Course Name: Engine System and Performance
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Lec16: Control system layout & types of sensors: Coolant temperature sensor & Crankshaft position sensor

I welcome you all to the session on engine system and performance. Today, we shall discuss this part, which is electronic devices used in the ECU. Then, we shall discuss this particular part, taking a control system layout. Thereafter, we shall discuss two different types of sensors in today's class. From our previous classes, we learned that the electronic control unit, also known as the engine management system, is very important for modern engines because it ensures the safety and smooth operation of the engine to meet emission guidelines and also allows the engines to operate always at their design condition.

Now, we have learned that the electronic control unit receives inputs from different parts of the engine, and depending on the requirement, this part makes some corrections to be and then accordingly, we get some output from the ECU, which is necessary to adjust the engine to changed or altered conditions. Before going into the layout of the control system, let us first discuss some introduction about the sensors. Why are sensors needed?

What should be the input to the sensors, and what type of output do we get from them? We all know that sensors are essentially provided to pass on some information about the operating state of an engine. As I said, if a particular engine is not operating or running at the designed condition or design value, certainly that information should reach the electronic control unit or engine management system, which will then make some corrections, and those corrections should be conveyed to the sensors located in different parts of the engine.

As I said, sensors are provided to pass on some information about the engine operating state or about the operating state of engine. Now question is, if sensors are really needed to do this, if the task of a sensor is to provide some information about the current operating state of engine to the electronic control unit engine to the ECU or Engine management system. So, this is basically the objective of a sensor.

Now if sensors are needed to provide some information to the ECU about the current operating state of an engine, certainly there must be some input to the sensor and there must be some output from the sensors. So now what should be the input to the sensor? Before going to discuss the particular part, question is sensor will receive about the current operating state of an engine. Then can sensor really provide that information directly to the electronic control unit? No.

So basically, sensor in a control unit or in a control system, sensors are provided to measure the physical variables rather the operating state of an engine and they will provide some measurements, some information in the form suitable for the microcontroller. So that means sensors will receive some information, and it is not a case that those information's will be directly conveyed to the electronic control unit. So, in a control system or in a control unit, sensors are provided to measure some physical variables, those are important to dictate the physical or operating condition of an engine.

And those physical variables will be measured in the form suitable for the microcontroller. So that is very important. So, if I write here that sensors measure physical quantities, these physical quantities are responsible to determine or dictate the operating condition of an engine. So, sensors measure physical quantities in the form suitable for microcontroller. So, this is important now question is then what should be the input to the sensor.

Typically input to the sensor is any physical variable of the plant being controlled. So, any physical variable of the plant being controlled. So, this is the input to the sensor. Then what should be the output from the sensor? So, output from the sensor is always an electrical signal. Now this is what we know by this time. So, input to the sensor should be any physical quantities. That is how the sole function of a sensor should be.

So, receiving any physical quantity or any physical variable, those physical variables or physical quantities are responsible for dictating the current operating state of the engine. And then, the output should always be an electrical signal. Now, the question is, if we talk about ideal sensors, typically ideal sensors respond to any particular physical quantity. But in reality, no sensor can be an ideal sensor because, as I said, ideal sensors respond to any physical quantities or stimuli, but ideal sensors do not exist in real applications. We call them real sensors, and real sensors respond to physical quantities or external stimuli in some way.

And let us now discuss what 'in some way' means for that physical quantity or stimulus. So, ideally, a sensor responds to only one physical quantity. But in reality, sensors respond in some way to that physical quantity or stimulus. For example, if we have a sensor and if the sensor is measuring pressure, for example, if we have a sensor integrated into the intake manifold, and the sensor is responsible for measuring the pressure of the air or incoming air, because we know that without a pressure difference, there cannot be any flow.

So, at the inlet of the intake manifold, if we have a sensor that measures the pressure of the air, the question is, that pressure will change if the surrounding temperature or the ambient temperature changes. So, whenever the sensor responds to that change in pressure or if we consider that as the stimulus, we certainly have to take into account the change in pressure due to the change in temperature. So, in real applications, sensors respond in some way to that physical quantity. Certainly, through proper signal processing, we can eliminate that effect.

So now, let us discuss one thing: an ideal sensor responds only to a physical quantity or stimulus. But in reality, we have real sensors. Real sensors respond in some way to the physical quantity being measured.

