IC Engines and Gas Turbines
Dr. Pranab K. Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 26
CI engine injection systems, Air-cooled and liquid-cooled engines, Modern trends

We will continue our discussion on IC engine. And today we will discuss about CI engine injection system, and then we will discuss about the cooling of the engines rather; how we can reduce the temperature of the engine cylinder that is very important part. And probably I have discussed this cooling, whether it is air cooled or water cooled you know in one of my lectures we have I have discussed this issues.

So, today I will start my discussion with CI engine injection system, then we will discuss about the engine cooling. We have discussed about the injection of a SI engine. We have seen that in a spark ignition engine normally air and fuel is introduced through a carburetor, but in a carbureted system we have identified the problems. And of course, if you have a modern carbureted then we can remove rather aluminates those problem.

Still, it would be better we have seen that from my last lecture that if we have if you have an injection system and then it is we can it is better for the engine, and we can supply the you know stoichiometric air fuel mixture. That is the chemically correct air fuel mixture depending upon the requirement of the load.

So, that is the SI engine injection system, and we have discuss about that mechanical mechanically operated injected, and then also you have discuss about electronically controlled unit- ECO. And we have given a you know level diagram, and how ECO control the amount of fuel or amount of air; normally amount of fuel to be pumped through the fuel through the fuel some to the engine depending upon the requirement of engine that is that is you know a sensed to the that is sensed by the ECO unit through the pressure temperature in the intake manifold, as well as exhaust manifold, and also the temperature of the cooling water jacket.

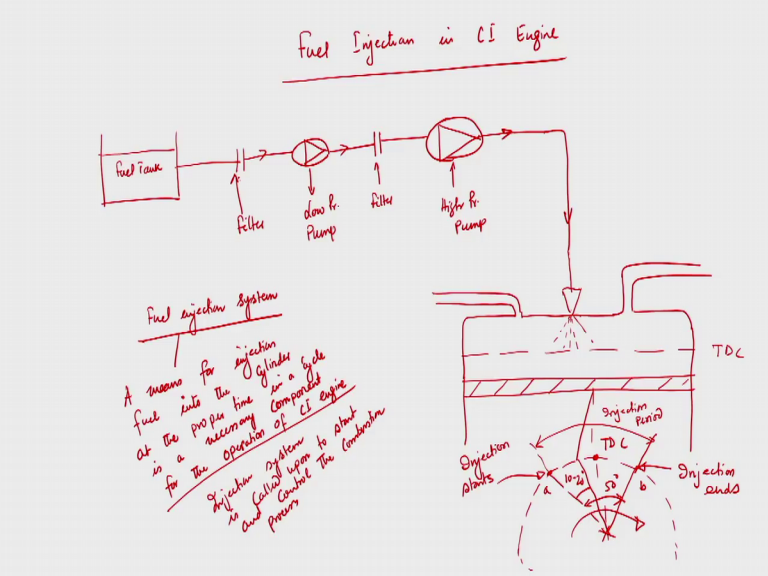
So, today we will discuss about CI engine injection system and you have seen rather we have discussed that; in a compression ignition engine we do not have any carburetor I mean what the what is there in a SI engine. But in a CI engine we have a fuel nozzle

whether fuel injection system through which we supply fuel into the cylinder during the end of the compression stroke.

So, this is the this is an important difference between SI and CI engine. In a CI engine we supply air through intake manifold during intake stroke then at the end of the compression stroke whenever temperature and pressure of the air is relatively high, that time we inject fuel through fuel injected in a in a in the form of a spray.

So, now fuel will a self ignite at that you know temperature and on pressure of the compressed air. And that is why do not recover external agent like spark plug for the initiation of combustion. So, today we will discuss about fuel injection in SI engine.

(Refer Slide Time: 03:32)



Sorry, fuel injection in CI engine; fuel injection we will discuss fuel injection in CI engine. So, we will now discuss about that we have a fuel pump, of course we have to have one fuel pump, then there will be a strainer of course, and then we will have a fuel pump.

So, then we have then we will have another strainer, then we have another pump, then ultimately fuel is coming to supply. This is top dead center. Then we have piston, and then this piston is having motion.

Now, this fuel is supplied into the nozzle, then is fuel is spread into the cylinder. Now if I try to draw the you know this you know different stroke, then perhaps. So, this is TDC, and here this is the point where injection ends. Injection ends, and here injection starts.

