Course Name: Engine System and Performance
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Lec 25: Electronic Fuel-Injection System: Injection schemes

I welcome you all to the session on engine system and performance. In today's class, we shall discuss the electronic fuel injection system, and thereafter, we shall see different types of injection schemes. We have discussed the ignition system and ignition circuit in our previous class, and we had seen that the electronic control unit is a very important part of modern engines. So, what we had understood is that the ignition circuit is important to provide or control the spark timing of each individual cylinder.

Now, fuel injection is also very important from the perspective of engine efficiency and better emissions, or emission control. So, fuel injection—that is, the injection of fuel or the required quantity of fuel at the perfect time to all the cylinders in a multi-cylinder engine—is very important, from the perspective of higher engine efficiency and better emissions. So, the electronic control system, or ECU, for the process of fuel admission, is an assembly of a few sensors, fuel injector assemblies, and wiring.

So, today we shall discuss how this fuel injection system, which should also be controlled by the electronic control unit, essentially controls the injection time, which should be based on engine speed and also, the ignition timing. So, all these things will be taken care of by the electronic control unit. And in this particular part of the ECU—that is, the electronic fuel injection system, it contains a few sensors, fuel injector assemblies, and wiring. So, write a few important points for this particular part, and then we shall discuss.

The objective of each and every component like sensors, fuel injector assemblies, and certainly if we need to convey some message to the sensor from the ECU or if we need to receive some message from the sensor to the ECU, we need to have wiring arrangements. So, the electronic control system for the fuel admission process is an assembly of a few sensors, fuel injection assemblies, and wiring. Now, this electronic fuel injection system, in short, EFI. This particular system again works on some feedback that will be received from a few sensors, and then, after receiving those signals from the sensors, the ECU will do some intermediate steps to control the pulse width or the width of the injection pulses. So, the ECU or inputs are received from the sensors. In fact, it is not a particular sensor,

but rather several sensors. Then after receiving these inputs, the ECU determines the basic pulse width. Now, after determining the basic pulse width, it will then be corrected for a few considerations. So, if I write that point also, then, the basic pulse width of an injection pulse. The basic pulse width is then corrected.

For several considerations. What are those considerations? So essentially, the ECU will receive input from several sensors. Based on those inputs, the ECU will determine a basic pulse width of an injection pulse. So, the basic pulse width needs to be corrected or modified for several considerations.

Those considerations are the width that should be determined finally by the ECU, such that the proper amount of fuel should be injected. So, it is not only that the ECU will determine the pulse width based on a particular consideration. It can be due to the oxygen present in the exhaust gas, so this particular consideration should be taken into account. Also, the amount of heat being supplied to the coolant should be taken into account, as well as engine speed. So, all these considerations are taken to correct or modify the basic pulse width.

And then, when the basic pulse width is corrected, the electronic control unit (ECU) will issue a current pulse that will actuate the solenoid-based actuator of the ECU. Essentially, for the desired pulse width of the injector. So, once again: after correcting the basic pulse width, what the ECU does is, issue a current pulse that will actuate the solenoid-based actuators of the ECU itself, essentially for the desired width of the injector pulse. So, if I write here briefly, then the ECU will issue current pulses.

That will actuate its solenoid-based actuators for the specified or desired pulse width. So, this is how an electronic fuel injection system works. So, the main idea behind having electronically controlled fuel injection is to provide an adequate amount of fuel to each and every cylinder in a multi-cylinder engine at the proper time. So as to maximize the engine efficiency and also to reduce emissions.

So, now the question is, what we have seen we have written here that inputs are received from several sensors, and the sensors that report to the ECU are basically the engine speed sensor, then air intake, air temperature sensor, manifold air pressure sensor, throttle position sensor, the sensor which is used to sense the presence of oxygen in the exhaust gas, and also the sensor which is used to measure the coolant temperature. So, all the sensors are used, or all the sensors report to the ECU, and receiving inputs from all these parts of the engine, this entire process is executed by the electronic fuel injection system.

Essentially, to admit or allow the injector to admit the required amount of fuel at a desired or at a proper time. So, as to minimize fuel loss, which in turn will maximize the engine efficiency and will reduce the fuel emissions. Now, the question is, if we go to the next slide, we will be discussing different types of injection schemes, but before discussing different types of injection schemes, what the different types of injection schemes are?

