Course Name: Engine System and Performance
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Lec 27: Modes for fuel control, Integrated engine control system

I welcome you all to the session on engine system and performance. The topics of today's discussion are fuel control modes and the integrated engine control system. From our previous classes, we have learned about the need for an electronic fuel control system. Essentially, this system is required to allow an engine to operate with fuel efficiency and reduced emission levels. We know that an engine can operate under varied conditions. If we need to have better fuel economy along with reduced emissions, the control system or unit must be capable of performing tasks to provide an adequate or desired air-fuel mixture for varied conditions.

As we know, the engine control system is responsible for controlling the quantity of fuel across all operating conditions of the engine. As I mentioned, the engine can run from idling to the cushioning zone and then the power zone. We have studied this in our internal combustion engine course.

Idling zone. To ensure the engine runs optimally or under design conditions, the air-fuel mixture supplied to the engine should always be at the optimum or stoichiometric ratio. To achieve this, several functionalities are required. The purpose of the engine control system is to control the quantity of fuel supplied to the engine for all operating conditions. The issue is that, there are a number of distinct categories of engine operation, and each of these operations, corresponds to a particular mode in the control system. So, engine operation, we have several distinct categories, and each category— corresponds to a specific and distinct mode—or rather, say, operating mode—for the engine control system. So, this is what we can see, and, the engine control system, this system is responsible for controlling the quantity of fuel to be supplied to the engine cylinder for all possible, fuel quantity— for all possible operating conditions. So, this is very important. So, this is the task of the engine control system. And we have seen that an engine can operate under several or several distinct modes of operation or several modes. So, an engine can operate under following—several modes, and each mode or each category corresponds to a specific and distinct mode. So, that means if we try to write in the next slide— that we have engine modes, say, for example, A, B, C, D, E, F, like this. So, all these are distinct categories.

So, these are several categories of engine operation. It may be idling, the engine needs to accelerate, the engine needs to decelerate, the engine needs to run in a power zone, or the engine is running in an idling condition. So, all these possible categories are here. We really do not know how many such categories there are. We will see soon.

And then, each category corresponds to distinct and several modes. So, this is M1, this is M2, this is M3, this is M4, this is M5, and finally M6. So, try to understand since there are a number of distinct categories of engine operation, and each of them corresponds to a distinct mode for the control system. Why is it so? Because the difference between two operations, whether A and B or B and C, or the difference among all the operations, is so large that it is not possible for any particular mode to control well for the categories of operation that we have discussed. So, the difference between two different categories of operation, or the difference among all the categories of operation, is so large that a particular one or two different modes is not enough to control the fuel for all the categories of operation. That is why each mode or each operation category needs a particular mode, and all of these modes have separate software routines. So basically, it has software routine S1, it will be having S2, it will be having S3, this mode will be having S4, this is having S5, and this is having S6.

So, difference between these two modes are so large that we need this dedicated software routine. for each mode. Because difference between two categories of engine operation or among all the categories is so large that it is not possible for any particular mode to control fuel for all the categories of operation. So, this is what it is. Now question is having said this, that an engine needs dedicated software routine for all the modes. So now question is that means if a particular engine has to switch between two categories of operation say for example when you start engine and then again when we try to draw up more power from the engine. So, these two are two different categories of operation. Maybe when we start engine we can skip the engine just starting it for a few minutes and then again, we start engine or we try to draw more power from the engine.

So, starting the engine will be having a particular category of operation and then again when engine will try to produce power. So, that would be another category of operation. So, these two different categories should be controlled by two different modes, but essentially the engine control unit that is the central part should be able to supply required quantity of air fuel mixture or fuel to precise for all the modes, even though the engine is shifting between or switching between one mode to another mode. So, that is very important. Now, then question is the control system.

So, the control system will house all the software routines essentially to control all these modes, which in turn will control all these categories of operation. So, the control system will house all the software routines. And if the engine has to switch from mode 1 to mode 3 or from mode 1 to mode 2, that is M1 to M2, because maybe the engine operation has changed from category A to category B, then the control system would be adjusted. Or the control system would be able to give some input to the injector to supply an adequate amount of fuel that is needed as the engine operation is changing from category A to category B, and accordingly, the mode of operation has to be changed.

So, this control system basically should determine the operating modes first, the operating mode from the existing sensor data and call the particular software routine. Software routine to adjust the changed condition. So basically, this is how the control, so this is the central part. So, the control system will be having that particular feature.