So, you know this angle is 10 to 20 degree, and total angle is near about 50 degree. This is almost 50 degree, and this is 10 to 20 degree. So, injection starts when piston is slightly high from TDC; that is we have discussed there is a first phase of combustion. So that means, the amount of fuel being injected into the cylindered in the first phase of combustion they will complete the combustion and piston is that TDC, and then the remaining part of the combustion will be completed.

So, injection start, the fuel injection start when piston is 10 to 20 degree below TDC and it continues till the total angle of injection or total angle of you know fuel spray is around 50 degree. So, this is the you know. So, this entire period is known as injection period. So, this period is known as Injection Period.

So, time required to travel piston from this location to that location; I mean from location a to location b is the injection period. So, this is fuel tank, this these are strainer or filter, because when we are this is low pressure pump low pressure pump and we have another filter before fuel enters into the high pressure pump. So, this is high pressure pump and then fuel goes into the nozzle and then it spread.

So that means, this is the fuel injection system. We need to have pumps which will take which will you know pump fuel from fuel tank into the nozzle. Because we have seen that there is a huge pressure drop across the nozzle, because nozzle we need to we need to increase the velocity. So, that we can have is a it is a diverging converging step. So, while fluid fuel is flowing through the nozzle there is a huge pressure drop at the cost of that we are having gain in velocity, kinetic energy.

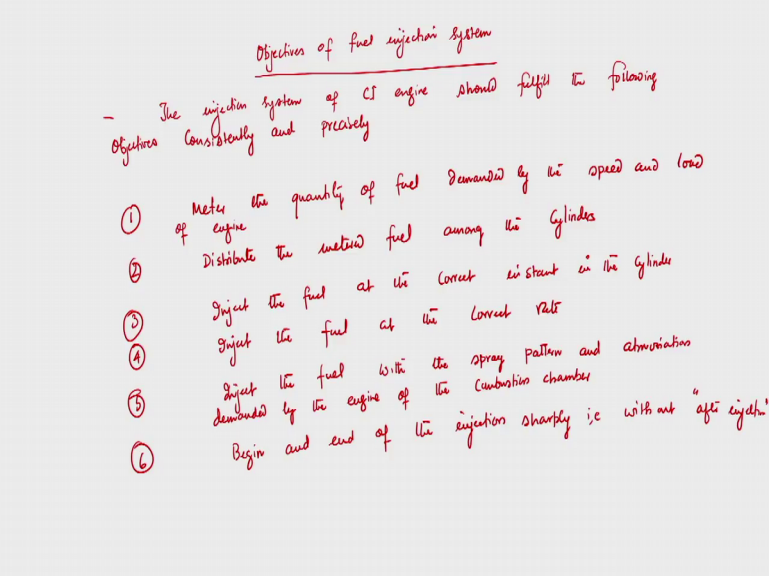
So, what do you mean by fuel injection system? So, this is, I can write fuel injection system a means of metering fuel into the cylinder at the proper time. So, what do you mean by fuel injection system? So that means, fuel injection system what do you mean by that. So, this is a mean; means for injecting fuel into the cylinder; into the cylinder at the at the proper time at the proper time in a in the cycle is a necessary component for the operation of CI engine; is a necessary component for the operation of CI engine. Since, the injection system is called upon to start and control the combustion process.

So, fuel injection system is a means which is used to inject fuel into the cylinder at a proper time and this is a necessary component for the operation of a CI engine for the for CI engine. So that means, the injection system is called upon to start and control the combustion process. This injection system is called upon to start and control the combustion process. That means, since we are not supplying fuel mix to the air during intake stroke we need to supply required amount of fuel at a proper time essentially to have a proper combustion. And that is why you need a system through which we can meter.

So, we will now we will now discuss about that what are the objective having the system, and then who accomplish the objective what they are they are we need a few functional you know elements. So, now you should know that fuel injection system we require only to supply fuel at a proper time which is a necessary component for the combustion of the CI engine. And if would like to supply fuel at a proper time, not only fuel that are required amount of fuel at a proper time then what should be the what will be the components for this fuel injection system rather what will be the functional elements. And before that we need to know what are the objectives of having this fuel injection systems.

So, now, we will discuss about the objectives. So, objectives of the fuel injection system.

