Fundamentals of Automotive Systems
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Lecture-05
Operation of Four Stroke Engines-Part 01

Greetings.

So let us get started with today's class. So a quick recap of what we did yesterday. So, we were looking at the components in a typical 4 stroke engine. So, yesterday we looked at the piston assembly, and then we learned how it is connected to the crankshaft. And then we also looked at the cylinder head, because in a 4 stroke engine the cylinder head contains the valve assembly, which consists of intake and exhaust valves for letting air into the cylinder and taking out the exhaust gases from the cylinder after combustion.

So we looked at the intake manifold and the exhaust manifold which are nothing but mechanisms that aid in this process. And we also looked at the valve assembly, which in most automobiles you know is a spring return valve wherein a dual coil spring is used to close the valve once the what to say corresponding processes is completed either the intake or the exhaust process, okay.

So we looked at what was called as valve float, which happens in typical spring return valves at high speeds and how it can be minimized and how you know one could eliminate it by using a desmodromic valve. So, that is where we stopped yesterday.

Let us start today's session by first looking at the camshaft. So the camshaft is also a component which is typically installed in the cylinder head. So, the main function of the what to say camshaft is that like it actuates the either the intake valve which I am calling it as IV or the exhausts valve as appropriate okay at a particular cylinder. So, as the name indicates the camshaft is nothing but a shaft which is placed above the valve assembly in the cylinder head and it consists of all these cam lobes, right.

So, I am sure all of us know what a cam follower mechanism is. So, the cam lobes essentially determine when a particular valve stem is going to be pushed downward to create an opening

CAMSHAFT

either in the inlet valve or the exhaust valve and as the cam lobe rotates with rotation of the camshaft, the contact may be taken away and the valve will close right as appropriate.

So that is a function of a camshaft, in a typical 4 stroke engine, the inlet valve and the exhaust valve what to say need to be open once in every 2 revolutions of the crankshaft okay because as we learnt by what is called a 4 stroke engine, in a 4 stroke engine one operating cycle of the engine is completed in 2 revolutions of the crankshaft that corresponds to 4 strokes of the piston right.

So, in one cycle I need the inlet valve to open once and the exhaust valve to open once right. So, in other words the each valve should be open once in every 2 revolutions of the crankshaft. So, this implies that the camshaft should rotated a half the speed of the crankshaft correct. So that is when you know you will have exactly one what to say rotation what to say of the camshaft for every operating cycle of the engine, right.

So that is what will happen right with this camshaft. Now, how is this camshaft rotated, obviously the camshaft is rotated by the energy that is provided by the crankshaft okay. So, the camshaft is driven by the crankshaft and how is it driven. So, typically the camshaft is connected to the crankshaft by means of what are called as timing belts or gears.

So, one can use what is called a timing belt or a timing gear okay. So to essentially get this functionality okay. So, let us say this is the camshaft, so what happens with that timing belt is that like the timing belt is a belt, which has these grooves it is just like a gear tooth, but then like it is flexible right. So, this is the timing belt. So, you can see that this timing belt is wrapped around the camshaft, because the main issue with the traditional belt, mechanism belt driven mechanism is that it can have slip.

And we do not want slip when we drive the camshaft using a crankshaft right because the timing of the opening and closure of the inlet and exhaust valves will get affected. So in order to address that issue, we use this timing belt, which have these projections to ensure that the what to say the camshaft is rotated relative to crankshaft fairly accurately. Of course, a belt is used if the spacing between the camshaft and crankshaft is large.

In some cases the camshaft may be closer to the crankshaft and people may use a gear assembly okay. But please note that either way there is needs to be a what to say reduction in the speed that is the camshaft needs to rotated at half the speed of the crankshaft in a typical 4 stroke engine okay. So that is the camshaft it is placed in the cylinder head and supported by bearings.

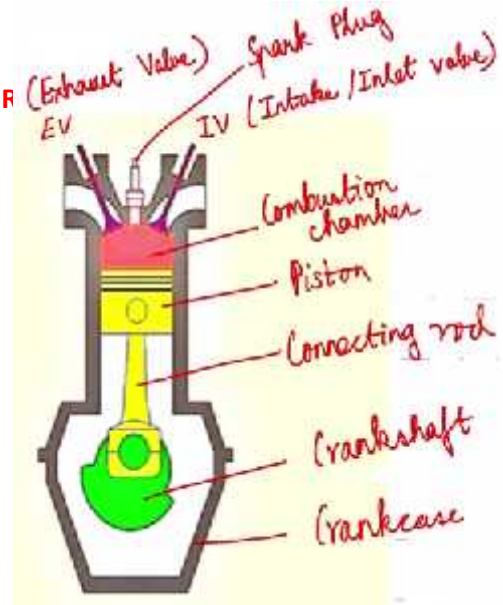
Obviously because even if the crankshaft is rotating at 3000 rpm the camshaft will rotate at 1500 rpm and it is going to continuously actuate you know many valves in a multi cylinder engine right over a period of all the time interval of 1 revolution of the camshaft. So it needs structural support also it is supported by bearings okay. So that is the role of a camshaft. What about other components in an engine you know like we will look at them as we go along.