So, it should be able to determine, so the control system should determine the operating mode first from the existing sensor data because there are many sensors. And after determining the mode based on the measurements from the existing sensors, then the control system will call upon a particular software routine to change, to adjust the air-fuel ratio to the changed condition. So, that is how this works.

Now, for a typical engine, there are seven different engine operating modes. And these modes are, number one is engine crank, or engine cranking. Then number two is engine warm-up. Number three is open loop control that we have already discussed.

Number four is closed loop control. That means we may require to switch the control system. We'll call upon the software routine to change the mode to adjust to this change operating condition, maybe from cranking to warm up, then warm up to open loop, open loop to closed loop. We'll discuss this, taking an example today. Then, 5 is engine acceleration. Or it is known as hard acceleration. Hard acceleration or heavy load. This is also heavy load. 6 is deceleration, Low load, and 7 is the ideal mode. So, all these 7 distinctive modes or engine operating modes are identified for a typical engine. So, we shall take an example to check how a particular control system, or how a control system which is integrated into the electronic control unit of the engine, is able to provide some control logic mode to change the engine operation from one to two, then two to three, three to four, or four to five, depending upon the requirement.

So, it may so happen that from the warm-up, we may need to go to 5. So, certainly, if we need to go from warm-up to hard acceleration or heavy load, we need to go through open loop, closed loop, etc. But even if we do not need to go from open loop to closed loop or from warm-up to hard acceleration or heavy load, certainly we have to cover these two different modes, but it is sudden. So, the control system would be able or capable to perform some task so that the software routine—the control system will call upon the software routine—to adjust the change condition, even if it is momentarily needed to change the operation from warm-up to heavy load condition. So, let us now take an example. So, if you go to the next slide. So, the program for mode control logic determines engine operating mode, from the sensor data and timers.

So essentially, the control system—that is, the central part of the electronic control system—is reliant on the sensors, taking feedback from the input sensors, the control unit of the electronic control system. The inbuilt program is used to change the mode control logic, or mode control logic, or control mode logic. So, this control mode logic will swing between, or will determine—so the program will first determine the logic to shift from one mode to another. So, this mode control logic passes the control system from one mode to another, determining or estimating the engine's operating condition at any particular instant of time, using sensor data.

So that is very important. So now let us what it is very important. This is important to know. This is the basically very important point based on which a control system works. So, if we now take an example say, an example we are taking now, an engine, say E. So, this engine E. If the engine, number one, when the ignition key is switched on, if we go back to the previous slide, I have written engine cranking what does it mean. This engine cranking is a process of using a starter to rotate IC engine so that it can start.

So that is very important. So, starter essentially. So, this is essentially, because although I had mentioned engine cranking, cranking refers to a process using a process of engine cranking is a process of using a starter, is a process by using a starter to rotate the engine so that it can start initially. That means, that even if you have two wheelers, we can have now battery operated system, if you switch on, the engine will start.

So that is the starter engine cranking; we are starting the engine. So now, the example that we are going to discuss today is when the ignition key is on. Essentially, if you switch on, if you want the switch in your two-wheeler, you are essentially turning on the ignition key. So, when the ignition key is on, the mode control logic on the mode control logic, that is MCL.

So, when the ignition key is on, the mode control logic—that means we have started the engine—the mode control logic automatically selects an engine start control scheme, that provides a high fuel-air ratio, not the air-fuel ratio, during engine start.

So, this is the idling zone. So, when we start the engine, we need to supply a rich air-fuel ratio, and that information should be given by the mode control logic. So essentially, the mode control logic of the control system automatically will select a particular mode. If we go back to the previous slide, this software routine—the control system—will use sensors to detect whether the engine is now going to start or not.

If the engine is, if we switch on the ignition key, that means we are trying to start the engine. Software routine will allow mode control logic or MCL to select a particular mode of operation and that mode is essentially. The mode should map to the scheme and that scheme should be able to supply reach failure ratio, so that to meet the requirement during that particular condition. So, if we go to the next, then number two. So, now it is start, when engine rpm increases or rises above the cranking value. That means we started engine E, then initially we had to supply each air-fuel mixture which is required during that particular mode of operation or category of operation.

Then when engine RPMs rises, essentially, we are trying to extract more load from the engine. Now if it is a, say, four-wheeler or two-wheelers, so when engine will start, driver will drive the engine, so then essentially engine needs to produce more power. Then RPMs will increase above the cranking value, then what will happen, then controller identifies engine started. So, then control will identify that engine is already started and process the control to program and process mode control logic, to the engine warm up mode. So that means try to understand we have taken this example. When we start the engine, the requirement is to supply reach fuel-air ratio and that should be controlled by the controller or control system. So, essentially controller or control system will take or determine the condition from the input sensor data.