And also, very important to know at this juncture is that the sensors which are used or which are essentially important for the proper functioning of the fuel injection system are- the engine speed sensor, throttle position sensor, manifold air pressure sensor, cooling water or coolant temperature sensor, and then the intake air temperature sensor, which is used to measure or sense or to understand the temperature of intake air and pressure. All these sensors are used to provide some feedback to the ECU, and based on these feedbacks, the ECU determines the basic pulse width, which is what we discussed. Now, we have understood that the pulse width of an injector is very important, that is, the time duration over which an injector will deliver fuel to a particular cylinder.

So, the frequency of the pulse width is very important, and we shall now try to understand what should be the frequency of the pulse width of a particular injector. So, before coming to this part, the frequency of the injector pulses is derived from the engine speed. And as I said, the sensors that report to the ECU in connection with the electronic fuel injection system are the engine speed sensor.

Then, we have discussed the manifold absolute pressure sensor, or MAP. The manifold absolute pressure sensor, the throttle position sensor, and then the engine coolant temperature, inlet air temperature, and all these things. The engine coolant temperature sensor, etc., and also, the intake air temperature and pressure sensor, and the sensor which is used to check the presence of oxygen in the exhaust gas. Now, the frequency of the injector pulses is derived from the engine speed, and so, engine speed is very important. So, similar to the ignition circuit that we have discussed in one of our previous classes, similar to the ignition circuit, the ignition pulses.

We have seen that the ignition pulses—basically, the ignition pulses from the negative side of the ignition coil—are used to determine the engine speed and also the pulse width of the injector pulses. We have discussed this part in the context of the ignition circuit or ignition coil, and similar to the ignition circuit, the ignition pulses from the negative side

of the ignition coil determine the engine speed as well as the pulse width of the injector. Now, essentially, what do we mean?

So, ignition pulses are used to determine the frequency of the injector pulses. So, ignition pulses are fed to the pulse shaper, which generates rectangular pulses from the triggered pulses. So, ignition pulses from the negative side of the ignition coil determine the engine speed and also the frequency of the injector pulses. So, the idea behind this discussion is that ignition pulses are responsible for determining the frequency of the injection pulses or injector pulses.

What is pulse width? The time duration over which an injector will deliver fuel to a particular cylinder of a multi-cylinder engine. So, essentially, the frequency of the injector pulse, which is very important for a particular engine, the ECU should know what the frequency of the injector should be? Injection pulse and that frequency of the injection pulse is determined from the ignition pulses, which in turn also depends on the ignition circuit. So, essentially, the proper operation of electronic fuel injection depends on the proper functioning of the ignition circuit or ignition system.

In a four-stroke engine, the intake valve is open when fresh charge—or if it is a CI engine, fresh air—is drawn into the engine cylinder. Now, when fresh air is coming into the engine cylinder, what is done essentially is that either a fresh fuel-air mixture is coming or if it is a CI engine, then air is coming, and in the manifold itself, fuel is sprayed. So, the time over which the fuel injector sprays fuel is essentially the pulse width.

And how frequent that particular injector will operate in a particular cycle, that frequency of the pulse width depends on the ignition. So essentially, we need to ignite the fuel and mixture if it is a SI engine or petrol engine. And then depending on the ignition pulses, this fuel injection pulse is controlled.

And that different types of injection schemes. So, what is an injection scheme? Injection time, that is the time over which fuel injection, fuel will be delivered, fuel will be spread.

So, this injection timing control determines when each injector will deliver fuel to its corresponding intake port. So, that is the injections, so basically this is important consideration based on which there are several injection schemes.

So, injection timing control determines when each injector will deliver fuel to its corresponding intake port. As I showed you, if it is the case that we need to supply fuel or

spray fuel into the intake port with the fresh air that would be drawn into the engine cylinder. So, when that particular injector needs to supply fuel, when a particular injector needs to deliver fuel, that is determined by the injection timing controller. So now, we shall discuss a few different types of injection schemes: whether we need to supply or inject fuel simultaneously to each and every cylinder in a multi-cylinder engine or if we need to deliver—if we need to design a fuel injection system, an electronic fuel injection system—in such a way that in a multi-cylinder engine, injectors will deliver fuel sequentially, or it may be required that an individual fuel injector is needed for each cylinder.

