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Department of Automobile Engineering

A

Class

Note

On

Automotive Electronics-I

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<p style="text-align:center">**Automotive Electronics-I**</p>

<p style="text-align:center">**Unit 1:**
Automotive Fundamentals</p>

Contents

Use of electronics in Automobile

Evolution of Electronics in the Automobile

The automobile Physical Configuration

- Engine
- Drive train (transmission, differential, axle)
- Suspension
- Steering
- Brakes
- Instrumentation
- Electrical/electronic
- Motion control
- Comfort/convenience
- Entertainment/communication/navigation

Use of electronics in Automobile

For most people, the automobile has come to be an appliance. It is arguably the most cost effective, most user friendly of appliances available today. The personal computer industry likes to refer to its products as user friendly. However, if the automobile had the same user friendliness as a PC, it would arrive in six or more large boxes and require the owner to install the engine wheels and seats and load the programs into its various electronic systems and the documentation would be unreadable. Moreover, in use it would break down every 100 or so miles. This comparison is offered tongue in cheek, but it does illustrate the relatively high reliability of modern automobiles with their various electronic subsystems. Although its utility is primarily for transportation, the new automobile electronics can give it a broad range of auxiliary capabilities, as will be illustrated in this book.

Evolution of Electronics in the Automobile

Electronics have been relatively slow in coming to the automobile primarily because of the relationship between the added cost and the benefits. Historically, the first electronics (other than radio) were introduced into the commercial automobile during the late 1950s and early 1960s. However, these features were not well received by customers, so they were discontinued from production automobiles.

Two major events occurred during the 1970s that started the trend toward the use of modern electronics in the automobile: (1) the introduction of government regulations for exhaust emissions and fuel economy, which required better control of the engine than was possible with the methods being used; and (2) the development of relatively low cost per function solid-state digital electronics that could be used for engine control and other applications. Electronics are being used now in the automobile and probably will be used even more in the future. Some of the present and potential applications for electronics are:

1. Electronic engine control for minimizing exhaust emissions and maximizing fuel economy.

2. Instrumentation for measuring vehicle performance parameters and for diagnosis of on-board system malfunctions.
3. Driveline control.
4. Vehicle motion control.
5. Safety and convenience.
6. Entertainment/communication/navigation.

The Automobile Physical Configuration

The earliest automobiles consisted of carriages (similar to those drawn by horses) to which a primitive engine and drivetrain and steering controls were added. Typically, such cars had a strong steel frame that supported the body of the car. The wheels were attached to this frame by a set of springs and shock absorbers that permitted the car to travel over the uneven road surfaces of the day while isolating the car body from many of the road irregularities. This same general configuration persisted in most passenger cars until sometime after World War II, although there was an evolution in car size, shape, and features as technology permitted. Beginning in the late 1960s, government regulations imposed severe design constraints on automobiles that led (as will be shown) to an evolution of electronic systems in automotive design.

For the remainder of this chapter, the basic automobile components and systems are reviewed as they pertained to the post–World War II, pre-emissions control era. This review provides a framework within which the present-day automobile with its extensive use of electronics can be understood. In this sense, the motivation for applying electronics to solve regulatory problems imposed on the industry can readily be seen. Readers with a solid background in basic automotive systems may want to skip the remainder of the present chapter. This early configuration is depicted in Figure, in which many of the important automotive systems are illustrated. These systems include the following:

- Engine
- Drive train (transmission, differential, axle)
- Suspension
- Steering
- Brakes
- Instrumentation
- Electrical/electronic
- Motion control
- Comfort/convenience
- Entertainment/communication/navigation

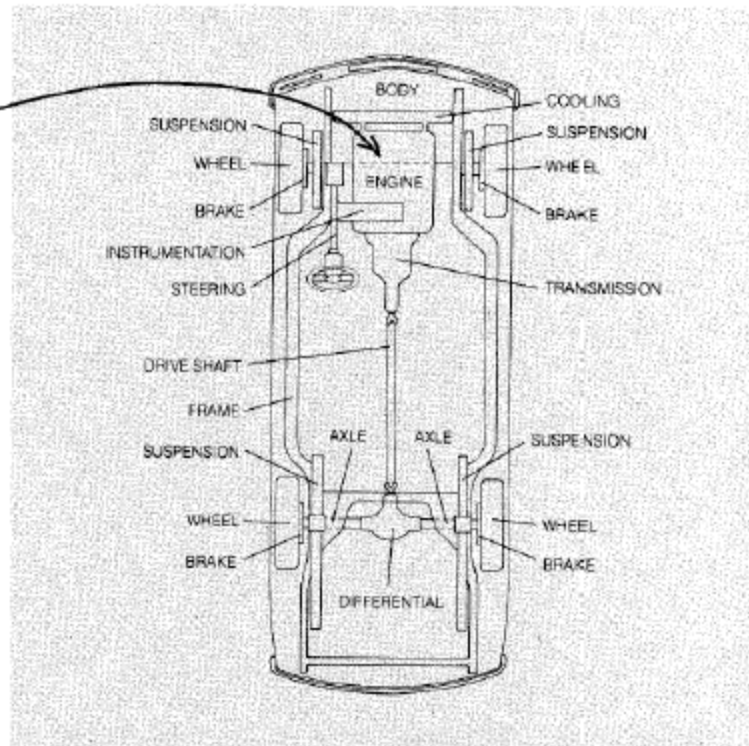*In most newer cars the engine is mounted transversely for front wheel drive.*

Figure: - Systems of the Automobile/ Physical Configuration of an Automobile

In Figure the frame or chassis on which the body is mounted is supported by the suspension system. The brakes are connected to the opposite end of the suspension components. The steering and other major mechanical systems are mounted on one of these components and attached as necessary through mechanical components to other subsystems. This basic vehicle configuration was used from the earliest cars through the late 1960s or 1970s, with some notable exceptions. The increasing importance of fuel efficiency and government-mandated safety regulations led to major changes in vehicle design. The body and frame evolved into an integrated structure to which the power train, suspension, wheels, etc., were attached.

Once again with a few notable exceptions, most cars had an engine in a front configuration with the drive axle at the rear. There are advantages in having the engine located in the front of the vehicle (e.g., crash protection, efficient engine cooling). Until recently, the so-called drive wheels through which power is delivered to the road have been the rear wheels (as depicted in Figure). This configuration is known as rear wheel drive. For safety and stability, the front wheels are used to steer the vehicle. This rear-wheel-drive configuration is not optimal from a traction standpoint since the relatively large weight of the engine/transmission is primarily on the front wheels. In order to take advantage of the engine weight for traction, many present-day cars combine steering and drive wheels in the front (i.e., so-called front wheel drive cars). In achieving front wheel drive, certain compromises must be made with respect to complexity and steering radius. Moreover, there is a tendency for the torque applied to the front wheels to adversely affect steering through a phenomenon known as "torque steer." Nevertheless, the technology of front engine front wheel steering is quite mature and has become commonplace in modern cars.

In front wheel drive cars, the engine is mounted transversely (i.e., with the rotation axis orthogonal to the vehicle axis as opposed to along the vehicle axis). In automotive parlance the traditional engine orientation is referred to as *North-South,* and the transverse orientation as *East-West.* The transmission is mounted adjacent to the engine and oriented with its axis parallel to the engine axis. The differential and drive axle configuration are normally mounted in the transmission; the combined unit is thus called the *transaxle.*

*****Thank You*****

AE-I

Unit 2:
The Basics of Electronic Engine Control

Contents

Motivation for Electronic Engine Control

Exhaust Emissions
Fuel Economy

Concept of electronic Engine Control System

Definition of General Terms

- Parameters
- Variables

Definition of Engine Performance Terms

- Power
- BSFC
- Torque
- Volumetric Efficiency
- Thermal Efficiency
- Calibration

Engine Mapping

- Effect of Air/Fuel Ratio on Performance
- Effect of Spark Timing on Performance
- Effect of Exhaust Gas Recirculation on Performance

Control Strategy
Electronic Fuel Injection System (Petrol and Diesel Engine)
Electronic Fuel Control System

- Engine Control Sequence
- Closed-Loop Control
- Closed-Loop Operation
- Open Loop Mode
- Analysis of Intake Manifold Pressure
- Measuring Air Mass

Electronic Ignition System

Motivation for Electronic Engine Control

The motivation for electronic engine control came in part from two government requirements. The first came about as a result of legislation to regulate automobile exhaust emissions under the authority of the Environmental Protection Agency (EPA). The second was a thrust to improve the national average fuel economy by government regulation.

Exhaust Emissions

The engine exhaust consists of the products of combustion of the air and gasoline mixture. Gasoline is a mixture of chemical compounds that are called *hydrocarbons*. This name is derived from the chemical formation of the various gasoline compounds, each of which is a chemical union of hydrogen (H) and carbon (C) in various proportions. Gasoline also contains natural impurities as well as chemicals added by the refiner. All of these can produce undesirable exhaust elements.

During the combustion process, the carbon and hydrogen combine with oxygen from the air, releasing heat energy and forming various chemical compounds. If the combustion were perfect, the exhaust gases would consist only of carbon dioxide (CO_2) and water (H_2O), neither of which is considered harmful to human health in the atmosphere. In fact, both are present in a human's breath. Unfortunately, the combustion of the SI engine is not perfect. In addition to the CO_2 and H_2O, the exhaust contains amounts of carbon monoxide (CO), oxides of nitrogen (chemical unions of nitrogen and oxygen that are denoted NO_x), unburned hydrocarbons (HC), oxides of sulfur, and other compounds. Some of the exhaust constituents are considered harmful and have come under the control of the federal government. The exhaust emissions controlled by government standards are CO, HC, and NO_x.

Fuel Economy

Everyone has some idea of what fuel economy means. It is related to the number of miles that can be driven for each gallon of gasoline consumed. It is referred to as miles per gallon (MPG) or simply *mileage*. Just like it improves emission control, another important feature of electronic engine control is its ability to improve fuel economy.

It is well recognized by layman and expert alike that the mileage of a vehicle is not unique. It depends on size, shape, weight, and how the car is driven. The best mileage is achieved under steady cruise conditions. City driving, with many starts and stops, yields worse mileage than steady highway driving. In order to establish a regulatory framework for fuel economy standards, the federal government has established hypothetical driving cycles that are intended to represent how cars are operated on a sort of average basis.

Concept of electronic Engine Control System

An electronic engine control system is an assembly of electronic and electromechanical components that continuously varies the fuel and spark settings in order to satisfy government exhaust emission and fuel economy regulations. The electronic engine control system receives input electrical signals from the various sensors that measure the state of the engine. From these signals, the controller generates output electrical signals to the actuators that determine the engine calibration (i.e., correct fuel delivery and spark timing). Figure shown below is a block diagram of a generalized electronic engine control system.
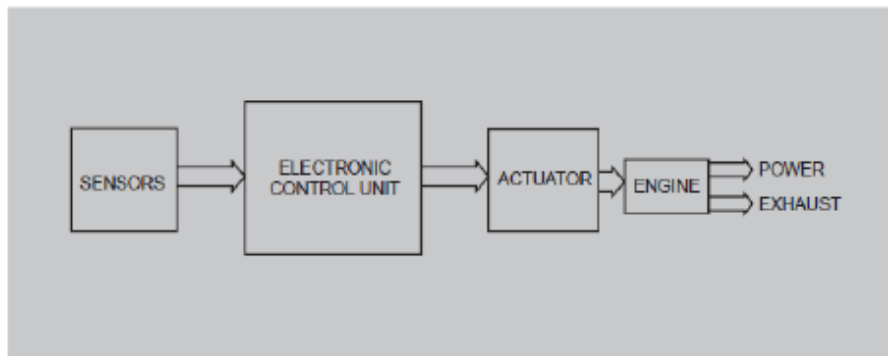
Figure Generic Electronic Engine Control System