(Refer Slide Time: 12:27)



Objective of fuel injection system right. So, the injection system of CI engines should fulfill the following: I mean I can write the injection system of CI engine should fulfill the following objectives consistently and precisely; consistently and precisely, right. Number 1 is: meter the quantity meter the quantity of fuel demanded by the speed and load of the engine this is very important. Meter the quantity of fuel demanded by the speed and load of engine. Number 2: distribute.

So first objector is that fuel injection system will have an element which will meter the required quantity of fuel depending upon the varying load and speed of the engine. So, not only this, once we meter the quantity of fuel or required quantity of fuel, then we should have another element which will be able to you know distribute the metered fuel into the or rather into the nozzle or among the cylinder.

So number 2 is distribute the metered fuel among the cylinders. That means, if we normally we will have multi cylinder engines; so that means, if we have multi cylinder engine then we need to ensure that each and every cylinder will get required amount of fuel at a proper time. So, whenever we will have a fuel injection system; that means, we need to ensure that metered fuel should be distributed among the engine cylinder. Number 3: also very important, we have distributed the metered fuel among the cylinder then distribution is not only the distribution is not the final task, then we have to inject the fuel at the correct instant in a cylinder So, there would be another elements which will be able to inject the fuel inject the fuel at the correct instant; at the correct instant in the cylinder.

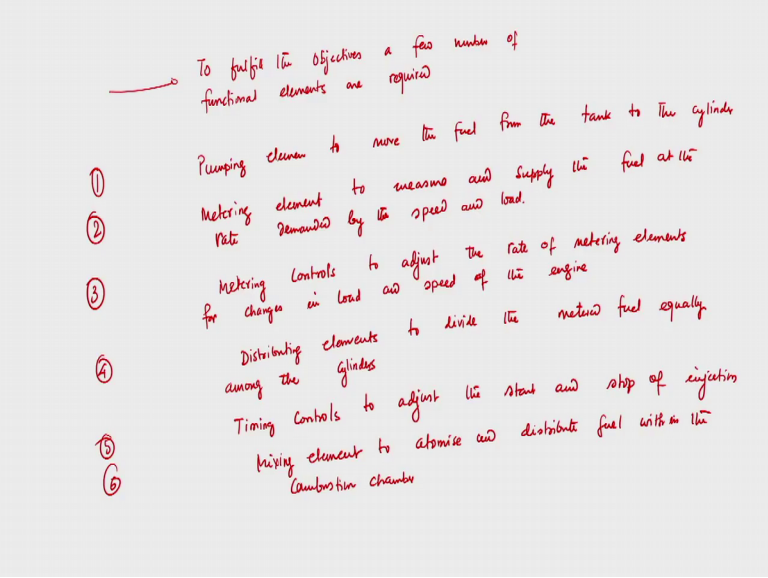
Number 4: so distributed fuel, we have distributed among the cylinder then we have to inject the fuel at a correct instant of time, not only that we have to inject the fuel at correct rate. Inject the fuel at the correct rate at the correct rate, so correct instant as well as the correct rate. And again I am telling that we have discuss this aspect as well, whenever you are supplying fuel through fuel nozzle into the cylinder we need to ensure the desired spray pattern with the you know desired finer spray pattern with the desired code angle. That means, you have to ensure that the spray should; the nozzle would be avail to spray the fuel in such way that there will be a even distribution as well as there should be fuel at the remote cornered.

So, if you have a you know when your piston is having cylindrical shape; that means, over the periphery of the piston phase rather almost the entire combustion phase will get the fuel essentially to have a smooth and efficient combustion. That means, we have to have inject the fuel another metering element which will be able to inject the fuel with the spray pattern atomization demand by the engine of the combustion chamber. Inject the fuel with the spray pattern; with the spray pattern and atomization demanded by the engine of the combustion chamber, right.

Number 6: begin and end the fuel injection without disturbing after or without you know sharply I mean without having any trouble. That means, begin and end of the injection sharply; that is without you know after injection without having after injection. We will we will we will discuss what do you mean by after injection.

That means, the six at the important objectives we should have we should considered while designing an injection system or fuel injection system for CI engine. So, we have discuss now to accomplish this objective; to accomplish this objectives and number of functional elements are required, right.

(Refer Slide Time: 19:10)



So therefore, I can write now. Therefore, to fulfill the objectives of few number of functional elements are required, right. So, number 1: what is number of objective meter the quantity of fuel, right. Meter the quantity of fuel demanded by the load and speed of

the engine. That means, we have a pumping element to move the fuel pump fuel tank to a cylinder.

