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Professor Name: Pranab Kumar Mondal
Department Name: Mechanical engineering
Institute Name: Indian Institute of Technology, Guwahati
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Lec 15: Memory-based and Adaptive-based control systems

I welcome you all to the session on Engine System and Performance. Today, we shall discuss two different types of control systems: memory-based system and adaptive system. So, if you try to recall in the last class or in our previous session, we talked about control systems and their classification. We could define control theory, and any control system used to run an engine smoothly relies on control theory. We had seen that control systems can be divided into two different types.

One is the open-loop type control system or open-loop type control, and the second one is closed-loop control or feedback control. We had seen that the feedback system, or feedback loop, allows the system to adjust to changing conditions, essentially to run the engine with optimum conditions and ensure reduced emissions. So, in line with our discussion from the previous class, we shall discuss today two other types: memory-based system or memory-based control system and adaptive control system. From the name itself, you can understand memory-based. Essentially, in a control system, the electronic control unit or the engine management system will have some tables containing stored data. Whenever the engine experiences any changing conditions, it will try to compare or map those data to the lookup table.

So, let us discuss this particular type first: memory-based control. So, if we write memory-based control. So, what it does? For an engine—or, as we have discussed—control systems are essential for ensuring reduced emissions, smooth and safe operation of the engine, and ensuring the engine runs under optimum conditions.

Optimum values of the control variables. What are those? Such as spark timing. Fuel injection period or pulse width. So, pertaining to this type of control, the system will store data or store values and of the control variables. What are those control variables?

Spark timing and fuel injection period, or fuel injection pulse width, and this they will store data for a range of operating conditions. And the system will store data, or systems will store data, in the form of a table or map. So, I will now be marking these two words, or I will put, or I will keep, these two words under the circle. The system stores optimum values of the control variables, such as spark timing and fuel injection pulse width, for a certain range of operating conditions. It is not the case that the system will store data only for a particular operating condition.

Essentially, to increase the flexibility of the system, we need to store data for these two control variables for a range of operating conditions in the form of a table. I have marked, or I have kept these two words in the circle. So, what is an optimum value? Optimum values are basically efficiencies. Optimum values are determined from the perspective of, or from, efficiency and emission considerations.

Essentially, these two things are important for any engine. So, we need to ensure always that whenever engines are modified, new systems are integrated, or more complexities are introduced. So, all these things are done essentially to improve the efficiency and not only to improve the efficiency, certainly a good designer will design the engine, or researchers, whenever they are doing some research on engine systems, their target should be to increase efficiency, certainly at the cost of reduced emission levels. So, it is not desirable to increase engine efficiency.

compromising or with a compromise in emission level. So, we have to have these two things simultaneously; we can increase efficiency with a simultaneous reduction in emission level. So, these optimum values that I have marked in the previous slide include efficiency, and emission consideration, and are derived from experimental tests.

So, we need to perform tests and take measurements on a test engine, collecting or obtaining those optimum conditions, which will be derived or obtained from experimental tests. We shall store those. So, these are the optimum values. Now, again, if we go back to the previous slide, you can see that we have written here again two words: optimum conditions. What does it mean?

So, these operating conditions, if we go back to the next slides. So, for any operating conditions, we need to look for optimum values of the control variables. So, these operating conditions are always optimum operating conditions will be stored in ROM in a microprocessor control system. That means We may have a certain range of operating conditions, so for the system, for each operating point. That means, if we know a particular operating point and if that operating point's control variables are the optimum control variables.

So, for each operating point, we need to figure out optimum operating conditions, and those optimum conditions will be stored in RAM in a microprocessor control. So, now this is basically memory-based control. So, it would be nice if we try to illustrate this type of system with the help of an example. So, with the help of an example, if we try to illustrate this system, that would be clearer to you all. So, now, let us, consider a particular example.

So, the example is, say, when engine load, that is, manifold pressure, or speed, when engine load changes to a new condition, a new value. So, this is an example. Say, for example, an engine is running at a speed with the help of a certain amount of air-fuel mixture. Certainly, we need to supply a certain amount of air-fuel mixture.

So, receiving certain amount of air fuel mixture if engine is operating or running and if we assume that the engine running condition is the optimum condition. Now, when that engine load certainly when engine is running at optimum condition then engine load would be optimum and that is the maximum efficiency we can expect from the engine. Now, if we increase the load or if we demand more load from the engine, then certainly engine operation or operating point should deviate from the optimum values.

