The engine management systems engineering essay

Engine management system controls the engine in response to both engine and vehicle inputs. A modern automobile EMS consists of a microprocessor based electronic control unit and (ECU) and a large number of electronic and electromechanical sensors and actuators. Sensors are the devices which monitor the engine and detect parameters like crank angle, engine speed and lambda values etc. ECU determines the ignition timing, amount of fuel and other parameters to keep an engine running by using the input values which are calculated from the inputs coming from the sensors. On the basis of all those calculations ECU (Electronic Control Unit) control all the actuators to obtain best possible engine operation in terms of fuel consumption, performance, exhaust gas emissions and driving smoothness.

Fig. 1. 1 popular mechanics (1997) online image

Sensors that can be found in a typical installation (Fig. 1. 1) are listed below with their signal type (analogue or digital).

Crankshaft position (digital)

It uses inductive pickup technology. It determines the position of crankshaft producing an analogue signal which is then signal-conditioned using a high-gain amplifier to produce pulses of constant voltage. These pulses can be generated on every degree of crank angle.

Camshaft position (digital)

Camshaft position sensor works together with crankshaft position sensor. Camshaft position sensor tells the ECU which stroke number one piston is on so it knows which cylinder to fire or inject fuel into. The crank position sensor can only send a signal telling the ECU that number one piston is at TDC but it can't tell it which stroke could be compression or exhaust.

Combined information from both these sensors is called crankshaft timing information which is used to control the following:

Ignition timing

Ignition coil on time

Start of injection

Throttle position (analogue)

Throttle position is provided by a potentiometer which indicates to the engine management system the load being demanded by driver. This immediate knowledge of throttle transients enables to employ a strategy for controlling fuelling changes during transients. Small changes in throttle position have a large effect on the air flow. When throttle starts to open, an idle speed control valve allows an air flow to go around the throttle plate to provide idle speed control.

Air flow rate (analogue)

Air flow rate is measured by pivoting a van with potentiometer or by a hot wire probe, which is more common because of its fast response (5ms compared with 35ms for the vane). (Stone and Ball 2004)

Air mass flow is measured by keeping the wire at a constant temperature above the air temperature and measuring the power that is dissipated by the wire. This air flow rate is used for determining the quantity of fuel to be injected and defining the engine operating point.

Inlet manifold absolute pressure (analogue)

The inlet manifold pressure is measured by a piezo-resistive transducer which consists of a silicone diaphragm that has strain gauges etched onto its surfaces.

The engine speed, air temperature and manifold absolute pressure allow estimating mass flow rate in to the engine, which when weighed against air mass flow rate make it possible to presume the level of exhaust gas recirculation.

Air temperature and Coolant temperature (Analogue)

Temperatures are measured by thermistors which combined with measurements taken by other sensors assist in the estimation of mass flow rate in to the engine.

Lambda Sensor (Digital or Analogue)

The ECU attempts to maintain, on average, a certain air-fuel ratio by interpreting the information it gains from the oxygen sensor. The primary goal is a compromise between power, fuel economy, and emissions, and in most cases is achieved by an air-fuel-ratio close to stoichiometric.

Knock detector (analogue)

A knock sensor is an accelerometer which senses engine structural vibrations. At the commencement of knock, accelerometer detects it and slows down the ignition, in doing so averting damage to the engine.

Advantage of knock detector is that it provides a safety edge which otherwise could be obtained by having a lower compression ratio or permanently retarded ignition.

Waste-gate control sensor

In addition to above mentioned sensors, in a turbocharged engine a waste-gate control is also used for reducing turbo lag. Additional benefit is that it helps to limit the maximum cylinder pressure. Waste-gate is a straightforward flap valve built-in the turbine casing.

Boost pressure in sensed with help of inlet manifold pressure sensor, when it rises above a certain level, some of the exhaust flow is allowed to go around the turbine. It stops the turbine over speeding and limits the boost pressure from the compressor.

Working of ECU

Control of fuel mixture

An engine control unit (ECU) determines the quantity of fuel to inject based on a number of parameters. If the throttle pedal is pressed further down, this will open the throttle body and allow more air to be pulled into the engine. The ECU will inject more fuel according to how much air is passing into the engine. If the engine has not warmed up yet, more fuel will be injected (causing the engine to run slightly 'rich' until the engine warms up).

