two-strokes. So the combustion process happens towards the end of compression stroke, and it is done almost at constant volume near TDC. So, if you see there are only two-strokes, that is one power stroke and one is compression strokes. So, it is a two-stroke cycle.

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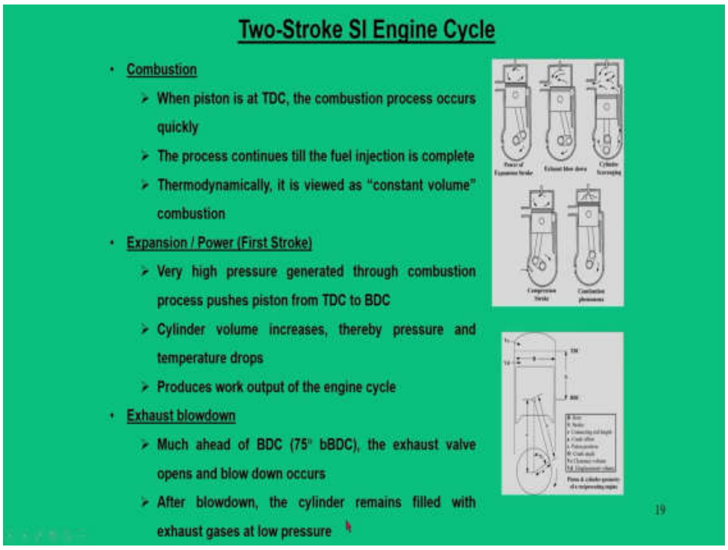

So, what I have explained earlier, and which is similar to a four-stroke cycle these are listed here combustion process. It is a constant volume combustion process if it is SI engine. And we have power stroke and we have exhaust blow down. Here we have given some notations that the in the blow down process the process starts 75 degree before

BDC. And after blow down, the cylinder remains filled with exhaust gases at low pressure.

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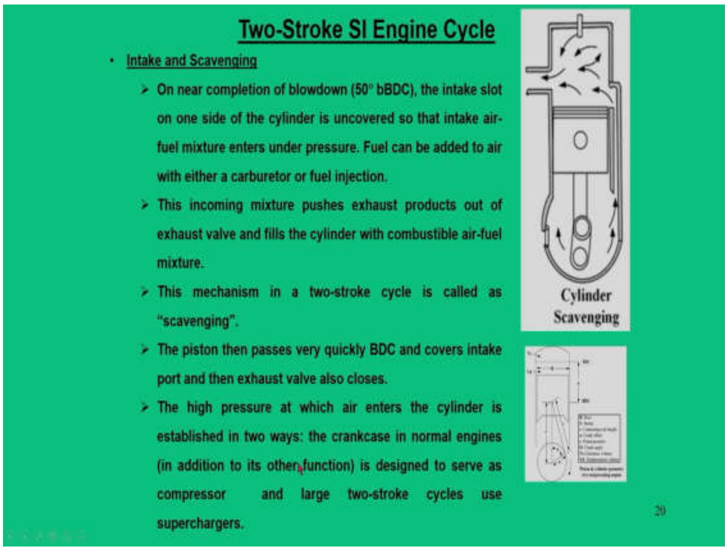

And this is the most important segment that is intake and scavenging. And this intake and scavenging starts near the completion of the blow down. It starts sometimes 50 degree before BDC.

Now, in this scavenging process, it can be a spark ignition mode, it can be a compression ignition mode. So, what we can have is that during the process fuel can be added to air either by carburetor or by fuel injections. So, scavenging is nothing but it is a preparation for engine for compression process.

And inside the cylinder, the high pressure at which air enters the cylinder is established in two ways, one is the crankcase in a normal engine or for large two-stroke cycle use supercharger. If this scavenging process does not give sufficient pressure then we have to use superchargers. So, this is an integral requirement for a two-stroke cycle.