Now, when engine load changes to a new value, then few minutes back we said that if we go back to the previous slide that these operating conditions are always optimum value of optimum operating conditions and would be stored in ROM in a microprocessor control system for each operating point. And this, if we mark again, this is known as library of the control unit. And those optimum values are stored in a table, in the form of a table and that table is known as lookup table.

So, when engine load changes to a new value, then certainly, the control system will try to, consult with the lookup table and from the lookup table they will try to find out the condition that at the present condition the data corresponding to the present condition and control unit or control system will try to adjust control variables like spark timing or fuel injection pulse width so as to adjust engine load with the optimum value by tuning the spark timing by tuning the fuel injection pulse width. So, let me tell you once again if engine is running at the optimum conditions then it is ok, but if the load say for example, load demanded from the engine is more than the optimum value certainly that would be manifested through some aspects through some characteristics curve of the engine, then speed will reduce, manifold pressure will fall. So, all these things will be there and these are the indication of the load deviation from the optimum value.

Now, that information will be sensed by the electronic control unit by control system. So, control system what control system will do? Control system will consult with the look up table and try to find out that what should what is the new condition, new operating condition and pertaining to the new operating condition engine issue will be will try to figure out what should be the control variables. So, control variables need to be adjusted.

So, if load increases, certainly we need to supply more amount of fuel, more amount of air. So, control system will now give some information to the control variables to adjust, to react to react the change condition. So, now, let us consider a lookup table. Say, if we consider a table and if we consider that is speed, so 1,000 rpm, 2,000 rpm, 3,000 rpm, 4,000 rpm, 5,000 rpm.

So, in this lookup table, in the topmost row, we have the speed values. So, these are the engine speed. Now if we look at the first column here we are having say for example we have like this. So, 1, 2, 3, 4, 5 like this. So, this the first column, is basically these are the load cite. So, increasing load cite number indicates increasing load.

So essentially these numbers indicate how far open the throttle valve is. So, if we keep the throttle valve opening for I mean if the throttle valve is widely open, then certainly more amount of air-fuel mixture will be supplied to the engine. So, engine load will be more. So, load that will produce by the engine will increase.

That means in the first column, we have inserted a few numbers. These numbers are basically indicative measure of increasing load. So, if we traverse from the top row and if we go up to the bottom row then we can see the number is increasing load cite number and load cite number increases that means engine load increases. Similarly, if we look at the first row, so what we can see that these are basically speed cite.

So, this is speed cite. So, you can see certainly, it is increasing, say is RPM. So, from 1,000 RPM, 2,000 RPM, 3,000 RPM, 4,000 RPM, 5,000 RPM. In fact, we can have this lookup table we can prepare based on the experimental data. So essentially, if we perform experiments using 10,000 RPM, we can have data.

Now, so we do not have any, say, this is 8, this is 8, 12, 12, 16, then we can have say for example, 14, 14, 18, 18, then 20; 24, 24, 24, 26, 26; 28, 28, then 28, 30, 30. Then we can have 32, 32, 34, 34, 36. So now, again I have inserted a few numbers in this table. Now question is, we shall take this example, rather we have taken this example to illustrate the functionality of a memory-based control system.

As I told you that there are two engine variables, rather control variables. One is speed, another is the load. So, I have already explained that if we go from the first row up to the bottom row of the first column, then this load cites number increases, that means engine load increases. Say for example, if engine is running at a given time at 2000 rpm and load produced by the engine corresponds to these three loads cite numbers. So, if we take this, these two control variables correspond to a particular operating condition of an engine.

So, engine is running at 2000 rpm and load produced by the engine corresponds to three loads cite number. Then we can see this 18, is the value that is spark value; control, spark timing that is 18 degree. So, you have studied in your undergraduate course that spark advancement, spark plug should be on when piston is, if it is a SI engine, piston is, when piston is about to reach TDC, before reaching TDC, spark plug should be on. So, the total sparking time that is degree, that is also important.