Control of ignition timing

A spark ignition engine requires a spark to initiate combustion in the combustion chamber. An ECU can adjust the exact timing of the spark called ignition timing to provide better power and economy. If the ECU detects knock, it will delay the timing of the spark to prevent this. A second, more common source, cause, of knock/ping is operating the engine in too low of an RPM range for the " work" requirement of the moment. The ECU controlling an automatic transmission would simply downshift the transmission if this were the cause of knock/ping.

Control of idle speed

The engine RPM is monitored by the crankshaft position sensor which plays a primary role in the engine timing functions for fuel injection, spark events, and valve timing. Idle speed is controlled by a programmable throttle stop or an idle air bypass control stepper motor. Effective idle speed control must anticipate the engine load at idle.

A full authority throttle control system may be used to control idle speed, provide cruise control functions and top speed limitation.

Control of variable valve timing

In engines having variable valve timing, the ECU controls the time in the engine cycle at which the valves open. The valves are usually opened sooner at higher speed than at lower speed. This can optimize the flow of air into the cylinder, increasing power and economy.

B: Methods used by an EMS to calculate spark advance and fuel injection quantity for given engine conditions - using OPEN LOOP Control.

Open loop control systems rely on a parameter (e. g., ignition timing) being set on the basis of stored information (in ECU's ROM), with the particular ignition timing being selected on the basis of measurements such as manifold pressure, engine speed and coolant temperature (Stone and Ball 2004).

Electronic control unit (ECU) controls air-fuel ratio via an electronic fuel injection system (EFI). Fig1. 2 shows a basic Electronic fuel injection system. EFI controls the amount of fuel injected into each cylinder by controlling 'on time' period of the injectors. These injectors are solenoid consisting of a spray nozzle and a solenoid-operated plunger which are connected to each cylinder.

Fig1. 2 Injection system fuel delivery (Smith, J. H 2002)

Fuel pressure in the delivery pipe is kept constant by a fuel pressure regulator which has fuel constantly flowing around it when activated.

According to (Smith, J. H 2002) Solenoid operated fuel injectors have opening and closing times of between 0. 5 and 1 ms. Taking into consideration an engine operating speed of 6000 rpm where the revolution period is 10ms this gives a sufficient control range of between 1 and 10ms for the injector on-time.

Two types of EFI control systems are commonly in use. Key input signals to both systems are engine speed and intake air mass. The way intake air mass is obtained tells apart the two types of EFI system; speed-density EFI and mass air-flow EFI.

Speed-density EFI

Since the basic fuel injection opening period is directly related to mass of air flowing into the engine, air-fuel ratio must be kept constant in steady-state operation. The mass of air flow is related to the manifold absolute pressure (MAP) by the equation

Where

: Displacement of the cylinder,

: Volumetric efficiency

: Manifold absolute pressure,

R: Constant

: Intake air temperature

As is a non-linear function of engine speed and exclusive to a particular engine design, combined with intake air temperature a look-up table is used to generate a basic injector opening time which has values for all combinations of engine speed and MAP. (Smith, J. H 2002)

Mass air-flow EFI

Contrary to speed-density EFI quantity of air drawn into the engine on each intake stroke is measured by an air-flow sensor (AFS) in this system. Some types of input AFS are flap-type, Karman vortex and hot-wire.

When air-flow is directly measured in this manner, it automatically compensates factors like variation in volumetric efficiency and in engine displacement due to speed and internal deposits.

Ignition timing

Primary sensors to control the spark advance or ignition timing are Crank angle (engine angle or TDC position), air-flow into the engine and throttle demand. Mapped ignition timing data is stored in ECU's read only memory (ROM) which has values for all the variable injection pulse duration and engine speed. The circuitry determines which cylinder needs fuel and how much, opens the requisite injector to deliver it, then causes a spark at the right moment to burn it. (Heisler, H. 1999)

C: Describe how this can be modified to CLOSED LOOP control using sensor information from a lambda (oxygen) sensor.

Closed loop control systems rely on measuring the effect of a parameter that is being varied, to control the parameter to a target value. Both types of EFI mentioned previously could be improved by adding a lambda sensor to establish a stoichiometric operation however a more complicated exhaust gas oxygen sensor is required to measure air-fuel ratio (Stone and Ball 2004).

Basically, either speed-density or mass air flow could be used for EFI control, but if the engine is to be controlled accurately around its stoichiometric or chemically perfect point when a three-way catalyst is to be used, it is essential to use a feedback system integrating such a sensor to retain an air-fuel ratio within 1%. This is only possible with closed-loop control combined with speed-density or mass air-flow EFI. (Smith, J. H 2002).