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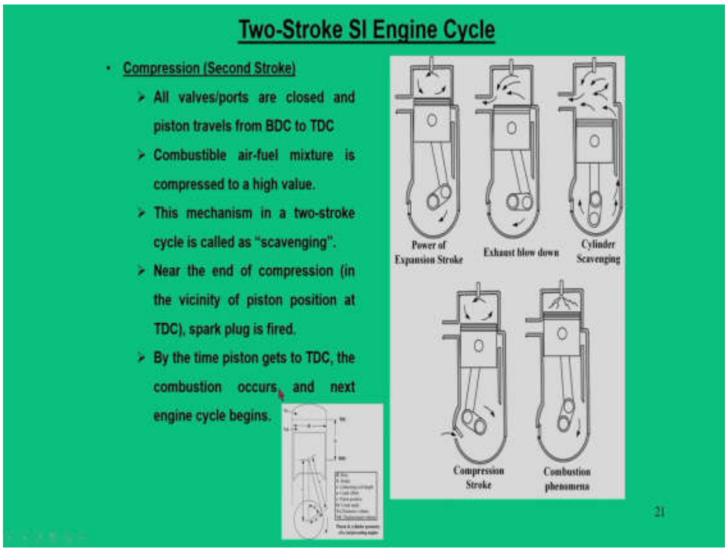

So, this is the second stroke, that is compression stroke for two-stroke engine cycle. So, there all valves are closed, pistons travels from BDC to TDC, and this mechanism in a two-stroke cycle is called scavenging. And near the end of compression, this spark plug is fired, so by the time the piston gets to TDC the combustion occurs, the next cycle begins.

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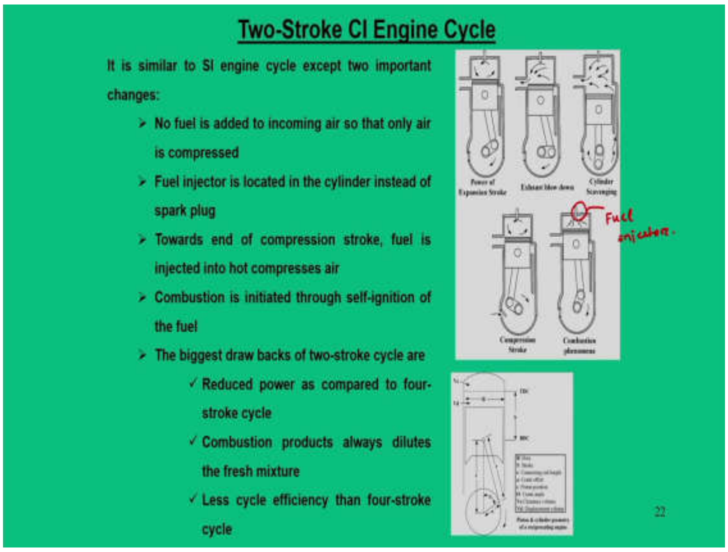

So, this is all about two-stroke SI engine cycles. Now, how way two-stroke CI engine cycle is different? So, two-stroke CI engine cycle is different in the sense that we know fuel is added to the incoming air. So, only air is compressed. So, during the compression stroke only air is compressed.

And fuel injector located in the cylinder instead of spark plug. So, what we see here, this particular components instead of spark plug we will call this as a fuel injector. So, what it does? So, when the entire air is compressed totally it, fuel is injected; this fuel sees a very high temperature charge air, and because of this high temperature, the fuel ignites on its own. So, we call this as a self-ignition.

But the biggest drawback in two-stroke cycles are they have reduced power with respect to four-strokes cycle. The combustion products dilutes the fresh mixture because it cannot be ensured that in one single port all unwanted gas goes out, still there are some unwanted combustion product remains in the cylinder. So, that is what it dilutes the fresh charge. Cycle efficiency is less as compared to four-stroke cycle.

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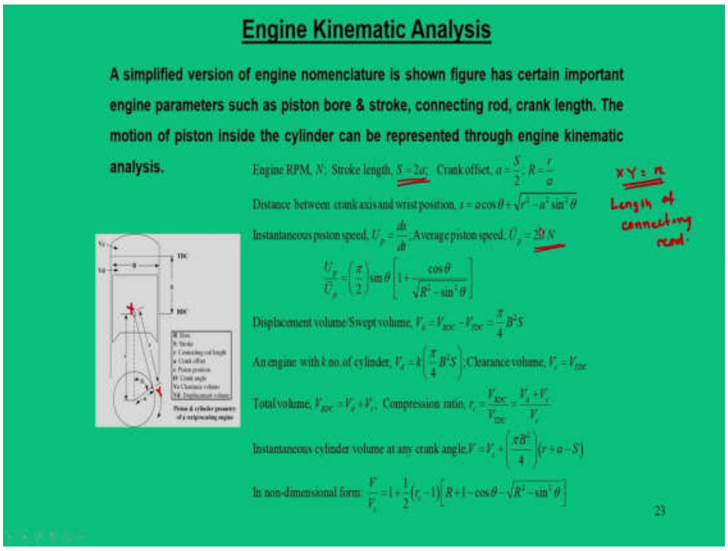