Figure below identifies the automotive functions that surround the engine. There is a fuel metering system to set the air–fuel mixture flowing into the engine through the intake manifold. Spark control determines when the air–fuel mixture is ignited after it is compressed in the cylinders of the engine. The power is delivered at the driveshaft, and the gases that result from combustion flow out of the exhaust system. In the exhaust system, there is a valve to control the amount of exhaust gas being recirculated back to the input, and a catalytic converter to further control emissions.
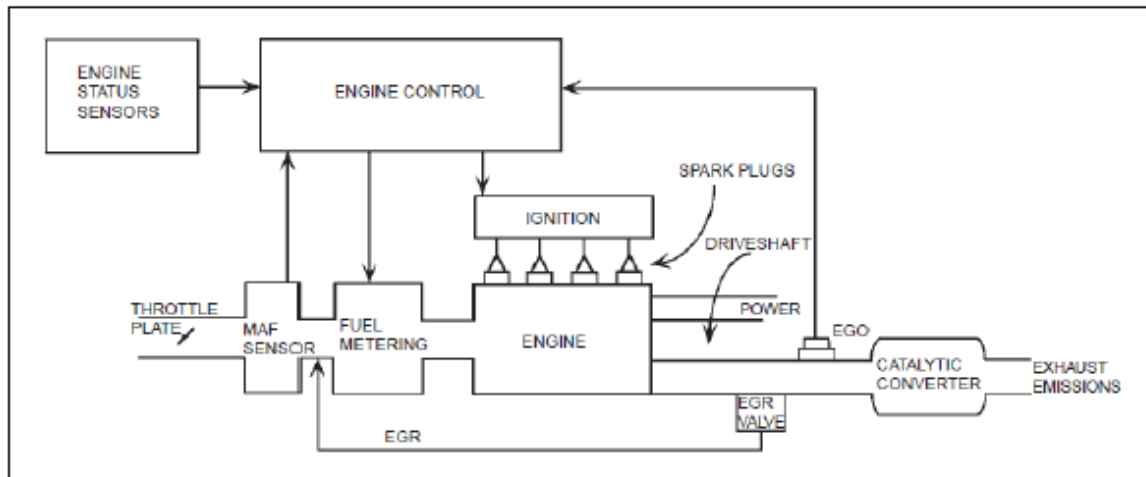
Figure: - Engine Functions and Control

Definition of General Terms

Parameters

A *parameter* is a numerical value of some engine dimension that is fixed by design. Examples of engine design parameters include the piston diameter (*bore*), the distance the piston travels on one stroke (*stroke*), and the length of the crankshaft lever arm (*throw*). The bore and stroke determine the cylinder volume and the displacement. *Displacement* is the total volume of air that is displaced as the engine rotates through two complete revolutions. *Compression ratio* is the ratio of cylinder volume at BDC to the volume at TDC. Other parameters that engine designers must specify include combustion chamber shape, camshaft cam profile, intake and exhaust valve size, and valve timing. All of these design parameters are fixed and are not subject to control while the engine is operating.

Variables

A *variable* is a quantity that changes or may be changed as the engine operates, typically under the control of the electronic control system. Some of the important engine variables are mass air flow, fuel flow rate, spark timing, power, intake manifold pressure, and many others.

Definition of Engine Performance Terms

Power

The most common performance rating that has been applied to automobiles is a power rating of the engine. It normally is given in kilowatts or, formerly, in horsepower (note: .746 kilowatt = 1 horsepower).
Power is the rate at which the engine is doing useful work. It varies with engine speed and throttle angle.
The power delivered by the engine to the dynamometer is called the *brake power* and is designated P_b.

BSFC

The engine is typically operated at a fixed RPM and a fixed brake power (fixed dynamometer load), and the fuel flow rate (in kg/hr or lb/hr) is measured. The fuel consumption is then given as the ratio of the **fuel flow rate (r_f)** to the **brake power output (P_b)**. This fuel consumption is known as the *brake-specific fuel consumption*, or BSFC. The units for BSFC are lb/hr/horsepower.

$$\text{BSFC} = \frac{r_f}{P_b}$$

Torque

Engine *torque* is the twisting action produced on the crankshaft by the cylinder pressure pushing on the piston during the power stroke.
Torque is produced whenever a force is applied to a lever. The length of the lever (the lever arm) in the engine is determined by the throw of the crankshaft (the offset from the crankshaft centerline of the point where the force is applied). The torque is expressed as the product of this force and the length of the lever.
The units of torque are N·m (newton meters) in the metric system or ft lb (foot-pounds) in the U.S. system. (One ft lb is the torque produced by one pound acting on a lever arm one foot long.) The torque of a typical engine varies with RPM.

Volumetric Efficiency

The variation in torque with RPM is strongly influenced by the *volumetric efficiency*, or "breathing efficiency." Volumetric efficiency actually describes how well the engine functions as an air pump, drawing air and fuel into the various cylinders. It depends on various engine design parameters such as piston size, piston stroke, and number of cylinders and is strongly influenced by camshaft design.

Thermal Efficiency

Thermal efficiency expresses the mechanical energy that is delivered to the vehicle relative to the energy content of the fuel. In the typical SI engine, 35% of the energy that is available in the fuel is lost as heat to the coolant and lubricating oil, 40% is lost as heat and unburned fuel in exhaust gases, and another 5% is lost in engine and drivetrain friction. This means that only about 20% is available

to drive the vehicle and accessories. These percentages vary somewhat with operating conditions but are valid on the average.

Calibration

The definition of engine *calibration* is the setting of the air/fuel ratio and ignition timing for the engine. With the new electronic control systems, calibration is determined by the electronic engine control system.

Engine Mapping

The development of any control system comes from knowledge of the plant, or system to be controlled. In the case of the automobile engine, this knowledge of the plant (the engine) comes primarily from a process called *engine mapping*.

For engine mapping, the engine is connected to a dynamometer and operated throughout its entire speed and load range. Measurements are made of the important engine variables while quantities, such as the air/fuel ratio and the spark control, are varied in a known and systematic manner. Such engine mapping is done in engine test cells that have engine dynamometers and complex instrumentation that collects data under computer control.

From this mapping, a mathematical model is developed that explains the influence of every measurable variable and parameter on engine performance.

Effect of Air/Fuel Ratio on Performance

Figure 5.8 illustrates the variation in the performance variables of torque (T) and brake power (BSFC) as well as engine emissions with variations in the air/fuel ratio with fixed spark timing and a constant engine speed. In this figure the exhaust gases are represented in brake-specific form. This is a standard way to characterize exhaust gases whose absolute emission levels are proportional to power. The definitions for the brake-specific emission rates are:
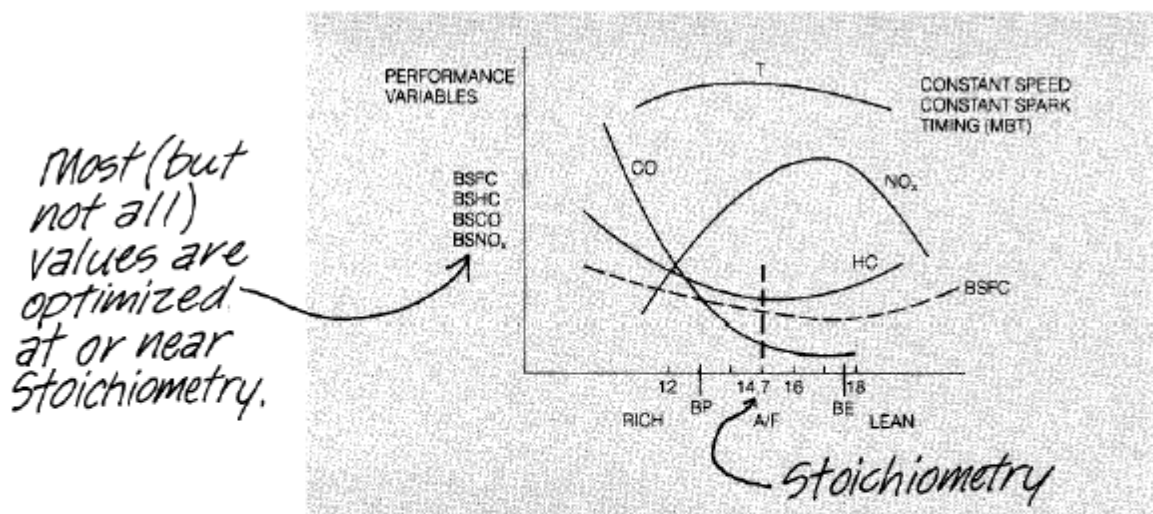
BSHC = brake-specific HC concentration

$$= \frac{r_{HC}}{P_b}$$

BSCO = brake-specific CO concentration

$$= \frac{r_{CO}}{P_b}$$

BSNO$_x$ = brake-specific NO$_x$ concentration

$$= \frac{r_{NO_x}}{P_b}$$

where

r_{HC} = HC rate of flow
r_{CO} = CO rate of flow
r_{NO_x} = NO$_x$ rate of flow

One specific air/fuel ratio is highly significant in electronic fuel control systems, namely, the *stoichiometric mixture*. The stoichiometric (i.e., chemically correct) mixture corresponds to an air and fuel combination such that if combustion were perfect all of the hydrogen and carbon in the fuel would be converted by the burning process to H$_2$O and CO$_2$. For gasoline the stoichiometric mixture ratio is 14.7: 1.

Stoichiometry is sufficiently important that the fuel and air mixture is often represented by a ratio called the *equivalence ratio*, which is given the specific designation λ (i.e., the Greek letter lambda). The equivalence ratio is defined as follows:

$$\lambda = \frac{(air/fuel)}{(air/fuel\ stoichiometry)}$$

A relatively low air/fuel ratio, below 14.7 (corresponding to λ < 1), is called a *rich* mixture; an air/fuel ratio above 14.7 (corresponding to λ > 1) is called a *lean* mixture. Emission control is strongly affected by air/fuel ratio, or by λ.

Effect of Spark Timing on Performance

Spark advance is the time before top dead center (TDC) when the spark is initiated. It is usually expressed in number of degrees of crankshaft rotation relative to TDC. Figure 5.9 reveals the influence of spark timing on brake specific exhaust emissions with constant speed and constant air/fuel ratio. Note that both NO$_x$ and HC generally increase with increased advance of spark timing. BSFC and torque are also strongly influenced by timing. Figure 5.9 shows that maximum torque occurs at a particular advanced timing denoted MBT.

Typical Variation of Performance with a Variation in Air/Fuel Ratio

Most (but not all) values are optimized at or near Stoichiometry.
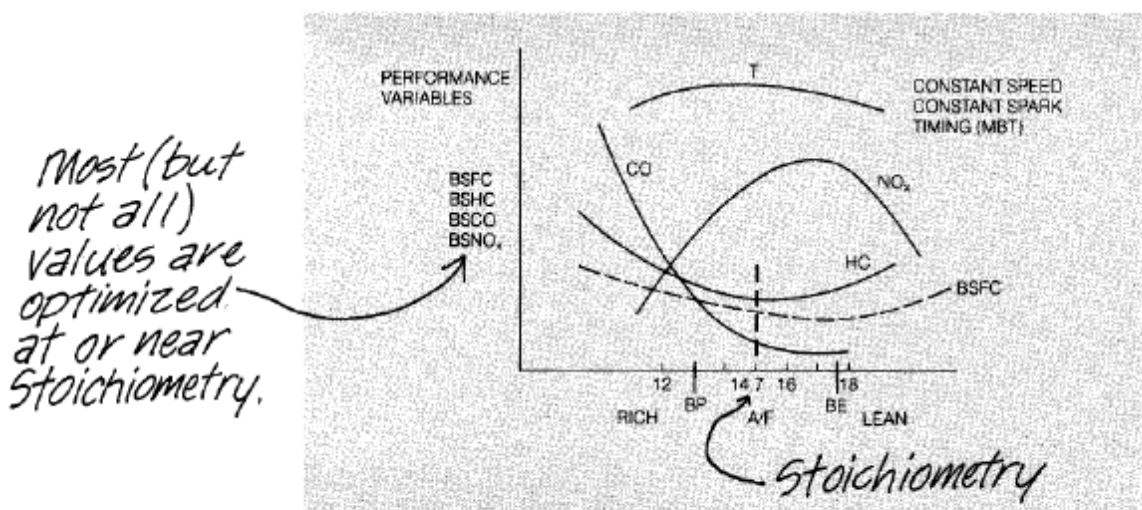
Operation at or near **MBT (Maximum brake torque)** is desirable since this spark timing tends to optimize performance. This optimal spark timing varies with RPM. As will be explained, engine control strategy involves regulating fuel delivery at a stoichiometric mixture and varying ignition timing for optimized performance. However, there is yet another variable to be controlled, which assists the engine control system in meeting exhaust gas emission regulations.
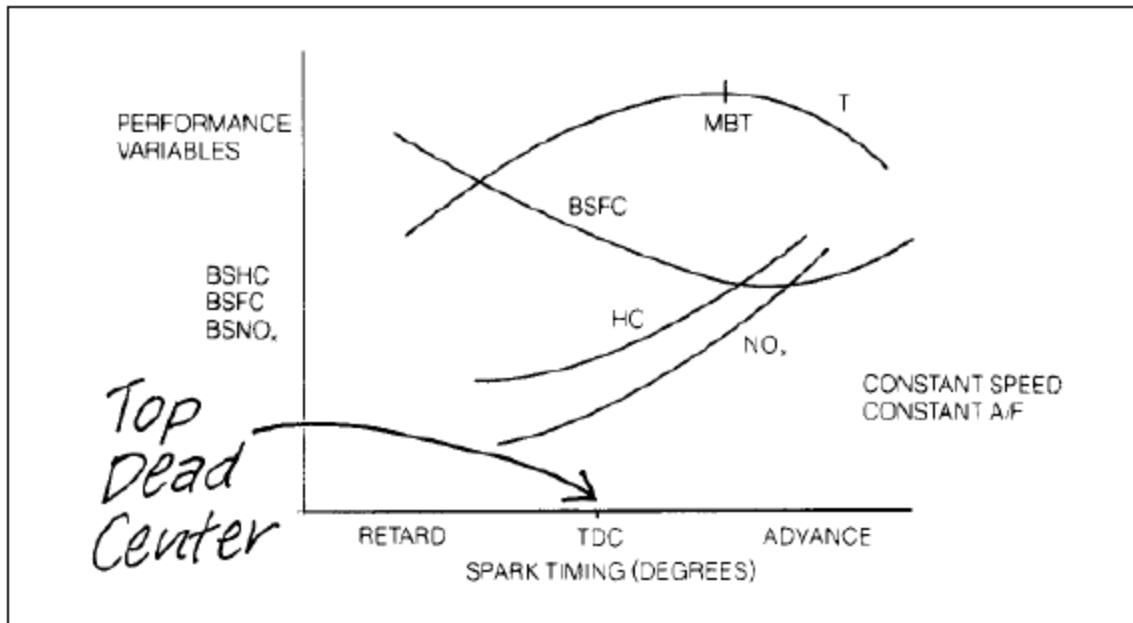