So, these are some of the main components, some other components which we would also discuss as we go along one would be what is called as a flywheel, okay. A flywheel is nothing but a mass, which is attached to the output of the crankshaft. The crankshaft is the link which comes out of the engine and it provides the tractive effort to drive the wheels and propel the vehicle.

So, a flywheel is typically attached to the what to say end of the crankshaft to ensure that any torque fluctuations due to the combustion process is are smoothened out right. So we will see why that happens as we discuss a 4 stroke engine okay. So, the flywheel is essentially used to smoothen out torque fluctuations you know like so that is one primary purpose of flywheel okay.

Then what are a few other components, we have a spark plug in a spark ignition engine or a petrol engine that provides a high voltage spark, okay. The purpose of a spark plug is to essentially provide a high voltage spark and that will ignite the fuel air mixture and initiate the combustion process. That is the function of a spark plug and in diesel engines or compression ignition engines there are elements called fuel injectors that will spray diesel into the combustion chamber at the appropriate time okay.

So that is the function of fuel injector okay. So, these are some other components that we would be encountering okay as we go along in this discussion okay. So now moving on from components, let us look at the operation of a typical 4 stroke spark ignition engine okay. So let us look at how it operates okay, what are the 4 strokes and what is the principle of operation. So, this is just a very simple schematic that illustrates 1 cylinder in a 4 stroke spark ignition engine.



CONSTRUCTION OF FOUR STROKE (SI)

So this is the inlet valve or the intake valve okay IV stands for the inlet or the intake valve, EV stands for the exhaust valve in this context. This is the spark plug and of course this is a piston, this is the combustion chamber, where the fuel air mixture is burn and essentially the process of combustion and what to say the energy transfer takes place. This is the connecting rod. This element is the crankshaft okay, this is the crank case.

These are the typical elements in a 4 stroke engine okay, 4 stroke spark ignition engine. So, what happens in a 4 stroke spark ignition engine is that typically either air or fuel air mixture is taken into the combustion chamber okay. And then the fuel air mixture is compressed to high pressures and temperatures, at the end of the compression process a high voltage spark is provided to initiate the combustion of the fuel air mixture.

And once the fuel air mixture combust you know we are going to generate thermal energy that is going to result in high pressure gases which are going to expand and push the piston down. And that is where you know like the energy transfer takes place and then the burnt gases which are the products of combustion are pushed out through exhaust valve. So, those are the typical strokes that happen in a 4 stroke spark ignition engine okay.

So, what are the 4 strokes, the first stroke is what is called as a suction stroke, the second one is the compression stroke, the third stroke is what is called as a power stroke or the expansion stroke and the fourth one is the exhaust stroke. So, all these 4 strokes put together contribute one cycle one operating cycle in a spark ignition engine okay. So these are the that is why it is called a 4 stroke okay.

So, this keeps on repeating and the engine continues to operate okay. Now, we can observe that in the spark ignition engine or a petrol engine a spark plug is provided to initiate the combustion process in a diesel engine or a compression ignition engine the spark plugs will not be present and we will have what is called a fuel injector which will spray the fuel into the combustion chamber you will look at the differences shortly okay.

So these are the 4 strokes and when the piston goes through these 4 strokes, you know, like we complete one cycle. If you look at this I am just approximately marking the top dead center, we will shortly see what is called as a top dead center and the bottom dead center. So the piston moves between these 2 limits right. So in the cylinder, okay or the combustion chamber okay.

So before we go and look at these 4 strokes in detail I am just going to write down a few definitions concerned with what to say engines IC engines okay.

Definitions:

1) **Cylinder bore (d):** Nominal inner diameter of the cylinder.

2) **Piston area:** Area of a circle whose diameter is the cylinder bore $\left(\frac{\pi d^2}{4}\right)$.

3) **Stroke (L):** Nominal distance travelled by the piston between 2 successive reversals in its direction of rotation.

4) **Dead Centre:** Position of the piston when it reverses the direction of rotation.

5) **Top Dead Centre (TDC):** Position of the piston when it is the farthest from the crankshaft.

6) **Bottom Dead Centre (BDC):** Position of the piston when it is nearest to the crankshaft.

7) **Displacement/Swept Volume (Vs):** Nominal volume swept by the piston as it travels from TDC to BDC. $V_s = \left(\frac{\pi d^2 L}{4}\right)$

8) **Engine Capacity (Cubic Capacity):** Sum of the displacement volume of all the cylinder.

9) **Clearance Volume (Vc):** Nominal volume of the combustion chamber when the piston is at TDC.

10) **Compression Ratio (r):** Ratio of the cylinder volume at BDC (Vt) to the clearance volume (Vc). $r = \frac{V_{BDC}}{V_{TDC}} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c}$

So the first one is what is called as a cylinder bore okay let me indicate it by a parameter ‘d’ okay. This is the nominal inner diameter of the cylinder or the combustion chamber okay. So, the cylinder bore is nothing but the nominal inner diameter of the combustion chamber or a cylinder okay.