So, this is all about discussion on engine cycle two, four-stroke. What we have discussed is four-stroke spark ignition cycle, four-stroke compression ignition cycle, two-stroke spark ignition cycle, two-stroke compression ignition cycle. And in current scenario the widely used engines, they follow mostly on four-stroke cycle either it can be SI mode or it can be CI mode. This is the one manufacturing company they use this particular concepts.

Now, we will discuss something on engine kinematic analysis. To represent this engine kinematic analysis we consider the simplest version of this particular figure, and till this point of time we always talk about TDC and BDC. Now, we will go something more details on the schematic diagram. So, what we see from this figure, that we have a schematic of a cylinder in which there is a piston. The piston has a wrist pin or piston pin one end and it is connected to the crankshaft through a connecting rod.

So, this we call as a connecting rod or length of the connecting rod and this length of the connecting rod, I can mention as X-Y, and that is r. And we have parameter a and we call this as crank offset length, that is diameter or a radius of this crankshaft is at offset 'a' with respect to centre point o of the crankshaft. And the ratio $R = \frac{r}{a}$.

The other notations that I can say that is stroke that is S that is distance between TDC and BDC. And diameter of the piston is B. So, we call this as a bore the engine has RPM N, and we also say that clearance volume V_c stroke volume V_d. So, these are the notations we follow with respect to this particular figure.

And here to start with we are saying engine has an RPM N. The stroke length is S that is normally kept as 2a. So, this is the standard relations that is always maintained for a given engine so that $a = \frac{S}{2}$. And we also mentioned the length of the connecting rod R and we can create a non-dimensional number that is $R = \frac{r}{a}$.

So, in kinematic analysis, the linear motion of the piston is converted to rotational motion of this crankshaft. So, what we see at any instantaneous position or theta angle? The piston has one particular location and its linear motions. So, θ is the instantaneous rotary position of this crankshaft and that refers to a particular instantaneous position of the pistons. That means, it is piston location is somewhere within the engine cylinder.

And if you try to correlate, then we can make a geometrical relations that is $s = a\cos\theta + \sqrt{r^2 - a^2\sin^2\theta}$. So, this is simply trigonometric relations that can be derived from this particular triangle.

So, once we know s, so we can find out the instantaneous piston speed; that means, by differentiating this equations. So, U_p is the instantaneous piston position that is $\frac{ds}{dt}$. This is how the instantaneous piston position is defined. We can also define average piston speed, $\bar{U}_p$ that can be based on the stroke length and N. So, we can say that average piston speed can be represented as $\bar{U}_p = 2S\,N$.

So, from this U_p and $\bar{U}_p$, we can find a relation $\frac{U_p}{\bar{U}_p}$ in terms of θ and r. So, first you find s, differentiate with respect to dt, then you get U_p, then you get this particular relation $\frac{U_p}{\bar{U}_p} = \left(\frac{\pi}{2}\right)\sin\theta\left[1+\frac{\cos\theta}{\sqrt{R^2-\sin^2\theta}}\right]$. So, this relation will help us to find out at instantaneous piston speed. And also, we can find out the displacement or swept volume $V_d = V_{BDC} - V_{TDC} = \frac{\pi}{4}B^2 S$.

So, between B and S, it can be a square engine, it can be a under square engine, or it can be over square engine. If it is under square or over square that relation between B and S needs to be specified.

So, if nothing is specified, we can make an assumptions that bore is equal to stroke then that is most of the cases we call this as a square engine. So, this representation is about one particular cylinder. If there are k number of cylinders then we multiply this by k.

Now, if you got little bit of more into it to find the compression ratio from this information of clearance volume and stroke volume. We can find the compression ratio, $r_c = \frac{V_{BDC}}{V_{TDC}} = \frac{V_d + V_c}{V_c}$. And likewise we can get the average piston speed, we can find out instantaneous volume of the cylinder at crank angle θ that is $V = V_c + \left(\frac{\pi B^2}{4}\right)\left(r + a - S\right)$.