Figure Typical Variation of Performance with Spark Timing

Effect of Exhaust Gas Recirculation on Performance

only the traditional calibration parameters of the engine (air/fuel ratio and spark timing) have been considered. However, by adding another control variable, the undesirable exhaust gas emission of NO_x can be significantly reduced while maintaining a relatively high level of torque. This new control variable, *exhaust gas recirculation* (EGR), consists of recirculating a precisely controlled amount of exhaust gas into the intake. Figure 5.5 shows that exhaust gas recirculation is a major subsystem of the overall control system. Its influence on emissions is shown in Figures 5.10 and 5.11 as a function of the percentage of exhaust gas in the intake. Figure 5.10 shows the dramatic reduction in NO_x emission when plotted against air/fuel ratio, and Figure 5.11 shows the effect on performance variables as the percentage of EGR is increased. Note that the emission rate of NO_x is most strongly influenced by EGR and decreases as the percentage of EGR increases. The HC emission rate increases with increasing EGR; however, for relatively low EGR percentages, the HC rate changes only slightly.

**Figure 5.10
NO_x Emission as a
Function of EGR at
Various Air/Fuel
Ratios**
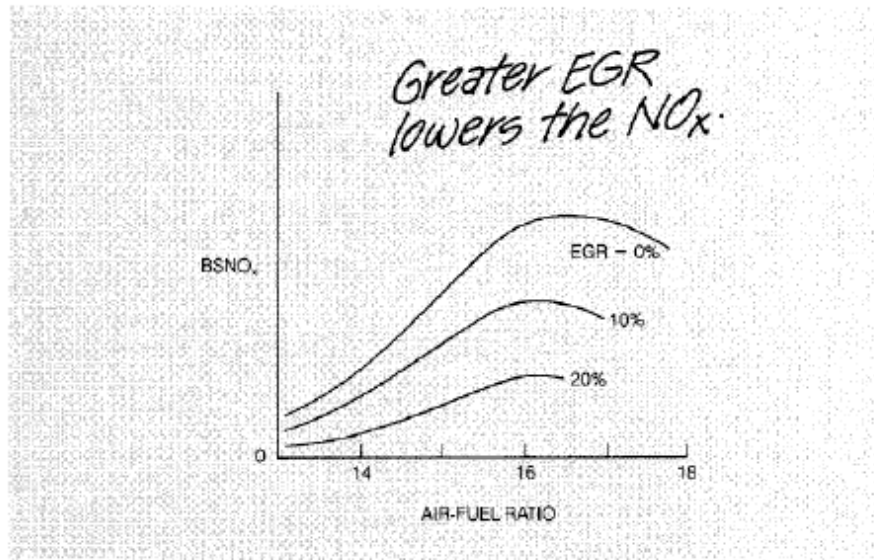
The mechanism by which EGR affects NO_x production is related to the peak combustion temperature. Roughly speaking, the NO_x generation rate increases with increasing peak combustion temperature if all other variables remain fixed. Increasing EGR tends to lower this temperature; therefore, it tends to lower NO_x generation.

**Figure 5.11
Typical Variation of
Engine Performance
with EGR**
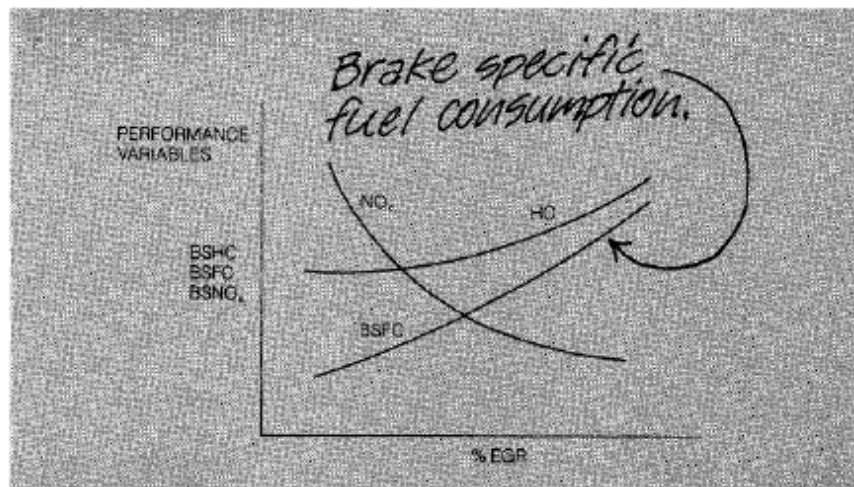
Control Strategy

It is the task of the electronic control system to set the calibration for each engine operating condition. There are many possible control strategies for setting the variables for any given engine, and each tends to have its own advantages and disadvantages. Moreover, each automobile manufacturer has a specific configuration that differs in certain details from competitive systems.

Typical electronic control system is one that has a catalytic converter in the exhaust system. Exhaust gases passed through this device are chemically altered in a way that helps meet EPA (Environmental Protection Agency) standards.

Essentially, the catalytic converter reduces the concentration of undesirable exhaust gases coming out of the tailpipe relative to engine-out gases (the gases coming out of the exhaust manifold).

**Figure 5.12
Oxidizing Catalytic
Converter**
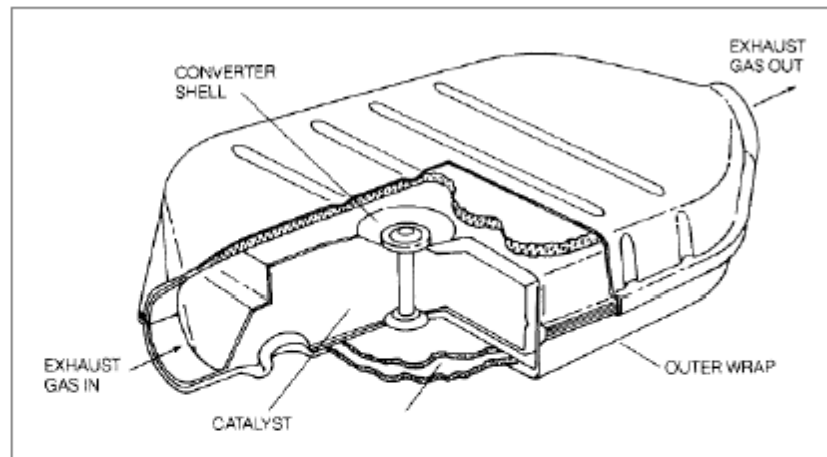
The exhaust gases that leave the tailpipe; therefore, if the catalytic converter reduces exhaust gas emission concentrations by 90%, the engine exhaust gas emissions at the exhaust manifold can be about 10 times higher than the EPA requirements. This has the significant benefit of allowing engine calibration to be set for better performance than would be permitted if exhaust emissions in the engine exhaust manifold had to satisfy EPA regulations. This is the type of system that is chosen for the typical electronic engine control system.

Several types of catalytic converters are available for use on an automobile. The desired functions of a catalytic converter include: -

1. Oxidation of hydrocarbon emissions to carbon dioxide (CO_2) and water (H_2O)
2. Oxidation of CO to CO_2
3. Reduction of NO_x to nitrogen (N_2) and oxygen (O_2)

Electronic Fuel Injection System (Petrol and Diesel Engine) (Assignment for Students)

Electronic Fuel Control System
The primary function of electronic fuel control system is to accurately determine the mass air flow rate into the engine. Then the control system precisely regulates fuel delivery such that the ratio of the mass of air to the mass of fuel in each cylinder is as close as possible to stoichiometry (i.e., 14.7).

Figure 5.15
Electronic Fuel Control Configuration
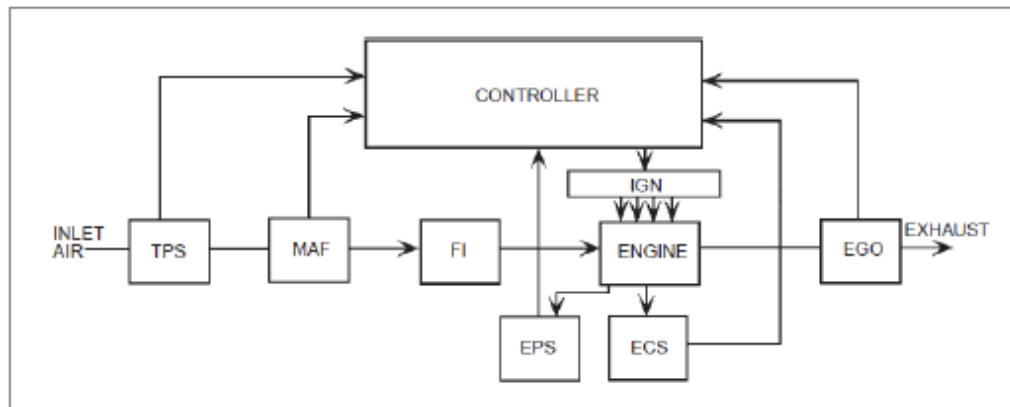
The components of this block diagram are as follows:
1. Throttle position sensor (TPS)
2. Mass air flow sensor (MAF)
3. Fuel injectors (FI)
4. Ignition systems (IGN)
5. Exhaust gas oxygen sensor (EGO)
6. Engine coolant sensor (ECS)
7. Engine position sensor (EPS)

The EPS has the capability of measuring crankshaft angular speed (RPM) as well as crankshaft angular position when it is used in conjunction with a stable and precise electronic clock (in the controller).

The signals from the various sensors enable the controller to determine the correct fuel flow in relation to the air flow to obtain the stoichiometric mixture. From this calculation the correct fuel delivery is regulated via fuel injectors. In addition, optimum ignition timing is determined and appropriate timing pulses are sent to the ignition control module (IGN).

Engine Control Sequence

Referring to Figure 5.15, the step-by-step process of events in fuel control begins with engine start. During engine cranking the mixture is set rich by an amount depending on the engine temperature (measured via the engine coolant sensor). The mixture is relatively rich for starting and operating a cold engine as compared with a warm engine.

Once the engine starts and until a specific set of conditions is satisfied, the engine control operates in the open-loop mode. In this mode the mass air flow is measured (via MAF sensor). The correct fuel amount is computed in the electronic controller as a function of engine temperature.

The correct actuating signal is then computed and sent to the fuel metering actuator. In essentially all modern engines, fuel metering is accomplished by a set of fuel injectors.

After combustion the exhaust gases flow past the EGO sensor, through the TWC, and out the tailpipe. Once the EGO sensor has reached its operating temperature (typically a few seconds to about 2 min), the EGO sensor signal is read by the controller and the system begins **closed-loop operation.**

Closed-Loop Control

In any closed-loop control system a measurement of the output variables is compared with the desired value for those variables. In the case of fuel control, the variables being regulated are exhaust gas concentrations of HC. For any given set of operating conditions, the fuel metering actuator provides fuel flow to produce an air/fuel ratio set by the controller output. This mixture is burned in the cylinder and the combustion products leave the engine through the exhaust pipe. The EGO sensor generates a feedback signal for the controller input that depends on the air/fuel ratio in the intake mixture. This signal tells the controller to adjust the fuel flow rate for the required air/fuel ratio, thus completing the loop.