So then the piston area is nothing but the area of a circle whose diameter is the cylinder bore okay. So or in other words it is going to be pi by 4 d square okay. So that is the piston area. Third term that we are going to look at is what is called as the stroke of the piston okay. Let me indicate it by the parameter L. The piston stroke or stroke of the piston is the nominal distance traveled by the piston between 2 successive reversals in its direction of motion.

So because the pistons direction of motion keeps on changing and the stroke, L is the distance traveled by the piston between 2 successive reversals in it is direction of motion, okay. That is the stroke L okay. So, this is connected to what is called as a dead center. So what is a dead center, so position of the piston when it reverses it’s direction of motion okay that is what is called as a dead center okay.

So just going back to this diagram, so you see that the piston is going to move up and down okay. The nominal distance moved by the piston between 2 successive reversals of its motion is L, okay, the stroke L. So, in this diagram, we are yet to define TDC and BDC but then like this distance will be the stroke L and dead center is the position where the piston reverses its direction of motion because, for example is a piston is moving up, it reaches the top dead center, it is going to reverse the direction of motion and start moving down right and vice versa on the bottom.

So, those are what are called dead centers. So, we are now going to define what is called as the top dead center okay abbreviated as TDC okay. TDC is the position of the piston when it is farthest from the crankshaft. So, that is what is called as the top dead center okay. The bottom

dead center or what is called as BDC is the position of the piston when it is nearest to the crankshaft okay.
So that is the definition of TDC and BDC okay and that is very obvious from the schematic right. So just going to the schematic you can see that when the piston is at TDC, it is the farthest from the crankshaft. This is the crankshaft, right and when it is in the bottom dead center, it is closest to the crankshaft okay. So that is the definition of TDC and BDC okay.

So the next set of definitions. The next term that we are going to look at is what is called as the displacement or swept volume which is indicated by V subscript s. So, what is this displacement or swept volume. It is the nominal volume swept by the piston as it travels from TDC to BDC okay, so that is a definition of swept volume okay. So we immediately observe that the swept volume Vs is going to be pi by 4 d L square right.

It is a cylindrical bore so that is the swept volume, the building on this we define something called as the engine capacity or the cubic capacity of the engine. What is this okay.

The engine capacity or cubic capacity is the sum of the displacement volume of all the cylinders okay. So that is the engine capacity or the cubic capacity. Of course, if I have a single cylinder engine, just what it is, right. If you have a multi cylinder engine, you need to add the sum of the displacement volumes of each cylinder. So let us say if I say I have an engine in a car with a capacity of 1.2 liters.

And that is a 4 cylinder engine. I can pretty much say on an average, you know, like the displacement volume of each cylinder is going to be 300 cc, right 1200 cc divided by 4 cylinders. On an average the nominal displacement volume is going to be 300 cc. So that is what I can say okay, that is the number which we encounter right when we look at engine specifications, okay.

So then there is something called as the clearance volume VC, what is this clearance volume VC, it is the nominal volume of the combustion chamber when the piston is at TDC. So, when the piston has reached up to the top dead center there are some volume what to say between the cylinder head surface and the piston right that volume is what is called as a clearance volume and

so for example will shortly realize that when we are doing what is called as a compression stroke we will have highly pressurized fuel air mixture in that clearance volume okay.
So, that is the clearance volume, building on this we define one more parameter which is extremely important for engines is what is called as a compression ratio which is denoted by the symbol ‘r’. So, what is the compression ratio, it is nothing but ratio of the cylinder volume at BDC okay which is indicated as V subscript t to the clearance volume okay. So that is the compression ratio okay.

So some people call it as total volume V subscript t that is when the cylinder is the bottom dead center whatever is a volume of the cylinder that is what is called as a total volume okay. That is the reason why we are using a subscript t okay. So, ‘r’ is defined as the volume at the bottom dead center divided by the volume at the top dead center. So, we can immediately observe that the volume at the bottom dead center I can rewrite it as VC which is a clearance volume plus the swept volume right.

And the volume of the top dead center is any way V subscript c. So, based on this we can immediately observe that the compression ratio can be written as 1 + V s + sorry 1 + V s divided by V c okay. So, that is a definition of compression ratio okay. So, compression ratio is going to be a very important parameter, okay like as far as engine performance is concerned. And we will see that what influence or impact it has on engine efficiency and fuel consumption and energy output and so on okay.

When we do engine analysis okay and depending on the type of engine whether spark ignition or compression ignition engines there are typical ranges of compression ratios. See for example in SI engines ‘r’ is typically between 6 and 10 okay. In CI engines it is typically in you know like anywhere from let us say 12 to 20 right. So it is a typical range okay of the values of compression ratios, okay. So by and large the compression ratio in diesel engines is higher than in petrol engines, we will see why okay as we go along.