Then the software routine that is already mapped, already built in with the system that sub train routine will be used and mode control logic or MCL will allow or will select automatically a particular mode. So, mode control logic has to map or will map a particular mode of operation or particular mode which should be compatible with the operating condition or operating category at that particular condition. So, when engine RPM will increase that is what I told you few minutes back, that when engine needs to produce more power that mode controller logic or control system will understand or will identify engine started.

So, controller will identify the engine started again based on the sensor data and then that controller will allow mode controller logic or will pass mode controller logic to the engine warm up mode. So, again we need to warm up the engine that means we need to increase the coolant temperature. So, that this way control system is responsible.

So, essentially in this condition, the air flow ratio to be supplied, and this operating mode keeps the air-fuel ratio low. Why it is? So, this particular, so essentially the controller will now pass MCL to the engine warm up mode that is true and essentially the sole objective is to again control the air fuel ratio and that should be low. Why it should be low? If we go to the next slide. So, in the warm up mode air fuel ratio should be low to prevent engine stalling or engine stall either during cool or cool weather until the engine coolant temperature rises above some minimum value. So, that means in the warm up mode we are trying to warm up the engine and that is why if we supply more air fuel ratio.

Beyond the stoichiometric one, then the presence of excess air in the air-fuel ratio will take away certain amount of heat. So instead of warm-up, it will not be possible to increase the temperature of the coolant. So, engine will stall. So, if I mark here, engine stall. It means stalling of engine or engine stalling. Since I have used this word, I am writing the meaning of this word in this context. Engine stalling means engine will stop. while driving or idling.

So, this is very important. So essentially, to prevent engine stall during cold weather until the coolant temperature reaches its maximum, we need to warm up. So, that is why the air-fuel ratio should be maintained low.

So, all this information should be provided by the controller or control system to the engine, to the injector specifically, through several modes of control logic or through several operational modes. So, you can understand how this system, the control system, is capable of providing an adequate air-fuel ratio or fuel-air ratio based on the engine's needs at a particular operating condition. Next, let us take this example for one case, then I will quickly complete it. So, say for example, hard acceleration or heavy load.

So, that means, from our understanding, we know that if the engine needs to produce more power to meet the requirement of a heavy load, that is called hard acceleration. In that case, what we have understood from our internal combustion engine course is that a rich air-fuel mixture should be given to the engine. So, this is called fuel enrichment.

So, which needs fuel enrichment, so that means what will happen. So, if the engine changes from the cruising zone to the power zone suddenly, then again, that sudden change in operating mode or operating condition should be taken care by the control system, so that engine stalling will not occur. If the engine needs to produce more power despite knowing the requirement of a rich fuel mixture, and if the controller fails to supply that information to the injector, then the engine will stall. So, this is what happens here. Just for the sake of completeness, I am writing that the Mode Control Logic (MCL). MCL chooses a scheme that provides a rich air-fuel mixture. For the duration of acceleration or heavy load.

So, if we go back to the previous slide, the controller or control system will now receive some or determine input data from the input sensors. And then, that Mode Control Logic (MCL) will map a particular mode which corresponds to that particular operation. So, if the operation changes from the cruising zone to the power zone or from the cruising zone to the zone where we need heavy load or acceleration, then certainly the mode has to map to that particular operating or operational category. So, that information should be given by the controller to change the Mode Control Logic or to shift the Mode Control Logic from one particular mode to another mode, and that particular mode will be compatible with that particular operating condition. Accordingly, the air-fuel ratio would be supplied. Because all these modes are responsible for supplying. For example, Mode 2 is responsible for supplying a rich air-fuel mixture. So, essentially, the controller will allow the Mode Control Logic to shift to M2 so that M2 now corresponds to operating condition B, which means heavy load condition. That way, it would be adjusted.

Now, the question is what happens in this zone if we supply rich air fuel mixture, certainly maximum torque will be produced, but it is not possible to have fuel economy and better emission. So though in this regime, torque produced will be maximum with a compromised fuel economy and emission.

So, as compared to stoichiometric one, to some extent, though we are trying to have maximum torque, so we have to compromise the fuel economy because it should be little away from the stoichiometric air-fuel ratio and essentially emissions should be beyond control. So, we have to compromise. Now, the question is, if the need for enrichment is over, so when the need for enrichment is over, control or mode control logic is return either to open control or closed control. Control is return either to open control or closed control depending on the selection of mode control logic depending on the control mode logic selection condition that section of MCL at that condition. So, if the requirement of that heavy load requirement is over, so now engine will face or encounter another condition. So, at that particular condition, the control has to return either to open control or close control depending on the selection mode control logic. So, controller will allow mode control logic to again map either with M1 mode or M2 mode or M3 mode depending on the state of the condition. So, if that particular period is over. So, this way the control system works, and essentially you can understand the sole responsibility is to control the amount or quantity of fuel to be supplied to the engine.