Simplified Typical Closed-Loop Fuel Control System
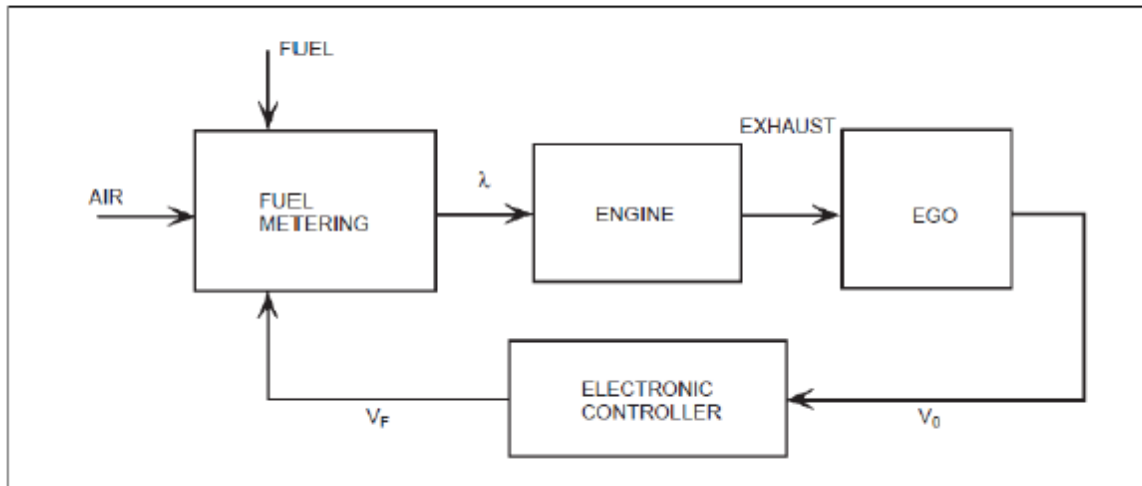
Closed-Loop Operation

The engine control system operates as a limit-cycle controller in which the air/fuel ratio cycles up and down about the set point of stoichiometry, as shown by the idealized waveforms in Figure 5.17. The air/fuel ratio is either increasing or decreasing; it is never constant. The increase or decrease is determined by the EGO sensor output voltage. Whenever the EGO output voltage level indicates a lean mixture, the controller causes the air/fuel ratio to decrease, that is, to change in the direction of a rich mixture. On the other hand, whenever the EGO sensor output voltage indicates a rich mixture, the controller changes the air/fuel ratio in the direction of a lean mixture.

The electronic fuel controller changes the mixture by changing the duration of the actuating signal to each fuel injector. Increasing this duration causes more fuel to be delivered, thereby causing the mixture to become richer. Correspondingly, decreasing this duration causes the mixture to become leaner. Figure 5.17b shows the fuel injector signal duration.

In Figure Below (a) the EGO sensor output voltage is at the higher of two levels over several time intervals, including 0 to 1 and 1.7 to 2.2. This high voltage indicates that the mixture is rich. The controller causes the pulse duration (Figure b) to decrease during this interval.

Figure (c) illustrates the actuating signals for a single fuel injector. The pulses correspond to the times at which this fuel injector is activated. The duration of each pulse determines the quantity of fuel delivered during that activation interval. This fuel injector is switched on repeatedly at the desired time.

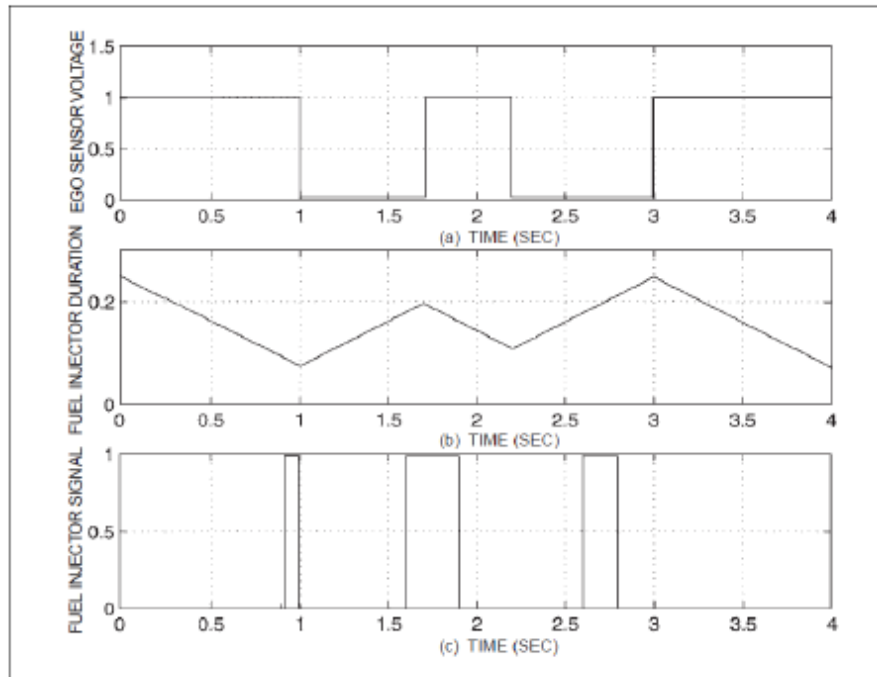Simplified Waveforms in a Closed-Loop Fuel Control System

Fig: - Closed Loop Operation

Open Loop Mode

In the open-loop mode the accuracy of the fuel delivery is dependent on the accuracy of the measurements of the important variables. In this mode the mass air flow is measured (via MAF sensor). The correct fuel amount is computed in the electronic controller as a function of engine temperature. Fuel control for an electronically controlled engine operates open loop any time the conditions are not met for closed-loop operation.

For a warmed-up engine, the controller will operate in an open loop if the closed-loop mode is not available for any reason. For example, the engine may be warmed sufficiently but the EGO sensor may not provide a usable signal. In any event, as soon as possible it is important to have a stoichiometric mixture to minimize exhaust emissions. The base pulse width T_b is computed as described above, except that the desired air/fuel ratio $(A/F)_d$ is 14.7 (stoichiometry)

Engine Control System Using the Speed-Density Method
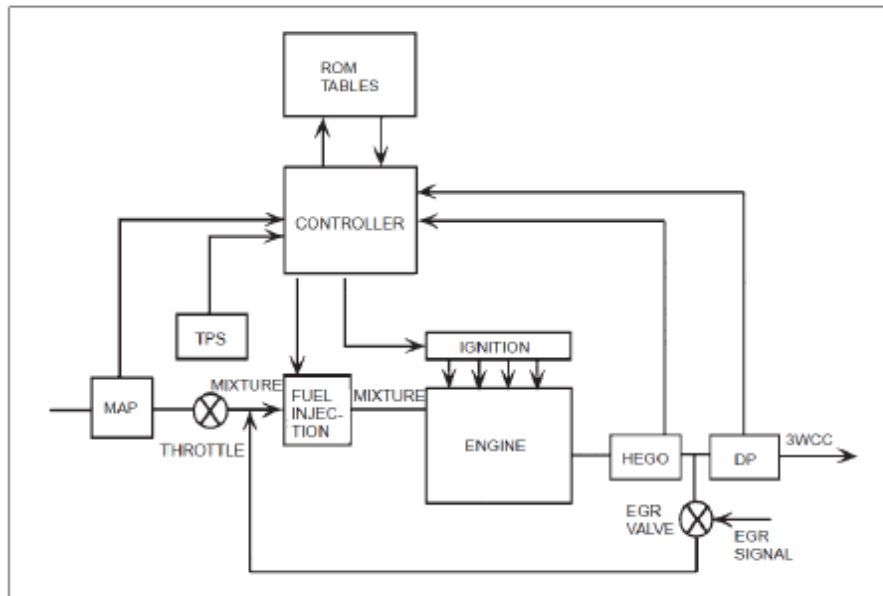
Analysis of Intake Manifold Pressure

Fuel control is based on a measurement of mass air flow rate and on regulation of fuel flow to maintain a desired air/fuel ratio. Mass air flow measurement can be accomplished either directly or indirectly via computation based on measurement of other intake variables. For an understanding of this important measurement, it is helpful to consider the characteristics of the intake system.

Figure 5.19
Simplified Intake
System
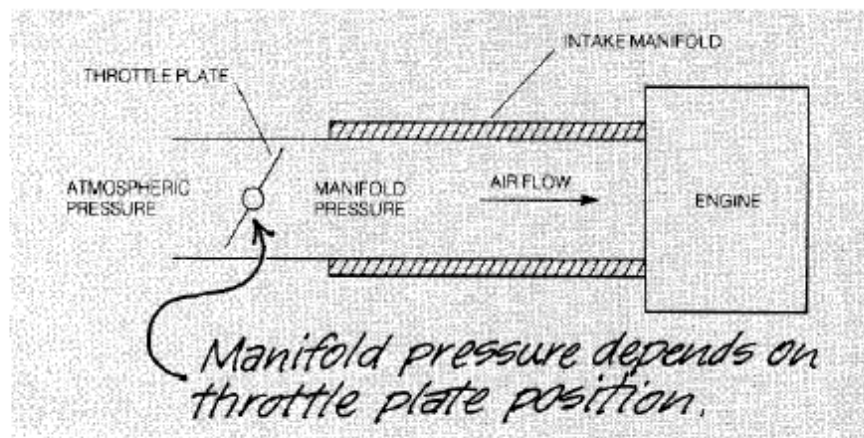
Figure 5.19 is a very simplified sketch of an intake manifold. In this simplified sketch, the engine is viewed as an air pump drawing air into the intake manifold. Whenever the engine is not running, no air is being pumped and the intake **MAP (manifold absolute pressure)** is at atmospheric pressure. This is the highest intake MAP for un- supercharged engine. (A supercharged engine has an external air pump called a supercharger.) When the engine is running, the air flow is impeded by the partially closed throttle plate. This reduces the pressure in the intake manifold so it is lower than atmospheric pressure; therefore, a partial vacuum exists in the intake.

The manifold absolute pressure varies from near atmospheric pressure when the throttle plate is fully opened to near zero pressure when the throttle plate is closed. Figure 5.20 shows manifold pressure fluctuations as well as average MAP. For a control system application, only average manifold pressure is required. The torque produced by an engine at a constant RPM is approximately proportional to the average value of MAP. The rapid fluctuations in instantaneous MAP are not of interest to the engine controller.

Figure 5.20
Intake Manifold
Pressure Fluctuations
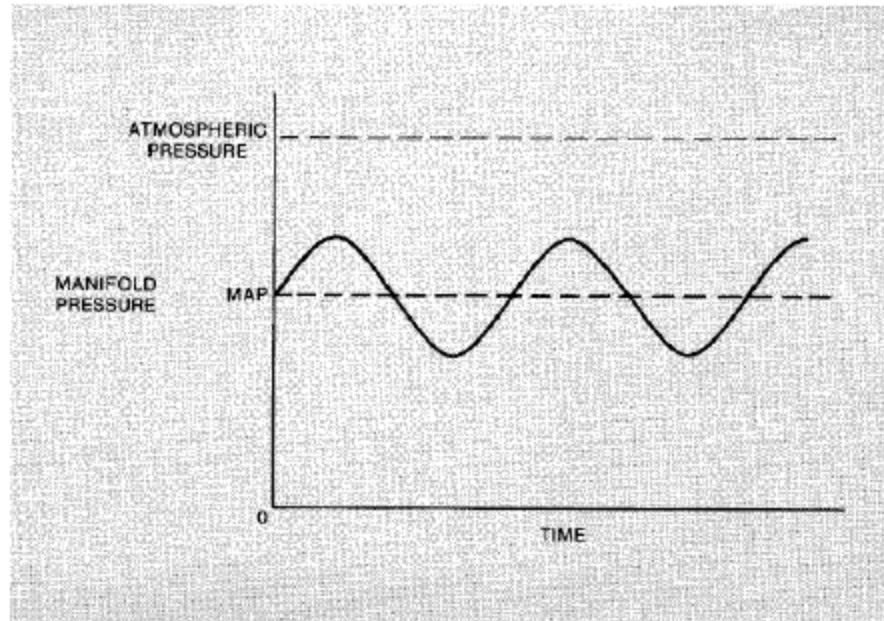
Measuring Air Mass