So, depending on the amount of fuel to be supplied, when a particular injector will deliver fuel to its corresponding intake port, based on this injection time controller—which is used to control that time, will determine. So now, we shall discuss a few injection schemes before we stop our discussion today. The first is simultaneous injection. From the name itself, you can understand that. So, simultaneous fuel injection. So, this is a type of injection scheme. This is a type of, multipoint injection scheme that injects fuel into all cylinders at the same time.

So, if we go back to the previous slide, then if we talk about a simultaneous fuel injection from the name itself, you can understand that fuel injection should be simultaneous. So, if there are 4 engines in all these cylinders of a multi-cylinder engine, scheme should be able to supply or inject fuel at a given time or at the same time. So, if we go back to the previous slide wherein a schematic depiction of this particular scheme is there. what you can see that it is simultaneous petrol injection.

If it is a petrol engine, then you can see that several symbols are used to indicate whether the valve is open, petrol injection and ignition. So, you try to understand petrol injection that symbol is at a given time. So, for example, if it is 0 degree, this is 360, this is 720 and like this. So, what we can understand at a given instant, this particular, following this particular scheme, it is possible to inject fuel to all cylinders.

So, there are four different cylinders that you can see, while try to understand that this is the ignition, this symbol is used to indicate ignition. So, though it is possible to inject fuel at the same time to all four cylinders, that is evident from the schematic depiction, when ignition is cylinder 1, then there is no ignition in, so when ignition is cylinder 3, there is no ignition in cylinder 1 and 1, 2 and 4 like this. So, it is kind of simultaneous injection.

So, this is the most common type injection system as this is the simplest injection. So, this scheme is the simplest scheme and most common injection timing method in use. Now, following this particular scheme if we need to supply or if we need to inject fuel at the same time to all cylinders in a multi-cylinder engine then what should be the hardware. I mean how come it would be possible to inject fuel to all cylinders in a multi-cylinder engine.

So, multiple fuel nozzles are used to work together to inject fuel into all cylinders at the right time or at the same time. So, there are multiple fuel nozzles, all nozzles should be actuated by the solenoid-based actuators of ECU to function at the same time, so as to fuel can be injected to all cylinders or into all cylinders at the same time.

Next is basically it is sequential injection. So again, it is depicted schematically this particular scheme that is sequential injection. And you can understand and then I will discuss. This is also most common type most common type. Number 2 is most effective injection scheme and sequential from the name itself you try to understand that following this scheme it would be possible to inject fuel sequentially to the cylinders in a multi-cylinder engine. So, this is the scheme is used to deliver or inject fuel to each cylinder at the right time. If it is possible to inject or deliver fuel to all cylinders at the right time, then perhaps we can ensure a proper combustion provided the stoichiometric air fuel ratio or closer to stoichiometric air fuel ratio is maintained and adequate air temperature is maintained, then efficiency of the engine can be increased. So, it improves or increases engine efficiency and reduce emission.

So, these four points, very important points for particular type and from the name itself, sequential injection. So, it is not a simultaneous injection. So, from the schematic depiction, again, the same type or same symbols is used to indicate intake valve open, petrol injection and ignition. So, what you can understand is, at a particular instant, say for zero-degree crank rotation, 360 degree and 720-degree crank rotation. You can see that petrol injection takes place sequentially. So, when injection is there in cylinder one, then there is no fuel injection in remaining other three cylinders. So, this schematic depiction is essentially for the sequential injection scheme to four different cylinders. And you can see when a particular cylinder is getting fuel or the scheme or the fuel injector is injecting or delivering fuel to a particular cylinder, then there is no fuel injection in the remaining cylinder at a particular instant of time.

So, now as we have already listed down a few important points for this particular type. And since it is possible to inject fuel at the right time, we can maximize engine efficiency. And if we can maximize engine efficiency, which is equivalent to saying that emissions can be reduced or controlled. Next, I will be talking about grouped injection.

Here, number 1 is injectors are grouped into pairs, then 2 is the pair. Injectors are grouped into pairs. So, two mean, two cylinders will use one pair. If it is a four-cylinder engine, that particular engine will use two different pairs; a six-cylinder engine will use three different pairs. So, the pair consists of two consecutive cylinders, which is what I said just now in the firing order.

And each pair is driven by a separate by a separate circuit, a separate driver circuit. It is not the case that a common circuit will be used to drive all pairs in a group injection scheme. So, following this scheme, injectors are grouped into pairs. The pair consists of two consecutive cylinders.