So, this is 18 degree. Now, if engine load changes to a new value, say for example, engine speed is, if I try to mark this value, so if the new condition is 3000 rpm and still we need to have the corresponding load cite number is 3 then at 3000 rpm if the load cite number is 3 you can see certainly we have to again control the spark timing then spark timing should corresponds to this value that is 24 degree. It might be a case that if the speed is 3000 rpm and load cite number is 4 if the speed is 3000 rpm and the load cite number is 4, then certainly we have to have this number for the spark timing that is 26 degree.

So, this information is stored in the memory-based control and whenever engine load changes, electronic control unit or engine management system consult with this lookup table and then immediately try to figure out what should be the spark timing or what should be the fuel injection pulse width so as to adjust with the new condition and engine can always produced maximum efficiency at a reduced emission level. So, this is all about memory-based control system but try to understand if a case is something like that that engine is operating at 3000 rpm and producing load cite corresponding to the corresponds to this number 4 and if the sudden speed changes to 3500 rpm then that information is not given in this look up table. So, electronic control unit is also programmed to interpolate between these two values. So, if it is 3500, certainly it is in between 3000 rpm and 4000 rpm.

So, if the load cite number is still 4, then the ECU will be able to interpolate between these two values, that is, 26 and 30, and calculate what the spark timing should be for that particular engine. So, this is all about, a memory-based control system. And the problem with this control system is, that this memory-based control system also has a few disadvantages. One is, these points, this control system is unable to adjust to changes when there is a shift from point to point in the engine components.

The second thing is that whenever we prepare this lookup table, we perform some experiments, and measurements are taken on a test of a given engine. Now, using this set of parameters, we cannot predict the performance of an engine that is not similar to the engine used to measure data during experimentation. So, that is one thing. The second thing is, sometimes, if the density of the fuel changes, then certainly, or, knock will appear; combustion knock will occur. That part is also not taken into account by this control system.

And so, having all these, basically, these are the limitations of this memory-based control system. Now, what about the adaptive control system? So, an adaptive-based control system. So, what I said is that the memory-based control system, we have tried to illustrate the functionality of this particular type of system with the help of an example.

And we have also listed down or we have also discussed about a few disadvantages of the system that is the system is based on the measurement the lookup table is prepared based on the measurement on a test engine and then if the table is used to operate or control an engine which is not similar to the test engine then I mean it will be difficult. Second thing is that if there is gum deposit and change in fuel then certainly this system won't be able to take into account that aspect and as I said you that sometimes if fuel density changes then knock will combustion knock will be there and ECU in that case ECU equipped with this memory-based control will be in a position to or will start malfunctioning. So, all these things are there.

So, what about adaptive control? In adaptive control, this system determines operating point for or from real time measurements of the engine variables and subsequently corrections of the lookup table. So, you can see the name itself, the adaptive control. So, the system will be adapting the change. As I said, if we try to recall the example that we had considered to illustrate the functionality of memory-based control, that when engine load changes. So, if the engine load changes, then electronic control unit will consult with the lookup table.

But pertaining to this adaptive control system, that system will try to determine the operating condition from the real time measurement of the engine variables. That means, when engine is even running then and then, that will correct the lookup table. So that is important.

So that means lookup table will be there. So, as I said you that if it is 2000 rpm and 3000 rpm, if engine load changes or if engine speed changes to 2500 rpm, then what should be the spark timing? System would be able to measure or determine that spark timing from the real time measurement from the engine itself. So, let us take an example. So before going to that subsystem that have used adaptive control.

So, there are many subsystems that have used adaptive control are exhaust gas recirculation, number two evaporative emission, number three air flow control and number four is air fuel ratio control. So, these four different subsystems, that is exhaust gas recirculation, and sometimes we call it EGR.

So, this is also known as EGR. Exhaust gas recirculation system, evaporative emission system, air flow control, and air fuel ratio control, these subsystems, use adaptive control system. So, again let us take an example to illustrate this particular type of system. So, if we consider an engine and if we allow perturbation to the ignition timing, we know ignition timing whether if it is kind of we need to ignite the fuel air mixture.