A critically important aspect of fuel control is the requirement to measure the mass of air that is drawn into the cylinder (i.e., the air *charge*). The amount of fuel delivered can then be calculated such as to maintain the desired air/fuel ratio. There is no practically feasible way of measuring the mass of air in the cylinder directly. However, the air charge can be determined from the mass flow rate of air into the engine intake since all of this air eventually is distributed to the cylinders (ideally uniformly). There are two methods of determining the mass flow rate of air into the engine. *One method uses a single sensor that directly measures mass air flow rate.* The other method uses a number of sensors that provide data from which mass flow rate can be computed. This method is known as the *speed-density method.*

Speed-Density Method

The concept for this method is based on the mass density of air as illustrated in Figure 5.21a. For a given volume of air (V) at a specific pressure (p) and temperature (T), the density of the air (d_a) is the ratio of the mass of air in that volume (M_a) divided by V:

$$d_a = \frac{M_a}{V}$$
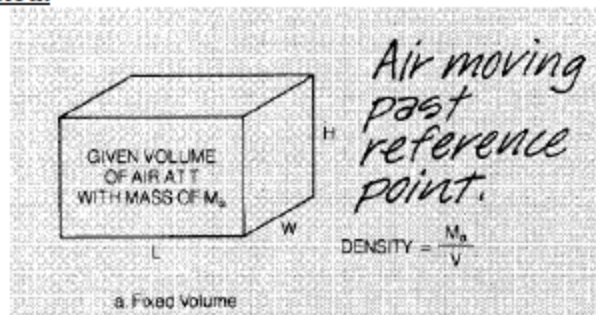
Electronic Ignition System

The engine ignition system exists solely to provide an electric spark to ignite the mixture in the cylinder. The engine performance is strongly influenced by the spark timing relative to the engine position during the compression stroke. The spark advance (relative to TDC) is determined in the electronic engine control based on a number of measurements made by sensors. The optimum spark advance varies with intake manifold pressure, RPM, and temperature.
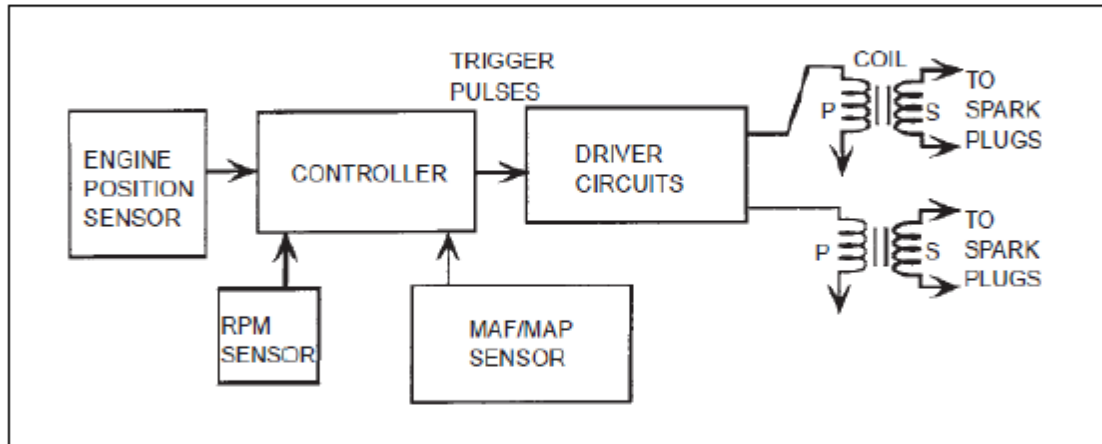

Figure Electronic Distributor Less Ignition System

In order to generate a spark at the correct spark advance the electronic engine control must have a measurement of the engine position. Engine position is determined by a sensor coupled to the camshaft or the crankshaft, or a combination of each, depending on the configuration for the electronic ignition.

The voltage pulse to fire the spark plug in any given cylinder was routed from the coil to the relevant spark plug via a rotary switch called a distributor. In modern engines, the **distributor** has been replaced with **multiple coils**, with each coil dedicated to one (or sometimes two) cylinder(s).

Electronic ignition can be implemented as part of an integrated system or as a stand-alone ignition system. A block diagram for the latter system is shown in Figure above. An ignition system such as this is often called a *distributorless ignition system* (DIS) because the multiple coil packs and drivers are a modern replacement for the (now essentially obsolete) distributor.

Thank you*

<mark>**Contents**</mark>

Application of Sensors and Actuators

Types of sensors based on variables measurement

- Air flow sensor
- Mass air flow (MAF) Sensor
- Oxygen Sensor
  - Unheated Oxygen Sensor
  - Heated Oxygen Sensor
- Throttle Position Sensor (TPS)
- Crankshaft Position Sensor (CKP)
- Camshaft Position Sensor
- Coolant temperature Sensor
- Intake air temperature Sensor
- Manifold absolute pressure Sensor (MAP)
- Differential particulate filter DPF sensor (Diesel)
- Vehicle speed sensor
- Knock Sensor

Set of Switches and Relay:

- Air conditioner clutch engaged switch
- Brake on/off
- Wide open throttle
- Closed throttle
- Reed switch
- Main Relay
- Fuel Pump Relay
- AC Blower Switch

Engine Crankshaft Angular Position Sensor

- Magnetic Reluctance Position Sensor
- Hall-Effect Position Sensor
- Optical Crankshaft Position Sensor

Throttle Angle Sensor

- Electronic Throttle Control System
- Types of Air flow sensor

Temperature Sensors

- Engine Coolant Temperature Sensor
- Intake Air Temperature Sensor
- Engine Oil Temperature Sensor

Sensor for Feedback Control
- Oxygen Sensor
- Knock Sensors

Automotive Engine Control Actuators
- Fuel pump
- Fuel Injectors
  - Piezoelectric Injectors
  - Transistorized Injectors
- IAC valve
- Exhaust Gas Recirculation Actuator
- Purge canister valve
- Ignition System
- Oil Control valve (OCV)
- Cooling Fan
- MIL, Indicators

Application of Sensors and Actuators

Sensors are devices that detect and respond to physical inputs or environmental conditions. They convert these inputs into measurable electrical, optical, or other signals that can be interpreted and used for further processing.

Actuators are devices that convert electrical, hydraulic, pneumatic, or thermal energy into physical action or movement. They are responsible for carrying out the desired control commands based on the inputs received from sensors.

In control system applications, sensors and actuators are in many cases the critical components for determining system performance. This is especially true for automotive control system applications. The availability of appropriate sensors and actuators dictates the design of the control system and the type of function it can perform.

Typical Electronic Engine Control System
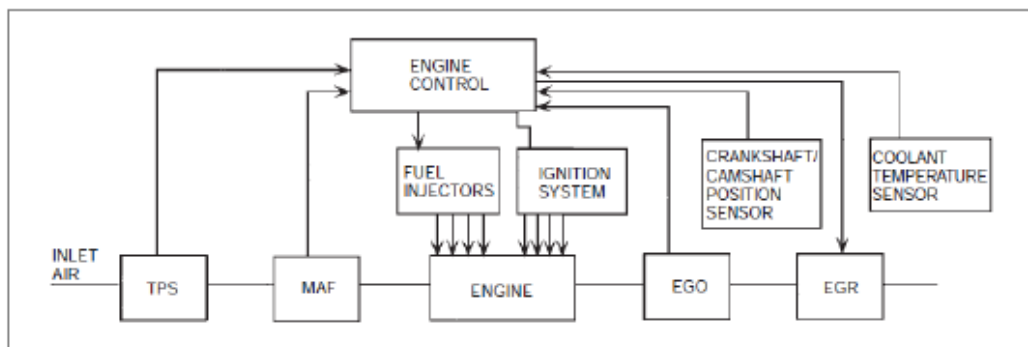
The sensors and actuators that are available to a control system designer are not always what the designer wants, because the ideal device may not be commercially available at acceptable costs. For this reason, often special signal processors or interface circuits are designed to adapt to an available sensor or actuator, or the control system is designed in a specific way to fit available sensors or actuators.

Types of sensors based on variables measurement

Air flow sensor

Air flow sensors measure either the volume or the mass of air flowing in a channel. In an automobile, the primary use of an air flow sensor is to determine the amount of air drawn into the engine through the intake manifold.
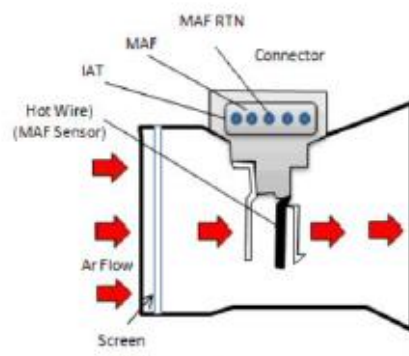

Fig: - Air Flow Sensor

Mass air flow (MAF) Sensor

A device in the throttle body, the mass airflow, or MAF, sensor helps the engine computer determine the proper air-fuel mixture by measuring the mass of the air flowing past it. Because a precise mixture is crucial to efficiency and clean combustion, the MAF sensor accounts for differences in air density, which varies with temperature and altitude. A failed MAF sensor is one of many events that will trigger a check engine light. It may also result in rough running, stalling or a drop in gas mileage.
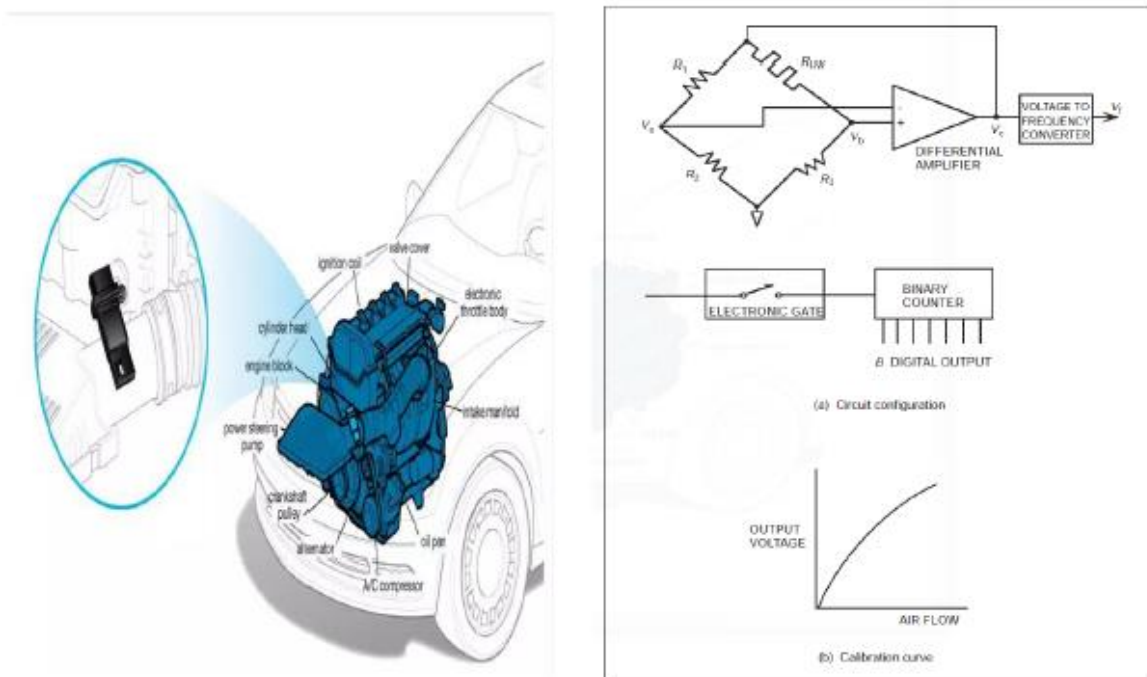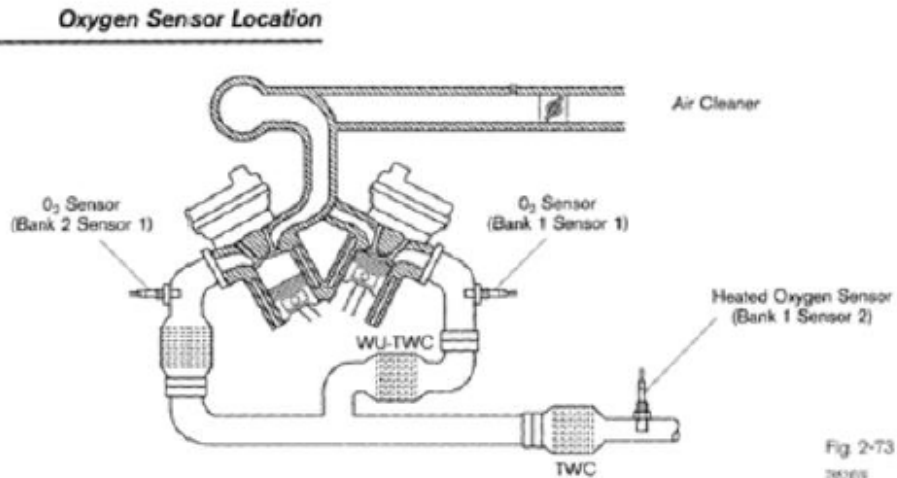

Fig: - MAF Sensor Configuration

Oxygen Sensor
- Unheated Oxygen Sensor
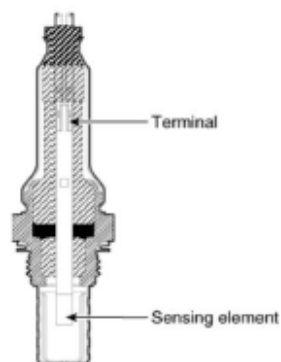- Heated Oxygen Sensor

Oxygen Sensor Location

Fig 2-73

An oxygen sensor is an electronic device used to measure the oxygen content in exhaust gases. In the automotive industry it is also known as a lambda sensor, and is used to regulate the air/fuel mixture and exhaust gas emissions in the internal combustion engine.