Once we get this and we also know clearance volume, so we can make a relation in non-dimensional form $\frac{V}{V_c} = 1 + \frac{1}{2}\left(r_c - 1\right)\left[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}\right]$ and here this non-dimensional relations as non-dimensional numbers like compression ratio, we have R.

And θ is the crank angle at any instantaneous position. So, this is how we can find out the entire information, and this comes under the heading that we say engine kinematic analysis.

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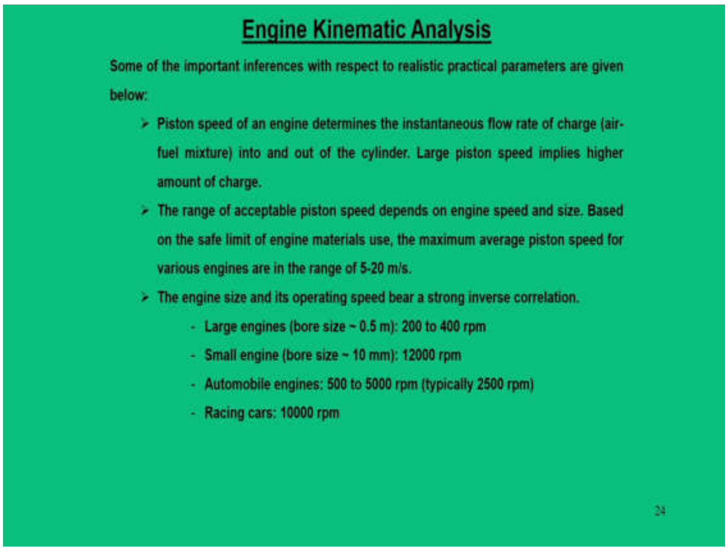

So, some significance of this engine kinematic analysis, it will tell you some realistic practical correlations. So, first thing is that it talks about the piston speed. And this piston speed of the engine normally determines the instantaneous flow rate of charge that comes into and out of the cylinders; that means, large piston speed implies higher amount of charge.

And in fact, as a user or as a manufacturer, one cannot use any kind of speeds because it creates many safety issues and for that there are range of piston speeds which are available for common engines that is in the within 5 to 20 m/s. And in fact, on this line, we can have a large engines where bore sizes is of the order of 0.5 m and there the engine rpm is in the range of 200 to 400 rpm.

For small engines the bore size is about 10 mm and where the engine rpm can go to 12000 rpm. And in normal automobile engines, the rpm is in the range of 500 to 5000 rpm. Racing cars will have in the range of 10000 rpm. So, these are the typical numbers that one should know which are commercial in the market.

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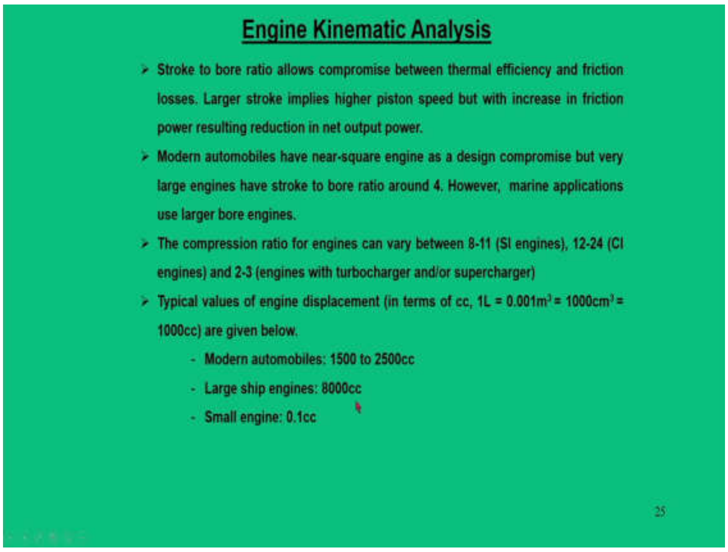

Now, some other information about this engine is that stroke to bore ratio. Stroke to bore ratio means we can have a oversize engine or we can say square engine which is normal and we can have a large bore engine. So, those engines are mainly used for marine applications, because large engine means we expect large amount of charge into the cylinder.

So, normally marine application use large bore engines. So, stroke to bore ratio can go up to 4. And other critical numbers for a conventional SI engines, the compression ratio is in range of 8 to 11, for CI engines it can be 12 to 14. And normally manufacturer specify engine displacement in the form of cc.