If we summarize this control system, the control system selects an operating mode based on the instantaneous operating condition, determined from the sensor measurements. This is number 1. Number 2 is, within any given operating mode, the desired air-fuel mixture is selected. That is very important, and this is desired, this is not stoichiometric, and that is what we had seen. Even if the engine needs to maintain a stoichiometric air-fuel ratio during cruising, the controller will supply it. If the engine experiences heavy load or acceleration, certainly the stoichiometric air-fuel ratio should be deviated. So, the air-fuel ratio should be deviated from the stoichiometric one, and the engine needs a rich air-fuel ratio. In that condition, we had seen a few minutes back that maybe the engine will produce maximum torque essentially to handle the heavy load, but with compromised fuel economy, and if the fuel economy is not there, certainly the emission level cannot be controlled.

So, the air-fuel mixture is selected, and the controller then determines the quantity of fuel to be injected into each cylinder during each cycle. So, the quantity of fuel is dependent on the particular condition the engine will experience. So, this is all about the control modes for fuel control.

Now, let us briefly discuss the integrated engine control system. So, what is an integrated engine control system? With the advent of digital technology, of course, sensors and other electronic devices, electronic gadgets, it is possible to integrate various functions into an integrated circuit.

So, we can see from our previous discussion that a typical engine has seven different operating modes or operating conditions. And the difference between two operating conditions or among the operating conditions is so large that it is not possible to have any particular mode to control or provide the desired air-fuel ratio into the engine cylinder. So, what we had discussed is that we need to have separate software routines for seven different operating conditions or seven different modes. Now, the question is, with the advancement of digital technology, is it possible to integrate various functions into a single control unit?

So essentially, the control unit, which is the central unit, the controller, should be a single unit. It is not possible to have eight or seven different control units to control seven different modes. So, if we go back to the previous slide, what you can see is that there are several engine operation categories, and to control all these categories, there are several modes or several control modes, but all these control modes should be controlled by a single unit instead of seven different units, and that is possible with the advancement of digital technology—not only digital technology but also computer algorithms and software. So, these three advancements or developments have led to integrating several functions into a single unit, and that is what an integrated control system is.

So, if you go to the next slide, the integrated control system, means the control system or control systems are integrated into a single unit and this is possible because of the advancement of digital technology computer or computational algorithms and software. So, earlier engines in many cases had several control units or control systems, but the trend at present is to have a single unit because that is possible using all these advancements in the field. Now the question is, if we can have an integrated control system. So, the integrated control system certainly has distinct advantages and disadvantages. The disadvantage is it is more compact, and so many electronic gadgets and circuits are placed therein, so we need efficient cooling to ensure the unit runs smoothly without issues.

So, cooling should be there, and that is also known as MEMS cooling. So, the integrated control system is compact, and several electronic circuits are placed therein. So, cooling is an issue. If adequate or proper cooling arrangements are not made, then the system may fail. But the advantage is this particular integrated control system (ICS) or systems has the capability to maintain stoichiometry and simultaneously optimize ignition timing. Ignition timing and fuel control, or control over ignition time and fuel injection period, are two very important things. If we can have proper ignition and a proper air-fuel ratio to be injected or drawn into the engine cylinder, then combustion can be efficient and emissions can be reduced. So, the integrated control system has the capability to maintain stoichiometry.

Stoichiometry that is closer to the ideal stoichiometry—of course, if the requirement is heavy load or acceleration, the air-fuel ratio should deviate from the stoichiometric ratio—otherwise, it will maintain stoichiometry in the air-fuel ratio while simultaneously optimizing emission levels and ignition timing.

To summarize today's discussion, we discussed control modes for fuel control to be precise, which is very important. Then, we discussed the integrated control system, and the current trend is toward such systems instead of using multiple units, as we can integrate several functions into a single unit. But we also mentioned or discussed the disadvantage of this particular system, the integrated control system. Excessive heat generation requires adequate cooling. Otherwise, this system has the advantageous feature of providing stoichiometry or near-stoichiometry, as well as optimum ignition timing.

With this, I conclude today's discussion, and we will continue in the next class.

Thank you.