The lambda sensor is used to indicate whether the fuel mixture is rich or lean. The levels of oxygen are determined by exposing one electrode to the outside air and another to the exhaust gas. The difference in oxygen content causes a flow of electrons through a ceramic element that generates a voltage potential between two boundary layers. The voltage created is directly related to the level of oxygen content in the exhaust gas.
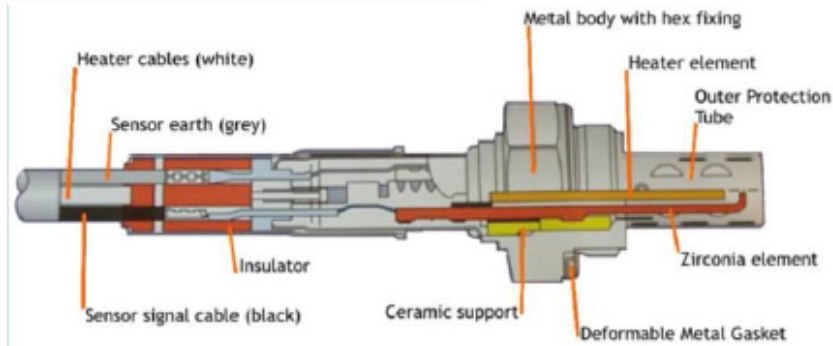
Unheated Oxygen Sensor

Unheated oxygen sensors, as the name suggests, do not have a built-in heating element. Instead, they rely on the hot exhaust gases to bring them up to operating temperature. Unheated oxygen sensors are typically found on older vehicles or on vehicles with lean-burn engines, such as diesel engines.

Heated Oxygen Sensor

Heated type oxygen sensor, also known as an oxygen or O2 sensor, is a crucial component of the automotive engine management system. The sensor provides feedback to the engine control unit (ECU) about the air-fuel ratio, allowing the ECU to adjust the fuel injection and ignition timing for optimal engine performance and emission control.

The heated type oxygen sensor consists of a ceramic element, usually made of zirconium dioxide, with a platinum electrode on either side. It is called a "heated" sensor because it contains a built-in heating element. This heating element ensures that the sensor reaches its operating temperature quickly and remains at a constant temperature during engine operation.

Throttle Position Sensor (TPS)

Another variable that must be measured for electronic engine control is the throttle plate angular position. The throttle plate is linked mechanically to the accelerator pedal. When the driver depresses the accelerator pedal, this linkage causes the throttle plate angle to increase, allowing more air to enter the engine and thereby increasing engine power.

Most throttle angle sensors are essentially potentiometers. A *potentiometer* consists of a resistor with a movable contact, as illustrated in Figure.
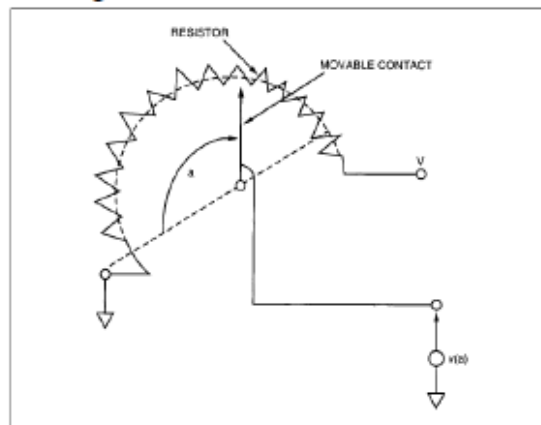

Figure Throttle Angle Sensor: A Potentiometer

A section of resistance material is placed in an arc around the pivot axis for the movable contact. One end of the resistor is connected to ground, the other to a fixed voltage V (e.g., 5 volts). The voltage at the contact point of the movable contact is proportional to the angle (a) from the ground contact to the movable contact. Thus,

$$v\,(a) = ka$$

where $v(a)$ is the voltage at the contact point, k is a constant, and a is the angle of the contact point from the ground connection. This potentiometer can be used to measure any angular rotation. In particular, it is well suited for measuring throttle angle.

<u>Temperature Sensors</u>
- Engine Coolant Temperature Sensor
- Intake Air Temperature Sensor
- Engine Oil Temperature Sensor

Engine Coolant temperature Sensor

A typical coolant sensor, shown in Figure below, consists of a thermistor mounted in a housing that is designed to be inserted in the coolant stream. This housing is typically threaded with pipe threads that seal the assembly against coolant leakage.

A *thermistor* is made of semiconductor material whose resistance varies inversely with temperature. For example, at -40°C a typical coolant sensor has a resistance of 100,000 ohms. The resistance decreases to about 70,000 ohms at 130°C.

The sensor is typically connected in an electrical circuit like that shown in Figure below, in which the coolant temperature sensor resistance is denoted RT. This resistance is connected to a reference voltage through a fixed resistance R. The sensor output voltage, VT, is given by the following equation.

$$V_T = V \frac{R_T}{R + R_T}$$

The sensor output voltage varies inversely with temperature; that is, the output voltage decreases as the temperature increases.
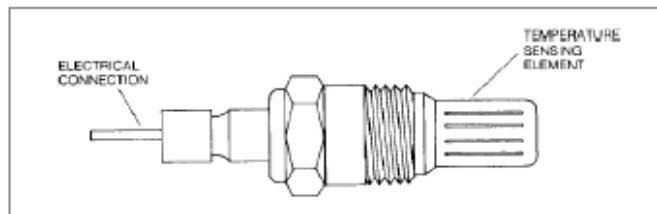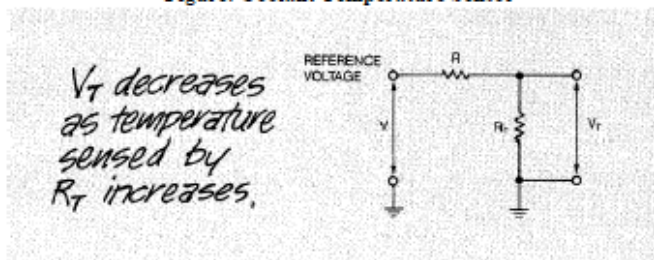

Figure: Coolant Temperature Sensor

Figure: Typical Coolant Temperature Sensor Circuit

Intake air temperature Sensor

The intake-air temperature sensor determines the temperature in the suction pipe and forwards the voltage signals arising from the temperature to the control unit. This evaluates the signals and influences the mixture formation and the firing angle.

The resistance of the temperature sensor changes depending on the intake-air temperature. As the temperature increases, the resistance is reduced, which reduces the voltage at the sensor. The control unit evaluates these voltage values, since they are directly related to the intake-air temperature (low temperatures result in high voltage values at the sensor, and high temperatures result in low voltage values).
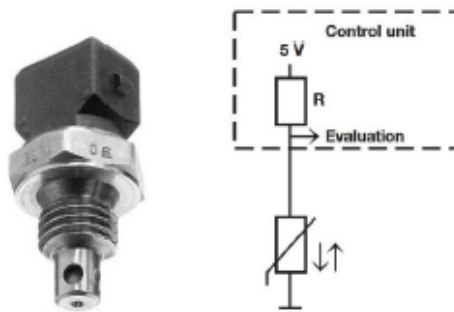
Fig: - Intake Air Temperature Sensor

Engine Oil Temperature Sensor

The oil temperature sensor sends its information to a separate instrument or to the ECU for monitoring the oil temperature of the engine. In modern vehicles, oil temperature sensors are integrated into the oil level sensor.

Temperature °C	Resistance kΩ
20	2.45
40	1.10
60	0.544
80	0.290
100	0.164

Fig: - Engine Oil Temp Sensor

Function of Engine Oil Temp Sensor

In the housing of the temperature sensor, there is a measuring resistor made of semiconductor material having a negative temperature coefficient (NTC). This measuring resistor has a high resistance at low temperatures, which decreases with increasing temperatures.

Manifold absolute pressure Sensor (MAP)

Several MAP sensor configurations have been used in automotive applications. The earliest sensors were derived from aerospace instrumentation concepts, but these proved more expensive than desirable for automotive applications and have been replaced with more cost-effective designs.

It is interesting to note that none of the MAP sensors in use measures manifold pressure directly, but instead measure the displacement of a diaphragm that is deflected by manifold pressure. The details of the diaphragm displacement and the measurement of this displacement vary from one configuration to another.
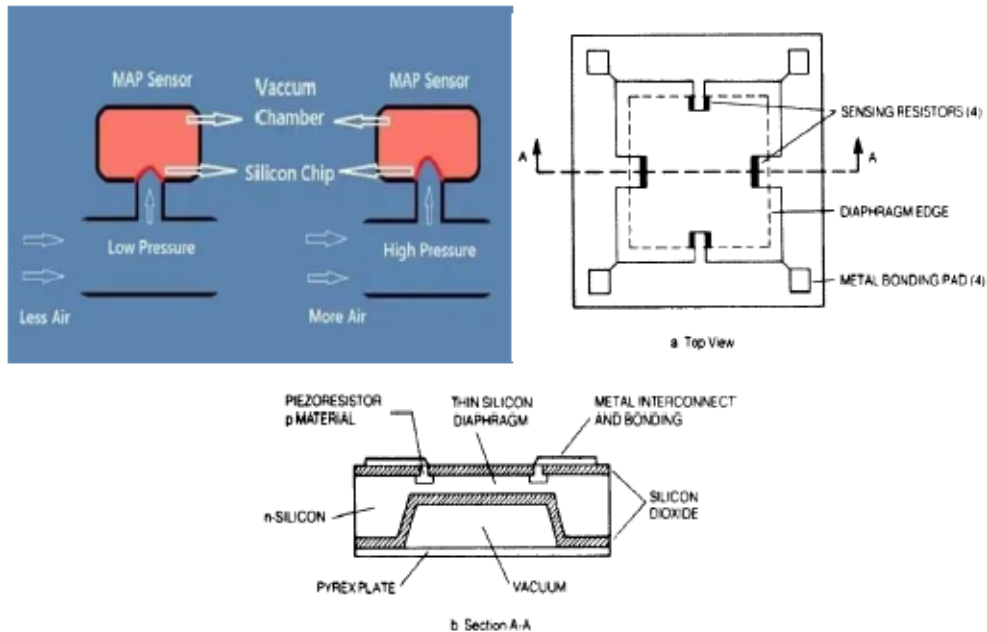
Figure Typical Silicon- Diaphragm Strain Gauge MAP Sensor

The MAP sensor measures the absolute pressure, which means it accounts for both atmospheric pressure and the pressure created by the engine's intake system. It provides a relative measurement of the engine load, as it senses changes in manifold pressure as the throttle opens or closes.

The MAP sensor generates a voltage signal that varies with changes in manifold pressure. Typically, the voltage output increases as the pressure increases. The voltage range varies depending on the specific sensor and engine system, but it is often around 0.5 to 4.5 volts.

Differential particulate filter DPF sensor (Diesel)

A diesel particulate filter (DPF) differential pressure sensor measures exhaust backpressure and signals when the power-train control module (PCM) should begin a regeneration process to clear the filter of diesel particulate matter (DPM), or soot.

Layout of DPF

As stringent emissions regulations increase to reduce emissions, diesel engines use an EGR valve to reduce NOx emissions and a DPF to remove soot from diesel exhaust. Installed near the beginning of the exhaust system, the wall flow design of the DPF traps on average 85% of the soot coming from the engine, and in certain conditions can even attain 100% efficiency. To keep the filter from clogging, the engine initiates a regeneration process by injecting fuel into the exhaust system. The injected fuel will raise the temperature of the DPF to 600 °C (or 1112°F) so the obstructing soot can burn off by converting it into ash.