We have explained this, so at least you understand the difference between an ideal and an actual or real sensor. But in reality, no sensor can be an ideal sensor. Now, let us discuss the control system. This is a typical layout of the control system for the SI engine. I should write here that this is the engine management system for the SI engine. So, this is for the spark ignition engine. As I said, to ensure the safety of the engine and that it runs always at its design condition, maintaining the emission level guidelines.

We should have this particular system: the engine management system or direct control unit. This system relies on a few sensors. Those sensors provide information about the engine's operating state to the ECU or engine management system. Altogether, all these components are known as the engine management system. That is what we discussed in one of the previous classes.

So what we can say from this particular diagram, that engine speed sensor so this sensor will receive some information about the speed of the engine and receiving that information sensor will provide some output as i said you output is always an electrical signal and that will directly go to the microprocessor system try to remember we said that sensors measure physical quantities say for example if it is the speed of the engine In the form suitable for the microcontroller. And that information will go to this microprocessor system. And eventually from there some information will go to the engine so as to control.

So, engine that is plant or that is ECU or engine management system. So as to control something, maybe we need to increase the combustion rate. We need to supply more amount of fuel. All these things.

Now, there is another important sensor that is crankshaft position sensor. So, if we now mark here, this is crankshaft position sensor. We have another one that is spark timing feedback sensor. We have engine temperature sensor. We have throttle position sensor.

We have a mass airflow sensor. So, all these sensors are needed. This engine speed sensor is responsible for measuring the speed of the engine. The crankshaft position sensor is very important for the fuel injection and ignition system control. So, to know the total time of fuel injection, to know the ignition delay or ignition lag of the engine.

The spark timing feedback sensor is also very important in the context of a spark ignition engine because that sensor is responsible for providing information about spark retardation or spark advancement. To meet the demand, the engine temperature sensor—which very well—is again a very important sensor for modern engines. We need to know about the engine operating condition and engine temperature, so sensors can be integrated into the cooling water jacket. That sensor can also be attached to the intake manifold to measure the temperature of incoming air. So, the incoming air—the air to be drawn into the engine cylinder—should have some specified temperature and pressure to ensure the combustion is efficient. Then, we have the throttle position sensor, which is also very important for controlling the load.

Now, if the engine—or if the vehicle which has an engine—is running at 45 kilometers per hour, the engine is generating a certain amount of load and power. Now, if the vehicle needs to off-wheel, certainly, the driver needs to adjust. So, if we do not have the provision of knowing that the engine is off-wheeling, that information should not reach the electronic control unit or engine management system, and then the engine speed will reduce. So, the vehicle speed will reduce.

So, this throttle position sensor is responsible for adjusting the air-fuel mixture, which is the amount of charge to be supplied to the engine cylinder if it is an SI engine. If it is a CI engine, again, a certain mass of air to be drawn into the engine cylinder should be controlled by this particular sensor. Again, there is a sensor which is the mass air flow sensor. So, all these sensors are very important for running the engine, whether the engine is a locomotive engine or a stationary engine. In both cases, the sensors play a very important role in the safety and smooth operation of the engine.

And receiving some input from all these sensors—the sensors will receive input from the plant being controlled. The plant is the engine here. Receiving some input from the sensor, that is, the microprocessor—or microcontroller or microprocessor system—will give some information to the ECU or engine management system to set up some corrections so that spark timing can be controlled, air-fuel mixtures to be supplied to the engine can be controlled, other masses of air-fuel mixture, and also the fuel injection time period can be controlled. So, we have understood all these, and this is how an engine management system or an electronic control unit works. And, if we look at the schematic definition, we can see there are two important types of sensors.

In fact, all sensors are very important for the safe operation of the engine. But in today's class, we shall be discussing two important sensors. What are those? So, if we try to mark them, one sensor is the engine temperature sensor. So, we shall be discussing the temperature sensor—I should write here 'air' or 'coolant'.

Measuring the temperature of incoming air, we can control the combustion rate. Measuring the temperature of the coolant, we can have some information about the engine present condition. So, air and coolant temperature sensor that we will be discussing today, that is number one. And then also we will be discussing this crank position sensor, number two.

That is crankshaft position sensors. So now let us quickly discuss about the first one. If we go here, again you can see this is the schematic depiction. So, I have tried to have the schematic representation of this particular sensor so as to make you understand this sensor functionality and also hardware.