So, if we now compare one objective with one you know requirement in a functional event. Then first objective was to meter the quantity of fuel as demanded by the load and speed of the engine. Therefore, we required one pumping element pumping, element to move the fuel from the tank to the cylinder.

Number 2: then objective was distribute the metered fuel among the cylinder. That means, there should be metering element to measure and supply the fuel at the rate demanded by the speed and engine. So, there will be a another element is what is known as which is known as metering element; metering element to measure and supply the fuel at the rate demanded by this demanded by the speed and load.

So, number 3: we have measured and supply the fuel according to the load and speed of the engine. Not only that we should have metering control to adjust the rate of metering element for the change in load and speed. So, not only that because I am telling that was the problem in a with a carbureted system.

So, once you design a carburetor then we cannot you know take care of the you know altitude and high. So, once you design the carburetor, that carburetor be able to supply a required amount of fuel and air fuel mixture. That carbureted system cannot be adjusted to supply you know required amount which is demanded by the engine may be at different load and different speed. So now, since we are going to have a metering fuel injection system that is injection system should be flexible enough. That means, it should metered the we should have a controlling unit. That means, metering element then we have a metering control; metering controls to adjust the rate of metering elements for changes in load and speed of the engine; for changes in load speed of the engine.

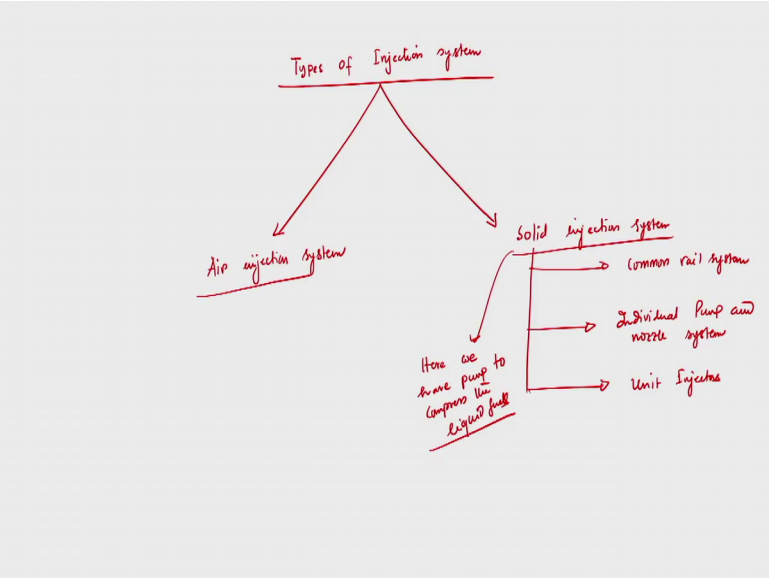
Number 4: you should have distributing elements to divide the metered fuel equally among the cylinder. Number 5: there should be a timing control to adjust a start and stop of injection. So, we should have another element integrated with that injection system; that is timing element timing controls to adjust the start and stop of injection. And finally, we should have one mixing element to atomize and distribute fuel within the combustion chamber.

So, these are the functional elements required which we need in a injection system to fulfill the objectives of a fuel injection system. So, now, we have seen that what are the objectives of having a fuel injection system. Initially we have seen the what is fuel injection system; it is a means of injecting fuel into the cylinder at a proper time and also at a proper rate which is required depending upon the load and speed of the engine.

Now, we have understood that the objectives of having metering system. And if we can recall the problems of a carbureted system then, perhaps we can differentiate that fine what will be the objectives of a injection system. And then to fulfill that objectives we need a few functional element and we have understood that those function elements are essential to satisfy or to fulfill the you know objectives.

Now this CI engine injection system can be classified into two categories.

(Refer Slide Time: 25:48)