Composition of inducted air-fuel mixture and the timing of ignition spark are the main factors which control the combustion process and so the economy and performance of the engine and also the quantity of pollutants in its exhaust.

Lambda sensors are used in such a way that determine whether the mixture is rich or weak, a control system is required which makes the air-fuel ratio closed to stoichiometric i. e. 14. 7: 1 (chemically perfect). This feedback control system can only be used only after the engine has warmed up because lambda sensors only work close to the temperature of approximately 300 ÌŠC (572 ÌŠF). By using an electrical heating element in the centre of the sensor this warm-up time can be reduced (to 20-30 s). (Stone and Ball 2004).

The exhaust gas oxygen sensor is made up of a pair of lambda sensors, constructed from three layers of zirconia. All layers are heated and the top two layers have platinum electrodes and electrical connections. The fig. 1. 3 shows a Universal exhaust gas oxygen (UEGO) sensor. It provides an electrical feedback signal indicating whether the mixture is above or below the stoichiometric.

When weak mixture is present concentration gradient between exhaust gas and measurement cavity will make the oxygen to diffuse through gas intake and electrical current in the pumping cell will be proportional to the oxygen concentration in the exhaust gas. With there is a rich mixture, partial products of combustion (CO, Hydrocarbons) will be oxidized causing more to diffuse through the porous intake. In result current will always stay proportional to the exhaust gas mixture.

Fig. 1. 3. (Stone and Ball 2004)

(a) Structure, (b) operation

D: Describe how control can be extended using sensor information from a knock sensor.

A knock sensor is an accelerometer which senses engine structural vibrations. At the commencement of knock, accelerometer detects it and slows down the ignition, in doing so averting damage to the engine. Combustion knock causes the engine to vibrate due to cylinder pressure oscillation.

Knock detector consists of a mass mounted on a spring, with a method of detecting movement on the mass or force in the spring. Fig. 1. 4 shows a typical piezo-electric knock detector. It is convenient to combine spring and sensing element which is done by mounting a mass on a piezo-electric crystal.

It is fitted on the engine where a good vibrational signal is found, which is located by carrying out tests on the engine. As the signal is observed for a particular time period, the knocking cylinder can be identified and ignition timing can be delayed selectively.

Fig. 1. 4 a piezo-electric knock detector. (Turner and Austin 2000)

Piezo-electric crystal has an advantage of high stiffness so it's easier to design a transducer with high natural frequency; disadvantage is that it produces electrical charge proportional to acceleration which needs to be amplified by an impedance amplifier to give a voltage signal.

Knock detector detects the structural vibrations at a particular frequency and if it corresponds to the natural frequency of the transducer, the resonance provides dynamic amplification and transducers give a better signal-to-noise ratio.

Advantage of knock detector is that it provides a safety edge which otherwise could be obtained by having a lower compression ratio or permanently retarded ignition.

E: Discuss the benefits and issues of EMS control regarding Wide-band lambda sensors.

Normal lambda sensors used in most vehicles are stoichiometric and they only indicate if the air/fuel ratio is rich or lean i. e. they have binary output. But they don't specify how rich or how lean the ratio is. Their output signal could be vertically on either side of stoichiometric ratio 14. 7: 1.

As emission standards are becoming tighter for vehicle, much advancement is being made in the emission control and precise signal measurement is required for this purpose. Recent advancements are made ad a new more complicated sensor is used nowadays called wide-band lambda sensor which can measure the actual lambda values (Olley, P. 2010). Wide-band lambda sensor informs the ECU of a range of air fuel rations from 9: 1 to air.

Wide-band lambda sensors are way more sophisticated than their predecessors. In these types of sensors exhaust gas oxygen levels are positioned in a sealed chamber of air within the sensor and not outside air. They also have a fitted heating element within those heats up the sensor more quickly from a cold start.

According to (CDX global online) Current through the heater is controlled by the ECU. This allows the correct operating temperature to be continuously maintained. A minute chamber within the sensor has access to the exhaust gas. This sensor works by using a solid state pump to add or remove oxygen from the exhaust gas chamber. The computer controls the current flowing through the pump so that the output is at stoichiometric. Current flowing in one direction through the pump adds oxygen whilst current in the opposite direction removes oxygen. The value and direction of current required to do this represents the level of oxygen in the exhaust gas. This allows the ECU to control the amount of fuel delivered and maintain correct emission levels.