So, what you can see that this sensor which is air stroke coolant temperature sensor because the same sensor can be used to measure the temperature of incoming air temperature or temperature of incoming air. The same sensor can be used to measure the cooling water temperature so as to know indirectly the temperature of the engine block or engine cylinder this sensor. Let us first discuss about the hardware then we shall discuss about the operating or operational procedure. So, what we know before going to discuss about the hardwares and also the operational procedure of this particular sensor. Let us first discuss why do we need to have a sensor to measure the temperature of incoming air. As such, if you try to recall in one of the previous classes, we have discussed that measuring the temperature of incoming air is very important for the efficient or smooth operation of the engine and efficient combustion. We know the mass of air. To be drawn into the engine cylinder. So, that is $\dot{m}_a$. So, if we write here, we can write this as

$$\dot{m}_a = \rho_i v_s \eta_v$$

This quantity we have used here is volumetric efficiency. Why have we multiplied this quantity with η_v, that is volumetric efficiency? Because, if we just consider these two terms, certainly we will get a theoretical amount of mass of air to be drawn into the engine cylinder. But in a real case, it is not this situation or scenario. So, the actual amount or actual mass of air taken into the engine cylinder for a given throttle position and for a given cycle should always be less than the theoretically calculated value.

And that is why this volumetric efficiency is there. And you have studied this part in your undergraduate, internal combustion engine course. Now, v_s is this is Swept volume, and most importantly, the quantity which will govern the amount of mass of air to be drawn into the engine cylinder is this. That is the density of incoming air. So, what we can do is have this expression in a slightly different form; that is,

$$\dot{m}_a = \frac{P_i}{RT_i} v_s \eta_v$$

where the subscript *i* stands for the incoming quantities. Now you can understand that if we can have air with a low temperature, then it would be denser. So that means, somehow, if we can control the temperature of the air or incoming air at a level where, for a given throttle position or throttle opening and also at a given cycle, a greater mass of air can be drawn into the engine cylinder.

If we can have a larger or greater mass of air in the engine cylinder, then certainly the combustion rate will increase, and we can produce more power output. But if the temperature increases—which is very likely because, depending on the ambient temperature, the temperature of the air taken into the engine cylinder will vary. If the temperature increases, then certainly we can understand that the mass of air drawn into the engine cylinder, even for a given throttle position and a given cycle, should be reduced. If this is the case, then the combustion rate would be reduced. Not only that, but in the absence of an adequate mass of air, the fuel supply should remain fixed, and then we won't be able to control the guidelines or meet the guidelines of the emission level. So, what this sensor does. The sensor can be attached to the intake manifold, to measure the temperature of the incoming air.

The sensor can also be attached to the cooling water jacket to measure the temperature of the engine block or engine cylinder. We can discuss a little bit of the hardware of this sensor. What we can see is that the sensor has a hollow, sealed brass tube. So, you can see that is a brass casing.

So, both ends are sealed. So, this sensor contains a hollow, sealed-at-both-ends brass tube. Inside the tube, there is a semiconductor resistor. So, inside this tube, we have a semiconductor resistor with a negative temperature coefficient.

From the sensor, you can see the electrical connection part. So, the output from any sensor is an electrical signal. Certainly, this electrical connection is there to get that signal. This is also known as a thermistor.

Thermistor air temperature sensor. Now, let us discuss the operational procedure of this particular type of sensor. This sensor has a semiconductor resistor with a negative temperature coefficient. So, we need to look again at the figure in the inset of this schematic depiction. If we focus our attention on this particular curve, negative temperature coefficient—what does it mean?

With increasing temperature, resistance drops. So, this particular semiconductor resistance is incorporated into the sensor. And when there is a change in ambient temperature—ambient air temperature—the sensor is responsible for measuring the temperature. It provides some output signal. That signal is given to the microcontroller, and that microcontroller even gives some information to the control unit to set up some correction to control the mass of air and the mass of fuel to be injected into the engine cylinder in such a way that it should be a stoichiometric air-fuel mixture.

So, this semiconductor resistance has a negative temperature coefficient: with increasing temperature, resistance drops. This semiconductor resistor has a Negative Temperature coefficient.

That you can see from this Insert figure. With increasing temperature, Resistance drops. I can give you some information about this sensor, that at $-40°C$, resistance is 100000 Ω.

Now if we increase the temperature say for example air temperature or temperature of the ambient air is increasing and that will certainly affect the mass of air to be drawn into the engine cylinder. So, this semiconductor resistor can work in the range when temperature is even 130℃ then resistance drops and becomes 70,000 Ω. So, you can see that this is the range of the temperature for which this thermistor air temperature sensor can work.