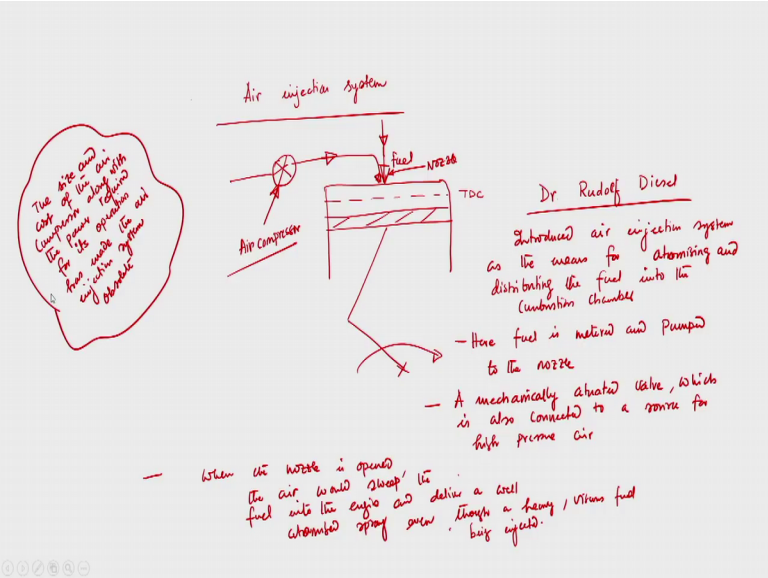
So, types of injection system. This is classified into two category: first one is, air injection system. And number 2 is, solid injection system. This is further classified into three different categories: first one is you know common rail system, individual pump and nozzle system, and last one is unit injectors.

In this solid injection system here we have pump to compress the; we have to pump we have we have pump to compress a liquid fuels to compress the liquid fuels. So, now I will discuss these two injection systems one by one. So, it is a first one is air injection

system we will now see what is air injection system and then the we have a solid injection system. And this is again classified into three subcategories: common rail system, individual pump and injection nozzle system, and we have unit injectors. In all these cases we have pump to compress the liquid fuels.

So, if we now go to discuss about air injection system. So now, I will discuss about the air injection system.

(Refer Slide Time: 27:59)



Schematically I will show. So, we suppose this is a engine cylinder, this is stopped at center, we need to supply fuel over here, and then we have one air compressor, and then this compressed air is taken over here. So, this is air compressor.

So, this is air injection system. Dr. Rudolf Diesel who first introduced this air injection as a means of atomizing and distributing the fuel throughout the combustion chamber. So, Dr. Rudolf Diesel introduced this air injection system; air injection system as the means for atomizing and distributing the fuel for atomizing and distributing the fuel throughout the combustion chamber rather into the combustion chamber.

So, Dr. Rudolf Diesel who first introduced this air injection system as a means for atomizing and distributing the fuel into the combustion chamber; by how. This is a mechanically actuated valve. So, air fuel was metered and pumped to the nozzle. So, this

is a nozzle, so maybe this is nozzle and fuel is coming. So, here fuel is you know fuel is metered and pumped to the nozzle.

So, we have a one metering element which will meter the fuel and then pump to the fuel up to the nozzle, right. A mechanically actuated valve which was also connected to a source for high pressure air. When the nozzle was open then a mechanically actuated valve, a mechanically actuated valve which was also connected to a source of high pressure air which is also connected to a source for high connected to a source for high pressure air. So, we have to have a source of high pressure air through compressor right.

So, when the nozzle was open the air would sweep the fuel into the engines and delivered a well atomized spray even though heavy viscous fuels are being injected. So, the idea is, even we supply a heavy and sorry a high viscous very high viscous fuel; if I pump high viscous fuel up to the nozzle maybe we can use a compressed air high pressure compressed air at the nozzle. And then the compressed air will try to sweep you know the you know the fuel into the engine and deliver a you know well atomized spray.

So that means, we need not to have a very precise nozzle, we need not to have a very high pressure pump, but only that is a first introduce this was the this is the first injection system introduced by Rudolf Diesel as a means for atomizing and distributing the fuel. So, we will supply fuel up to the nozzle. And if you can supply fuel with the high heavy fuel with the high viscous with the high viscosity even then if we have a; even if it is connected with a you know line of compressed air then the compressed air will try to sweep the liquid into the cylinder with a very finer atomized in a well atomized spray and in a better distribution we will be obtained.

So that means, I am writing that when the nozzle was opened; so when the nozzle. So, fuel is metered and pumped to the nozzle, then a mechanically actuated valve which is also connected to the source of high pressure air and that will be also going to the fuel nozzle. So, when nozzle is opened the air would sweeps the fuel, the air would sweep the fuel into the engine and delivered a well atomized spray even though heavy; even though a heavy viscous fuel is being introduced or being injected.