In the firing order. So, cylinder 1 should be fired first, and then cylinder 2 will be fired. Each pair is driven by a separate driver circuit, which is very important. So, for the simultaneous fuel injection system that you had seen over here, for this particular system, basically what is done. We need to have a certain pulse for the injectors. So, all injectors for this particular type—that is, simultaneous fuel injection—for this particular type of injection scheme, all injectors are pulsed by a common driver circuit.

So, that is what I forgot to mention. Now, I'll write here. So, I may mention here that all injectors are pulsed by a common driver circuit. So, that is very important.

So, it is not the case that every injector will have a separate driver circuit. So, that is why it is the simplest one. So, now, we should come back to our discussion on grouped injection. Each pair is driven by a separate driver circuit.

Now, as I mentioned that if it is four-cylinder engines, for example, mean, since injectors are grouped into pairs, so four-cylinder engines are used two different pairs, six-cylinder engines used will use three different pairs all these things. Now, so important point that I should write for this particular scheme is that, fuel injection is timed to deliver or inject the fuel immediately preceding the intake stroke for leading cylinder in the pair.

Four cylinders engine use two different pairs. So, each pair is responsible to supply fuel into two different cylinders. and what it is written over here, fuel injection is time to deliver fuel immediately preceding the intake stroke for leading cylinder in the pair. And

another important point is, it is two pairs, three pairs, so the entire group is pulsed one per engine cycle. The entire group is pulsed, one per engine cycle. So, following this injection scheme, rather the ignition timing, the injection timing, following this scheme, the timing method. Essentially, we have discussed about three different schemes. So, what we are trying to say in a way is timing method.

So, following the scheme, the timing method, ensure that fuel injection or fuel delivery does not linger behind the intake valve. So, that will reduce the emission. So, just following the the grouped injection timing method. Following the grouped injection timing method, fuel does not linger behind the intake valve. So, thereby, this particular aspect reduces emissions. So, what is very important point? So, injection time does not allow or ensure fuel, ensure that fuel does not linger behind intake valve.

So, if it is a case, then certainly we can reduce emissions. Then final scheme is independent injection that you have studied in your basic IC engine course. So, this is the last one is independent injection. So, following this scheme injectors are driven independently and sequentially by separate driver circuits. Number 2 is injection is timed to deliver entire fuel just prior to each intake valve opening. So, from these two particular characteristic features, we can say that, this timing method provides optimum engine performance in terms of emissions and fail economy. So, following this timing method or scheme injectors are driven independently and sequentially by separate driver circuit. So, try to understand injectors are driven separately and also sequentially. So, if it is a multi-cylinder engine. So, for each an individual cylinder will be having a dedicated injector and all injectors are driven independently and also sequentially. It is not a case that when cylinder 1 will be receiving fuel, cylinder 2 will not like this and injection is timed to deliver entire fuel just prior to each intake valve opening. that control should be done by ECU. So that entire fuel amount or fuel mass should be injected before intake valve opening.

So, accounting for these two important or distinctive features, this particular scheme provides optimum engine performance because of entire fuel is injected just before the intake valve opening and we can reduce. First of all, it is sequentially and individually, so we can meter or we can supply metered quantity of fuel to each and individual cylinder. So, that way we can bring fuel economy and second thing is we can reduce fuel or the better emission because see that emission should be, we have discussed in the context of previous two methods that right time. So, if a particular cylinder is having a dedicated injector, then it is possible to deliver an inject fuel at a right time. If it is a case, then we

can bring in, we can establish or we can ensure better fuel economy as well as reduce fuel emissions.

So, to summarize today's discussion, we have tried to understand the electronic fuel injection system, or EFI. The electronic fuel injection system is part of the electronic control unit, and in the context of the electronic control system, the fuel admission process is an assembly of a few sensors, injector assemblies, and wiring. So, all these parts together form the electronic fuel injection system. We have seen that this particular unit should work based on the inputs received by a few sensors from several parts of the engine.

After receiving signals from several sensors, the ECU will derive the basic pulse width first. It will then be corrected based on a few considerations, and the final width will be derived. The most important part we have discussed is the frequency of the pulse width—how frequently the injector will be in operation. That is also determined by the ignition pulses. We have seen, and thereafter, we discussed a few schemes or injection timing methods typically used for engines.

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

Thank you.