If temperature increases, then resistance will drop. If resistance drops, then there will be some voltage alteration. That information will be given by the sensor. to the microcontroller and that microcontroller will give some feedback to the electronic control unit and what electronic control unit will do receiving that some mismatch in the voltage output from the sensor because certainly the voltage at a higher temperature of the incoming air should not be the designed or accepted voltage from this particular sensor so a change in voltage from this sensor will be read by the microcontroller unit and that microcontroller unit will give some feedback to the electronic control unit and then electronic control unit will set up some correction so as to control the fuel injection time.

So now let us discuss about why do we need to have fuel injection time control. So, if temperature increases from, say for example 20℃ to 50℃. So, a reduction in resistance of the semiconductor resistor will alter the voltage and that voltage will be, that output signal will be, taken by the microcontroller. Microcontroller will give some input to the ECU and ECU will try to adjust or set up some corrections so as to control the full injection time.

So, with increasing temperature, mass of air to be drawn into the engine cylinder for a given throttle position or throttle opening will reduce. So, if we do not give some input or give some information to the fuel injection valve that try to reduce the fuel to be sprayed into the engine cylinder, then excess fuel in absence of inadequate air will reduce. Create some additional issues like combustion will not be proper and emission level will increase. So, that means receiving that signal ECU will give some information to the fuel injection valve to reduce the fuel injection so to match the air and fuel ratio and it should be stoichiometric air fuel ratio. So, this is how air temperature or coolant temperature sensor works. So, now let us discuss about another important type of sensor as such I should say this crankshaft position sensor is the very very important sensor for the modern engine and this sensor is used to control the fuel injection time and also the ignition system.

So, if I write here that this sensor crankshaft position sensor is a very important Sensor for the fuel injection system and ignition system of the modern engines. So, for the modern engines, if we need to control the fuel injection time, if we need to control the ignition timing, this particular sensor plays a very important role. So now again let us look into the schematic depiction. What we can see from the schematic depiction, there are two different types.

One is a variable reluctance sensor, which is also known as a magnetic pulse generated type sensors. And in the bottom panel of the schematic, we can see a Hall effect sensor, which is type B. So, this is type B. Now, this variable reluctance sensor, which is also known as a magnetic pulse generated type sensor, is also known as a two-wire sensor, because this has two different wires, so this is also known as a two-wire sensor, whereas this particular type of Hall effect sensor is also known as a three-wire sensor. Now, the question is, you can see the extreme left part where there is a toothed disc.

So, this toothed disc is basically a shaft. So now the question is, that we need to know the shaft position. So basically, the shaft speed. So, this sensor can be located either on the crankshaft or on the distributor shaft.

So, this is a toothed disc and this sensor works following a non-contacting method, typically electrical or optical. So, you can see there is no direct contact.

So, the toothed disc, the sensor can be placed or located either on the crankshaft or on the distributed shaft. So now this is non-contact type because there is no direct contact between this toothed disc and the sensor. And what you can see for the first one, that is magnetic pulse-related type or variable reactant sensor, there are two different wires. I mean, these two wires, it is because of this presence of two wires, it is also known as two-wire sensor.

So, that output from the variable reluctance sensor is an analog signal. Whereas for the Hall effect sensor, output is a digital signal.

Now question is we can see three wires in this particular type sensor and this particular sensor for this particular sensor that is hall effect sensor. We need an external voltage supply or external voltage source unlike the two-wire sensor. For the two-wire sensor, there is no need of having this external voltage source, but for the Hall effect sensor, we need this. This sensor works following, purely non-contacting method. Typically, these sensors, employ electrical or optical methods to get some excitation, and this toothed disk is one which excites the sensor, producing a signal.

That signal is basically an analog signal for the variable reluctance sensor output, certainly, and it is a digital signal for the three-wire sensor. That signal is again passed to the electronic control unit to control or to set up some correction therein. Some information will be given to the fuel injection valve to reduce the fuel injection time, and that information can even be passed to the ignition system to control the ignition time.

To summarize today's discussion, we have discussed sensors—to be precise, some introduction about sensors. We have discussed the input and output of a sensor: what type of input a sensor will receive and what the output from the sensor should be. Then, we have discussed a typical layout of the control system, essentially for SI engines, and then we have discussed the operational principle of two different sensors: one is the air-coolant temperature sensor, and the second one is the crankshaft position sensor. With this, I will stop here today, and we shall continue our discussion in the next class.

Thank you.