So, this is the total overall injection system. We will have a metering element and then pump, which is used to meter and pump the liquid up to the up to the nozzle. And then, there will be a mechanically actuated valve visuals are connected source of the high

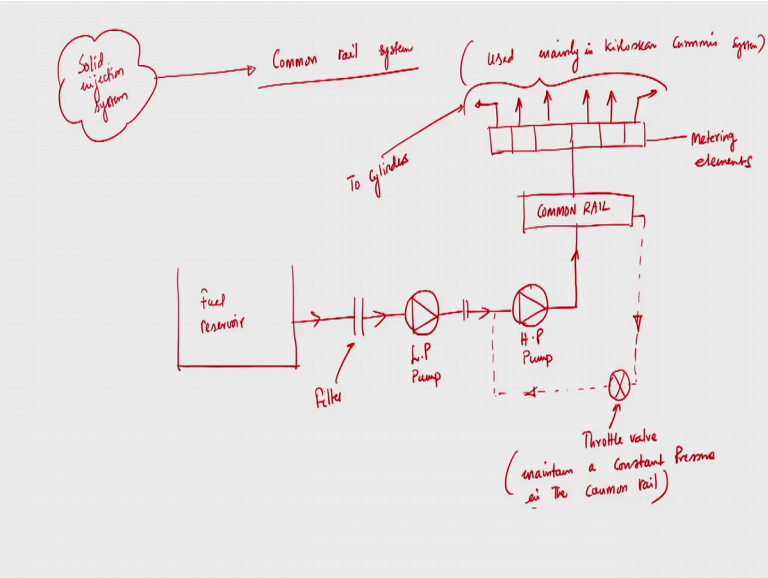
pressure air. Now whenever you are supplying nozzle into a cylinder that fuel line will be connected with the high pressure air. And then when nozzle is open that air would sweep the fuel into the engine and deliver well atomized spray even though heavy and vicious being injected.

But what is the what is the problem? The size and cost of the air compressor along with the power required for its operation has made the air injection system obsolete. So, this is nowadays used. So, I am writing here the size and cost of the air compressor along with its operation; along with the power required for its operation operational cost, along with the power required for its operation has made the air injection system obsolete. So, this is very important.

That means, although we can have a better or well atomized spray pattern, we can handle heavy and high viscous fuel still we need a separate compressor and size and cost. Of course is very high, not only that it operational cost that is the power equal to operate it also very cost this. All these aspects if we combine together and then perhaps all these issues I mean are important. And if we consider all those aspects probably because of that, this air injection system is nowadays is not popular rather it is now obsolete. So, this is air injection system.

Now, we will discuss about the you know solid injection system. So, as a solid injection system we have seen that here, if we go back if we go back to my previous slides where it is we have a pump to compress the liquid fuel.

(Refer Slide Time: 37:20)



So that means, in a air a solid injection system we have it can be sub classified into three categories: common rail system, individual pump, and nozzle then unit injectors.

So, common rail system which is mainly in is it is used mainly in Kirloskar Cummin's engine. So, I can write that common rail system. So, this is solid injection system, and in this sub classified is common rail system; very important. So, this common rail system is used mainly in Kirloskar Cummin's systems. So, it is a very important, we will discuss that what is common rail system. That, we have a fuel reservoir, we have fuel reservoir then we will have two one pump; sorry low pressure pump that is what we have. So, we have LP pump, this is one filter. Then we have another high pressure pump and that is used to supply fuel in a common rail.

So, we have a common rail. And then another line is connected if the you know throttle valve to maintain a constant pressure in the common rail, if pressure becomes high then it again taken back at the inlet to the high pressure pump. So, we have a throttle valve; we have a throttle valve. So, this is throttle valve; throttle valve these valves maintains a constant pressure in the common rail right.

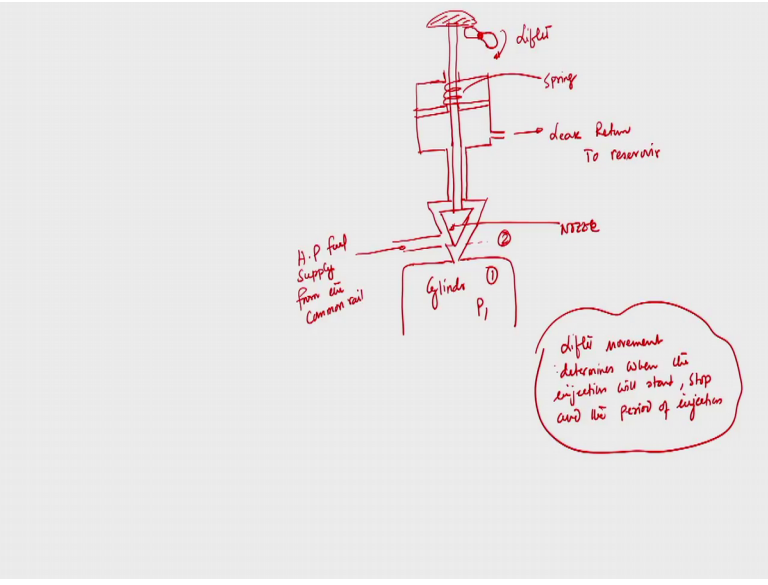
So, this is common rail. And then we have metering elements, and we have metering element maybe we can supply there will be a metering element. So, all these are the metering element and then we can two cylinder. So, all these are going to two cylinders. So that means, this is a common rail system. We have a fuel reservoir, then it is a filter