So, modern automobiles, their engine displacement comes in the range of 1500 to 2500 cc, ship engines can have 8000 cc, and even for small engines can have .0.1 cc. So, this is nothing, but cubic centimetre. So, this is how the engine specifications are made and with their engine displacement. So, with this we conclude this particular lecture.

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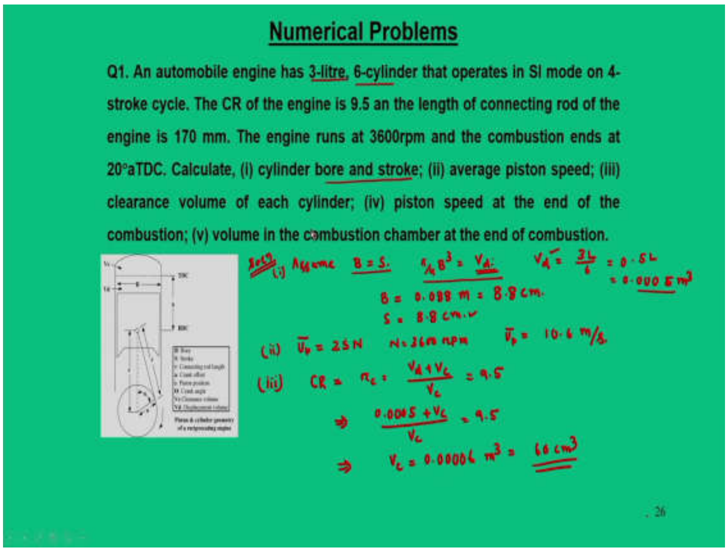

So, now we will try to solve some numerical problems and which is mainly on the engine kinematic analysis. So, the first problem goes like this, that we have an automobile engine that has a 3 litre capacity and it is a 6-cylinder engines and it operates in SI mode four-stroke cycle. So, entire information is there in this line.

Next line talks about this engine kinematic study, it has a connecting length later length of 170 mm and compression ratio of 9.5. The engine runs at 3600 rpm. The combustion ends 20° aTDC. So, we can say instantaneous θ could be 20°. So, we are asked to find out the cylinder bore and stroke, average piston speed, clearance volume, piston speed at end of the combustion, volume in the combustion chamber at the end of the combustions. So, let us try to solve this problem.

So, start the problem. What we are going to typically see that for the first problem we need information of bore and stroke, but no relations has been given. So, we can assume B = S which is a safest approach. So, when B = S, we can find out $\frac{\pi}{4}B^3$ which is nothing but the displacement volume.

And we have 3 litre, 6-cylinder. So, total V_d can be 3 / 6 = 0.5L or 0.0005m^3. So, once you know V_d, then we can find out from above relation that is bore as 0.088 m. So, this is about 8.8 cm. So, when you have bore and stroke are same, so we can say S = 8.8 cm. So, we got the first answer.

Second answer is average piston speed. So, if you recall our last slide we say average piston speed, we denote this as $\bar{U}_p = 2SN$. So, from this relation you can say $\bar{U}_p$ will be 10.6 m/s.

Third question is clearance volume. So, for this clearance volume we have to recall compression ratio $r_c = \dfrac{V_d + V_c}{V_c} = 9.5 \Rightarrow \dfrac{0.0005 + V_c}{V_c} = 9.5 \Rightarrow V_c = 0.00006\text{m}^3 = 60\text{cm}^3$.

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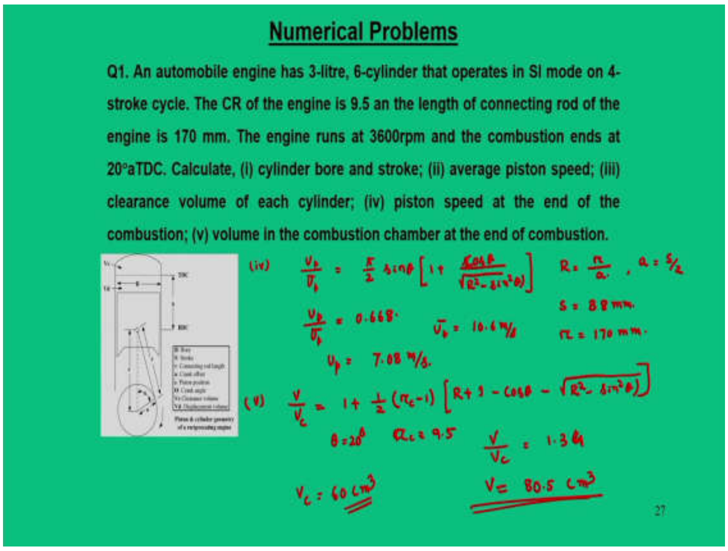

So, next thing what we are looking at the we are trying to get the piston speed at the end of the combustions. So, here we have to recall this relations that is $\dfrac{U_p}{\bar{U}_p} = \left(\dfrac{\pi}{2}\right)\sin\theta\left[1 + \dfrac{\cos\theta}{\sqrt{R^2 - \sin^2\theta}}\right]$.