Working of DPF differential pressure sensor

The DPF differential pressure sensor is usually mounted in the engine compartment to protect it from heat. The sensor is connected to the engine control unit (ECU) by an electrical connector and connected to the DPF via two silicon hoses. One hose connects before (upstream) the DPF, the other connects after (downstream) the filter. By measuring and comparing the difference in pressure of the exhaust gas before and after the filter, the sensor can estimate the amount of DPM that is trapped in the filter and signal the PCM to start the DPF regeneration process.

Fig: - DPF Sensor

Vehicle speed sensor

A vehicle speed sensor generates a magnetic pulse in the form of a wave, proportional to the speed of the vehicle. The power control module (also known as the electrical control module) uses the VSS frequency signal to manipulate multiple electrical subsystems in a vehicle, such as fuel injection, ignition, cruise control operation, torque, and clutch lock-up.

Engine Crankshaft Angular Position Sensor / Camshaft Position Sensor

In automobiles with electronic engine control systems, angular position can be sensed on the crankshaft directly or on the camshaft. As we know the piston drives the crankshaft directly, while the valves and the distributor for the spark ignition are driven from the camshaft. The camshaft is driven from the crankshaft through a 1: 2 reduction drivetrains, by the help of gears, belt, or chain. The camshaft rotational speed is one-half that of the crankshaft, so the camshaft angular position goes from zero to 360° for one complete engine cycle. At the present time, there appears to be a trend toward measuring crankshaft position directly rather than indirectly via camshaft position.
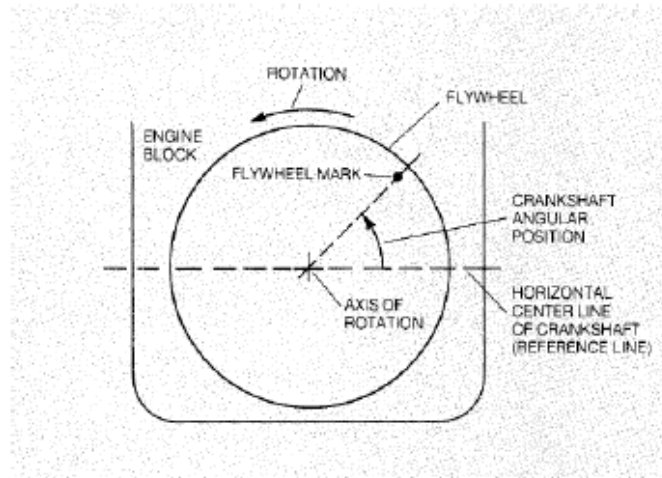
Figure Engine Crankshaft Angular Position Measurement

It is sufficient for engine control purposes to measure crankshaft/camshaft position at a small number of fixed points. The number of such measurements (or samples) is determined by the number of cylinders. **The camshaft** sensor enables the engine control to determine the exact position of the crankshaft drive. This information is required to calculate the ignition point and injection point, among other things.

Magnetic Reluctance Position Sensor

This sensor consists of a permanent magnet with a coil of wire wound around it. A steel disk that is mounted on the crankshaft (usually in front of the engine) has tabs that pass between the pole pieces of this magnet. This sensor is of the magnetic reluctance type and is based on the concept of a magnetic circuit. It uses a magnetic circuit having closed path made through magnetic materials like iron, cobalt, nickel, or synthetic magnetic material called ferrite.
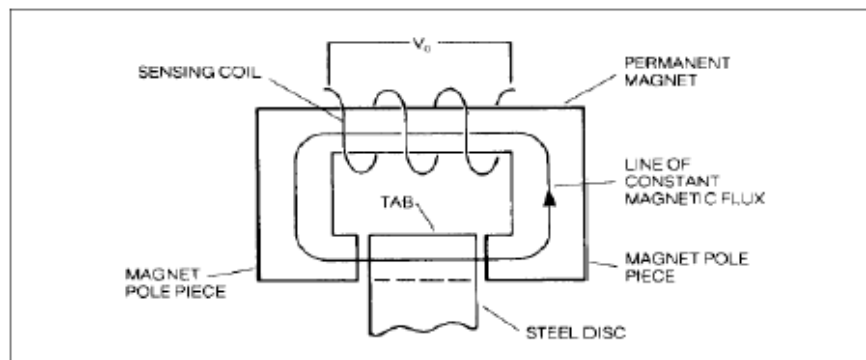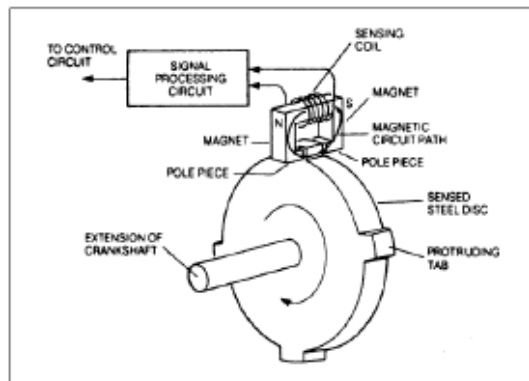
The magnetic field in a magnetic circuit is described by a pair of field quantities i.e., *magnetic field intensity*. This exerts a force similar to the voltage of a battery. The response of the magnetic circuit to the magnetic field intensity is described by the second quantity, which is called *magnetic flux*. And the magnetic flux is similar to the current that flows when a resistor is connected across a battery to form a closed electrical circuit.
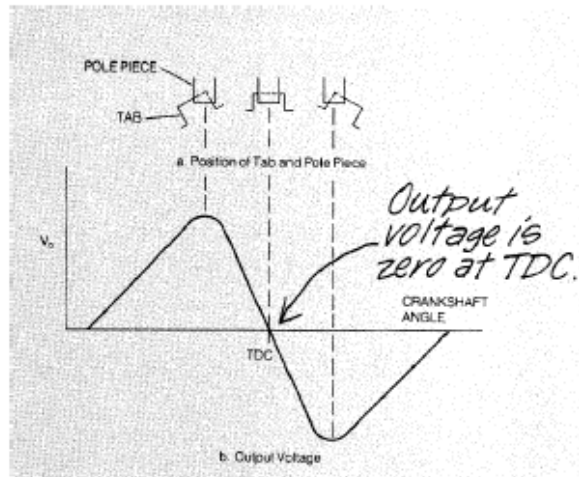

Figure Output Voltage Waveform from the Magnetic Reluctance Crankshaft Position Sensor Coil

The voltage generated by the magnetic reluctance position sensor is determined by the strength of the magnetic flux. When a tab on the steel disk passes through the gap, the flow of the magnetic flux changes significantly. And the voltage induced in the sensing coil varies with the rate of change of the magnetic flux. When the tab is centered between the poles of the magnet, the voltage is zero because the flux is not changing. The process changing polarity helps to determine the engine crankshaft position.

**Hall-Effect Position Sensor**

This sensor can be used to measure either camshaft position or crankshaft position. A Hall-effect position sensor is shown in Figure below. This sensor is similar to the reluctance sensor in that it employs a steel disk having protruding tabs and a magnet for coupling the disk to the sensing element.
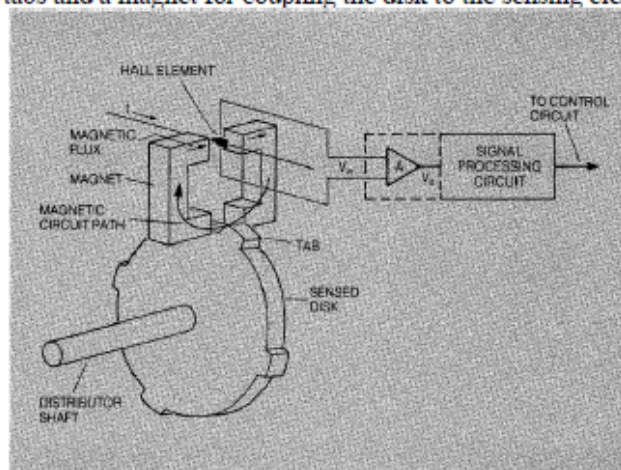
The Hall Effect

The Hall element is a small, thin, flat slab of semiconductor material. When a current, I, is passed through the slab by means of an external circuit as shown in **Figure (a) below**, a voltage is developed across the slab perpendicular to the direction of current flow and perpendicular to the direction of magnetic flux.

V_0 is proportional to strength of magnetic flux.
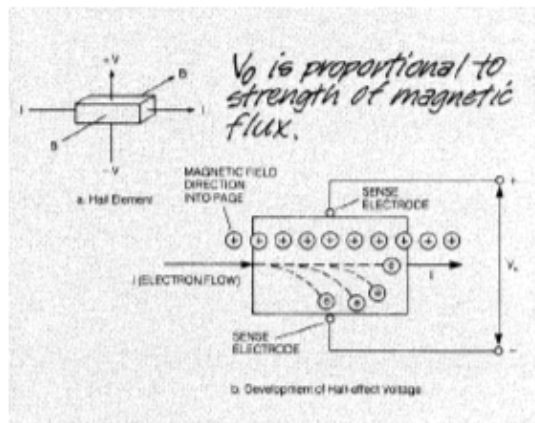
This voltage is proportional to both the current and magnetic flux density that flows through the slab. This effect—the generation of a voltage that is dependent on a magnetic field—is called the *Hall effect*.

In Figure (b) above, the current, I, is represented by electrons, e, which have negative charge, flowing from left to right. The magnetic flux flows along the legs of the magnet as indicated and is generally perpendicular to the face of the semiconductor Hall element.

Whenever an electron moves through a magnetic field, a force (called the *Lorentz force*) that is proportional to the electron velocity and the strength of the magnetic flux is exerted on the electron. The direction of this force is perpendicular to the direction in which the electron is moving. In **Figure (b) above**, the Lorentz force direction is such that the electrons are deflected toward the lower sense electrode.

Optical Crankshaft Position Sensor

A Crank shaft position can also be sensed using optical techniques. Figure shown below illustrates such a system. With the help of magnetic system, a disk is directly coupled to the crankshaft. The disk has holes in it, that correspond to the number of tabs on the disks of the magnetic systems. Each side of the disk are mounted with fiber-optic light pipes. The hole in the disk allows transmission of light through the light pipes from the light-emitting diode (LED) source to the phototransistor used as a light. Light would not be transmitted from source to sensor when there is no hole because the solid disk blocks the light. As shown in Figure below, the pulse of light is detected by the phototransistor and coupled to an amplifier to obtain a satisfactory signal level. The output pulse level can very easily be standard transistor logic levels of +2.4 V for the high level and +0.8 V for the low level. Used as pulses, the signals provide time-referenced pulses that can be signal processed easily with digital integrated circuits.
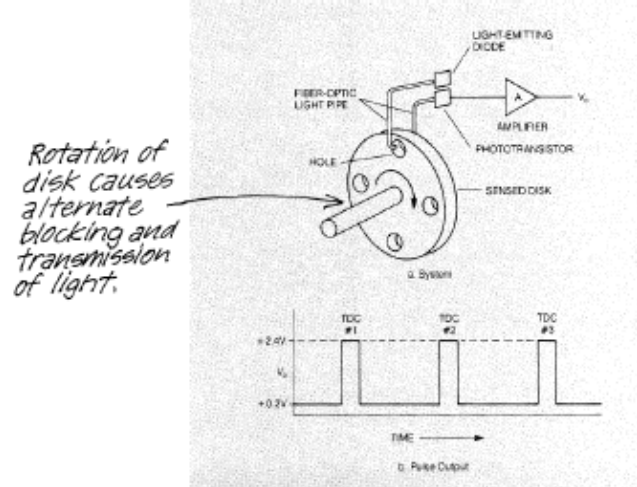

Rotation of disk causes alternate blocking and transmission of light.