So, if it is a spark ignition engine we need to ignite the air fuel mixture by switching on the spark plug so if we allow perturbation. So, if we give some perturbation to the ignition timing then torque. So, basically that if you try to recall as such you have studied in internal combustion engine course that if we delay the ignition, if we advance the ignition, the effective influence will be there on the torque that would be produced by the engine. So, if we give some perturbation to the ignition timing and then from the ignition timing torque curve is inferred from the engine load or engine speed. So, if we give some perturbation to the ignition timing and then of an engine then from the then perturbation that ignition timing and torque curve is inferred from the response of the engine speed rather try to understand that in the former case that is for the memory-based control.

we had lookup table and when engine speed or engine load changes, control unit will consult with the lookup table and try to determine the operating condition and corresponding to the new operating condition, lookup table, from the lookup table, control unit will give the optimum control variable that is spark timing and fuel injection pulse width. But in this case, that it is certainly it will be having lookup table, but the system will correct the lookup table value. So, that means system what this particular system will do that operating conditions will be measured from the as I had written over here that operating conditions will be measured from the real-time experiments right and real-time measurements from the engine variables and subsequently that they will lookup table will be corrected the data, those will be there in the lookup table will be corrected. So, what example we have taken today that if we consider an engine and if we try to perturb the ignition timing then certainly ignition timing torque curve will be changed and then if we perturb up the, ignition timing, engine speed will change. So, ignition time torque curve is inferred from the response of the engine speed. This way, what we can do, we can find the ignition timing for a particular operating condition. So, and then store, and this way we can find the ignition timing for a particular operating condition, and we can store that data in the lookup table.

Following this, as I have mentioned, we can have control the NOx emission using this exhaust gas recirculation control. If we can have emission control, we also can have air flow control and we can have air flow ratio control. So, this is adaptive based control. That means, engine will try to adapt the changes.

So, engine will try to adapt to the changes of the environments or of the environments and then engine will try to determine the operating condition from the real-time measurements of the engine and subsequently corrections will be done in the lookup table. So, this is very important. what was done in the memory-based control that those data lookup table was there and from the data that is stored in the lookup table whether it is readily available from the table then we can that ECU will take the data. If it is not readily available then ECU is also programmed to interpolate. But corresponding or pertaining to this particular type of system that is adaptive based control Engine, the control system has the capability to determine the operating condition from real-time measurement.

Not only that, but they will also correct the look-up table data. So, this is all about the memory-based control and adaptive control system. Now, we have talked about the electronic control system or engine management system. So, what are the input parameters for any control unit? So, let us briefly discuss all these things.

So now, we have also mentioned the disadvantages of memory-based control. So, when we talk about adaptive control, this particular system still has a disadvantage: the system is very complex. So now, input to the control system. What are those? One is the throttle position sensor (TPS).

Number two is the mass air flow rate (MAF). And then, number three is the engine temperature coefficient. Engine temperature or coolant temperature (CT).

Number 4 is engine speed and crank position. And exhaust gas recirculation, number 5 is exhaust gas recirculation that is EGR. And number 6 is exhaust gas oxygen (EGO). Oxygen concentration in exhaust gas.

So, these are the input to the control system. And what about the output? Output from controllers. So, we will be giving input to the controllers of the control system and we will be getting output from the controllers.

Try to recall the block diagram that we have used to discuss about open type and closed type control system. So, what are the output from controllers? One is, fail meter control. Number two is ignition control. Number three is ignition timing control. And number four is exhaust gas recirculation control. So, these are, basically the outputs from the controllers.

So, to summarize today's discussion, we have talked about two different types of control systems today: memory-based control and adaptive control. We have tried to discuss or illustrate the concept or functionality of memory-based control with the help of an example, and we have also discussed the lookup table.

As I mentioned, in this lookup table, I forgot to say that when engine speed or engine load—I should write engine load or speed—changes, then the ECU will consult this lookup table. Now, at any particular instant of operation, the engine can sense engine speed using the crankshaft sensor and can also measure engine load using the throttle valve sensor. By measuring or sensing these two control variables—load and speed—the engine ECU can consult the lookup table and try to figure out the current operating condition. Corresponding to that current operating condition, the engine can determine the value of spark timing, which is another important control variable. Then we talked about adaptive-based control, as well as the differences between these two control systems, which we could discuss today.

We also discussed what the inputs to the control system are. Similarly, by providing some input to the control system, we are expecting to get some output from the controllers. That is, as expected. We have also listed the outputs from the controllers. As such, we have seen that there are many sensors: throttle valve, throttle position sensor, air flow rate sensor, and others.

So, in our next class, we shall discuss a few different types of sensors. So, with this, I will stop here today.

Thank you.