So, here you require about the information R. So, $R = \dfrac{r}{a}$, and $a = \dfrac{S}{2}$, S we have 88 mm, r we have 170 mm. So, by putting all these numbers, we can get this ratio $\dfrac{U_p}{\bar{U}_p} = 0.668$. And since you already know $\bar{U}_p$ as 10.6 m/s, so we can say U_p would be, 7.08 m/s.

And the last component of this problem is the volume of the combustion chamber at the end of the combustions. So, here you have to use and the last non-dimensional relations that is instantaneous volume with respect to clearance volume. So, this expression is

$$\frac{V}{V_c} = 1 + \frac{1}{2}(r_c - 1)\left[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}\right]$$. So, here θ is 20° and you have r_c is equal to 9.5. So, by putting all these numbers we can get $\frac{V}{V_c} = 1.34 \Rightarrow V = 80.5\text{cm}^3$.

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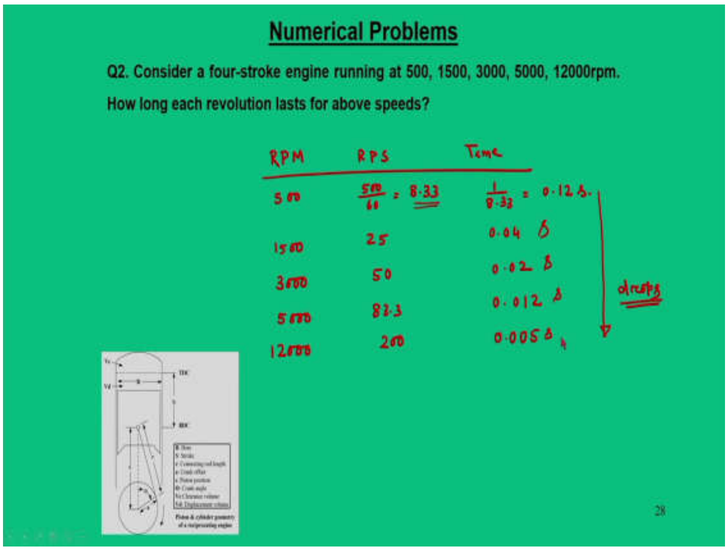

So, next problem which I am going to discuss is a very simple problem, but just to refresh your concept. Consider a four-stroke engine running at 500 rpm, 1500 rpm, 3000 rpm, and 5000 rpm, and 12000 rpm. And typically these are some realistic rpm that engines operate.

Normally, IC engines operate between 3000 to 5000 rpm and all aircraft engines operate at 12000 rpm. And this is a very small number 500 rpm, small engine that can operate. So, for that entire range of engine speed, we are asked to find out how long each revolution lasts. So, to do that what we are going to prepare is a table, what you can say RPM, RPS and time.

So, for 500 rpm if you convert revolution per seconds. So, you can say 500 / 60. So, this turns out to be 8.33 and that means, 8.33 rps. So, one revolution lasts for 1/8.33 = 0.12s. So, in a similar logic, we can find out for 1500, RPS would be 25, time would be 1/25 that is 0.04. 3000 would be 50, it will be 0.02. And 5000 would be 83.3, and time would be 0.012. And 12000 would be 200 RPS and this 0.005 seconds. So, all these are seconds.

So, if you look, when the engine speed increases the time for revolution also drops. So, just to give an insight or feeling that when we go for very high rpm or revolutions hardly, in a naked eye you can see that one revolution lasts for about 0.005 seconds, so close to 0.5 milliseconds. So, this give some kind of a realistic number that normally talks about in IC engine terminology that for each revolution what is the time. So, with this, I hope you I have cleared this concept.

So, thank you for your attention. And thanks for the today's class. So, we will meet in the next class.