we taking a low pressure pump, then it is used it is taken again to high pressure pump and before that we have another filter. And we are supplying fuel into the common rail.

We need to maintain a constant pressure in the common rail and for that if the pressure is somehow become high, it may because may be because of the malfunction of the nozzle or metering element, then there will be a throttle valve to reduce the to (Refer Time: 41:35) in the constant pressure, so that we can take back certain amount of fuel into the again at the end at the beginning of the high pressure pump or at the entry of the high pressure pump. And from common rail we are supplying fuel into the into different cylinders through metering elements. So, this is normally used in Kirloskar Cummin's engine and this is the overall you know block diagram through which we can supply fuel into the common system. That means, there will be again nozzle.

So, then we have to discuss that fine we are taking element up to metering element then we will have a nozzle. And then by how we can you know we can supply that fuel into the cylinder. So, before going to cylinder; that means we have a nozzle, I mean then how this acting. So, I am writing now if we have a cylinder if I take only one cylinder then.

(Refer Slide Time: 42:43)



So, this is one. So, this is a schematic nozzle, so it take high pressure supply from that common rail, then it you know it strikes the nozzle you know nozzle face. Then this nozzle is connected with a spring you know loaded spring, so this lifta is there one this is

called lifta this is lifted. So, the lifta determines when the injection starts and when injection will end and the period of injection. So, the lifter movement.

So, the lifter movement determines when the injection will start, stop, and the period of injection. So, this is the overall. That means, the movement of the lifter controls the amount of because it is used. So, whenever high pressure high power high pressure fuel supply from the common rail striking the nozzle face. So, and it is it if you decompose the force acting on the nozzle then, perhaps you know and if it is from both sides then horizontal compound will balance each other. While, the normal compound we will try to lift the spring lift this nozzle with a through the spring. And it will try to create a gap between the you know send a nozzle the normal tendency of the nozzle is to remain seated at the at with the cylinder at the you know valve seat.

So, whenever there is a net horizontal net vertical force that vertical force will try to lift those nozzle by through a certain height. And the gap between the nozzle and cylinder will try to; the gap that is created between the nozzle and the cylinder valve that I mean the open area through which the fuel will be supplying to the cylinder.

So, it depends upon the pressure cylinder pressure, and pressure of the nozzle outlet that we will discuss you know in the next class. Also they are might have some return certain amount of fuel that we that will return into the reservoir through this leak or leak port. That is what I have shown here. So, the lifta movement that will control and that will start that determines when the injection will start stop as well as the period of injection.

So, we have discussed today about the what is fuel injection system, and then what are the objectives of having a fuel injection system. And we have you know identified and then we also have seen what are the metering a functional element required to fulfill that those objectives. And then we have classified that CI engine CI engine injection system into two categories: air injection system and the solid injection system. Air injection system that was first introduced by Dr. Rudolf Diesel, and we have seen that we can you know you know supply fuel in a well mannered spray into the cylinder. But for that we need to have one compressor, but the cost and size of the compressor as well as its operational cost you know has made this system obsolete nowadays.

So, it is nowadays almost all the engines are having solid injection system. And solid injection system we need to have a pump to compress the fuel and for that the first

subcategory is a common rail system which is used mainly in the Kirloskar Cummin's engine. And we have seen that how a common rail system is you know you know functioning. And then we also have seen that whenever you are taking fuel high pressure fuel from the common rail into the nozzle, and then this is a mechanically operated system. And then by how can control the movement of the nozzle, so that we can we can supply fuel into a cylinder.

With this I stop here today, and I will continue a discussion in the next class.

Thank you.