Figure: Crank shaft Optical Position Sensor

Throttle Angle Sensor

- **Electronic Throttle Control System**

  The electronic throttle control system includes the accelerator pedal, ETC module, and throttle body. The accelerator pedal looks the same as it always has, but its interaction with the throttle body has changed. The throttle cable has been replaced by the accelerator position sensor (APS), which detects the exact position of the pedal at any given moment, transmitting this signal to the ETC module.
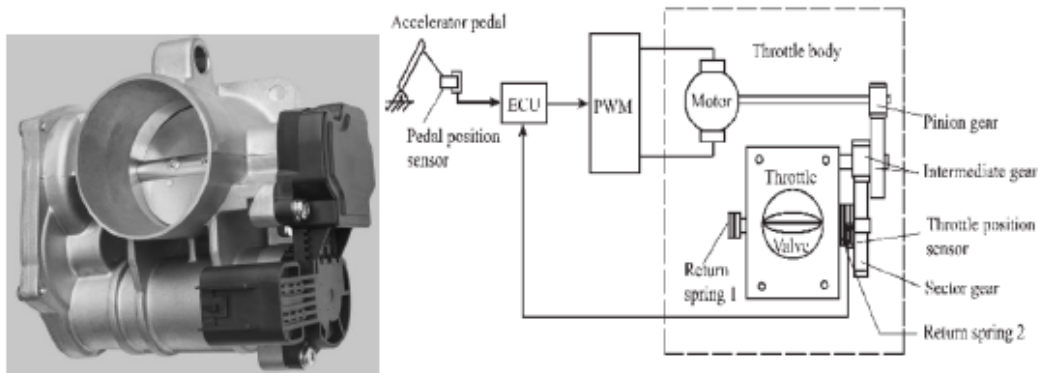

Fig: Electronic Throttle Control System

- **Types of Air flow sensor (Assignment for Students)**

Sensor for Feedback Control

The sensors that we have discussed to this point have been part of the open-loop (i.e., feedforward) control. We consider next sensors that are appropriate for feedback engine control. The feedback control for fuel delivery is based on maintaining the air/fuel ratio at stoichiometry (i.e., 14.7: 1). The primary sensor for fuel control is the exhaust gas oxygen sensor.

- **Oxygen Sensor / Exhaust Gas Oxygen Sensor**

  The amount of oxygen in the exhaust gas is used as an indirect measurement of the air/fuel ratio. As a result, one of the most significant automotive sensors in use today is the exhaust gas oxygen (EGO) sensor. This sensor is often called a *lambda sensor* from the Greek letter lambda (l), which is commonly used to denote the equivalence ratio:

  The zirconium dioxide EGO sensor uses zirconium dioxide sandwiched between two platinum electrodes. One electrode is exposed to exhaust gas and the other is exposed to normal air for reference.

$$\lambda = \frac{(\text{air}/\text{fuel})}{(\text{air}/\text{fuel at stoichiometry})}$$

- **Knock Sensor**

  A knock sensor is essentially a small "listening" device in or on the engine that detects irregular vibrations and sounds that come from the engine block. The knock sensor picks up vibration and sound coming from the engine block, turns it into an electronic signal and sends that signal to the engine control unit (ECU). **A knock sensor using magneto strictive** techniques is shown in Figure below. *Magnetostriction* is a phenomenon whereby the magnetic properties of a material depend on stress (due to an applied force). *When sensing knock, the magneto strictive rods, which are in a magnetic field, change the flux field in the coil due to knock-induced forces.* This change in flux produces a voltage change in the coil. This voltage is used to sense excessive knock. Other sensors use piezoelectric crystals or the piezo resistance of a doped silicon semiconductor. Whichever type of sensor is used, it forms a closed-loop system that retards the ignition to reduce the knock detected at the cylinders.
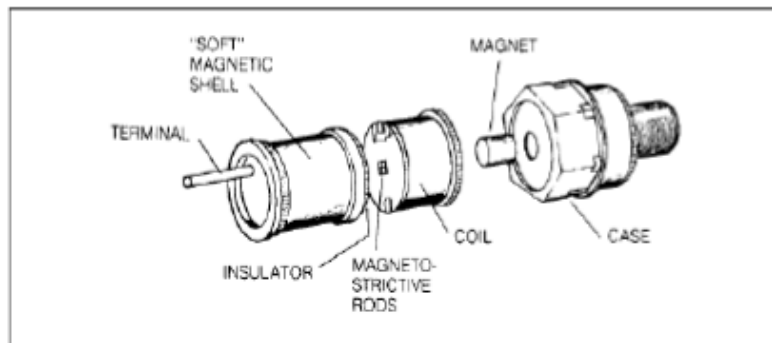
Figure Knock Sensor

An actuator is a device that receives an electrical input (e.g., from the engine controller) and produces a mechanical or thermal (or other) output. The set of sensors, electronic engine control is critically dependent on a set of actuators to control air/fuel ratio, ignition, and EGR. Each of these devices will be discussed separately.

Fuel pump

A fuel pump is a mechanical or electrical pump that draws fuel from a tank to provide the fuel supply for a carburetor or fuel injection system. A fuel pump is a critical component in the fuel delivery system of an internal combustion engine (ICE). Its primary function is to supply a steady flow of fuel from the fuel tank to the engine, ensuring proper fuel pressure and volume for combustion.

Fuel Injectors

A fuel injector is (in essence) a solenoid-operated valve. The valve opens or closes to permit or block fuel flow to the engine. The valve is attached to the movable element of the solenoid and is switched by the solenoid activation.
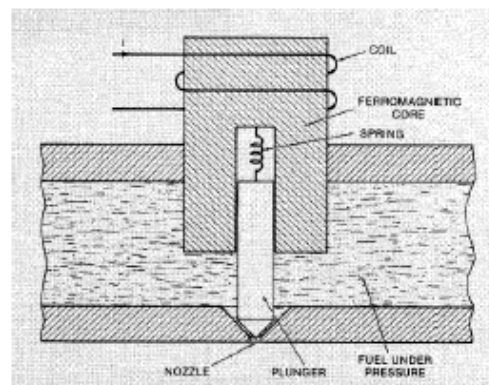

Fig: Schematic of fuel injector

- **Piezoelectric Injectors**

  Piezoelectric injectors, also known as piezo injectors, are a type of fuel injector commonly used in internal combustion engines (ICE). They utilize the piezoelectric effect to precisely control the fuel delivery into the engine cylinders.

  Piezoelectric materials exhibit the ability to generate an electric charge when subjected to mechanical stress or deformation. This effect is reversible, meaning they can also

deform when an electric charge is applied to them. Piezoelectric injectors consist of a piezoelectric crystal, typically made of materials like lead zirconate titanate (PZT), encased in a housing. The crystal is mechanically coupled to a needle valve, which controls the fuel flow by opening and closing the injector nozzle.
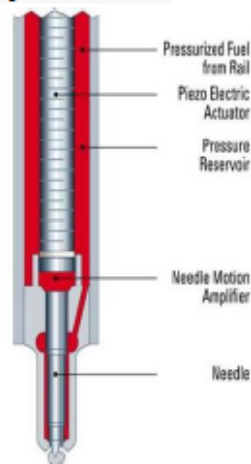
When an electrical voltage is applied to the piezoelectric crystal, it undergoes a deformation, resulting in the movement of the needle valve. This movement precisely regulates the fuel flow rate and injection timing. By controlling the electric voltage applied to the crystal, the injector can adjust the amount of fuel injected into the engine.

IAC valve

An idle air control actuator or idle air control valve (IAC actuator/valve) is a device commonly used in fuel-injected vehicles to control the engine's idling rotational speed (RPM). In carbureted vehicles a similar device known as an idle speed control actuator is used.
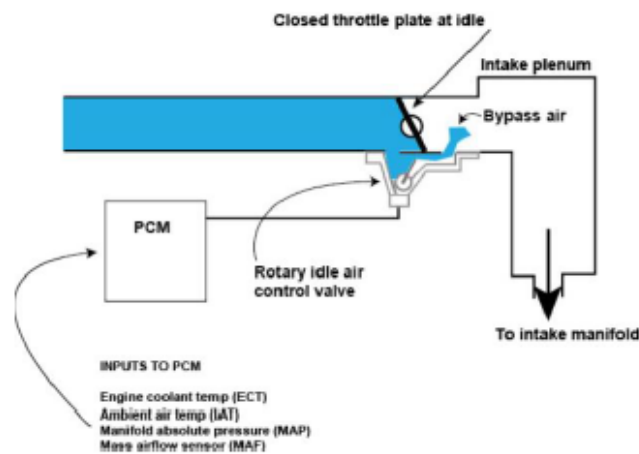

Fig: - Idle Air Control Valve

The idle air control valve bypasses air around the closed throttle valve and sends it to the engine, allowing it to receive the air it needs to combust fuel while idle. The idle air control valve only works when the throttle body valve is closed.

Exhaust Gas Recirculation Actuator

The exhaust gas recirculation (EGR) is utilized to reduce NOx emissions. EGR actuator is a variable-position valve that regulates the EGR as a function of intake manifold pressure and exhaust gas pressure. This actuator is a vacuum-operated diaphragm valve with a spring that holds the valve closed if no vacuum is applied. The vacuum that operates the diaphragm is supplied by the intake manifold and is controlled by a solenoid operated valve. This solenoid valve is controlled by the output of the control system.
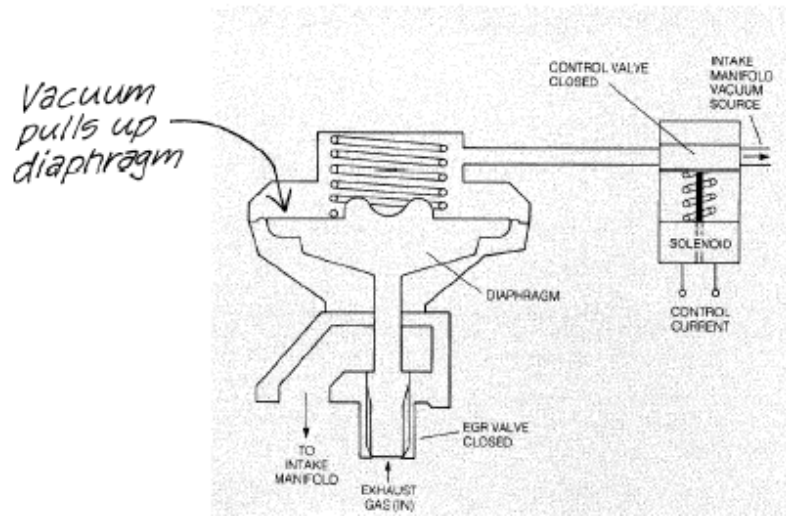

Fig: - EGR Actuator

Whenever the solenoid is energized (i.e., by current supplied by the control system flowing through the coil), the EGR valve is opened by the applied vacuum. The amount of valve opening is determined by the average pressure on the vacuum side of the diaphragm. This pressure is regulated by pulsing the solenoid with a variable-duty-cycle electrical control current.

Purge canister valve

The purge canister valve, also known as the purge solenoid or purge control valve, is a component of the vehicle's evaporative emission control system. It is responsible for controlling the flow of fuel vapor from the charcoal canister back into the engine for combustion.
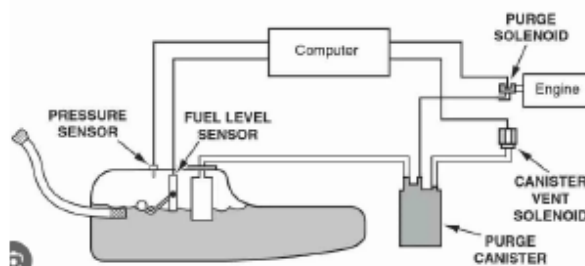
Ignition System

Actuator for the ignition system on an engine is the combination of the spark plug, the ignition coil, and driver electronic circuits. This is the subsystem that receives the electrical signal from the engine controller and delivers as its output the spark that ignites the mixture during the end of the compression stroke.
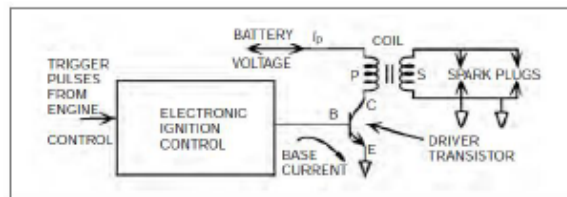
Fig: - Circuit diagram of an electronic ignition

The primary circuit of the coil (depicted as the left portion P of the coil in Figure above) is connected to the battery and through a power transistor to ground. For convenience, the collector, emitter, and base are denoted c, e, and b, respectively. The coil secondary S is connected to one or more spark plugs. A relatively large current (denoted I_p) flows through the primary windings of the coil (P), creating a relatively large magnetic field that is linked to the secondary coil.

The magnetic field (linked to the secondary S) generates a very high voltage (30,000 to 50,000 volts), which, in turn, creates the spark across the spark plug electrodes, igniting the mixture and, finally, initiating the power stroke for the engine.

Oil Control valve (OCV)

The Oil Control Valve (OCV) is a critical part used in every engine that is fitted with variable valve technology (VVT). A single control valve will regulate the supply of oil to a designated VVT hub, to advance or retard the timing by altering the camshaft angle position. Controlled by the ECU, the OCV receives electrical signals, instructing it to adjust the oil flow as required, in accordance to current driving conditions.
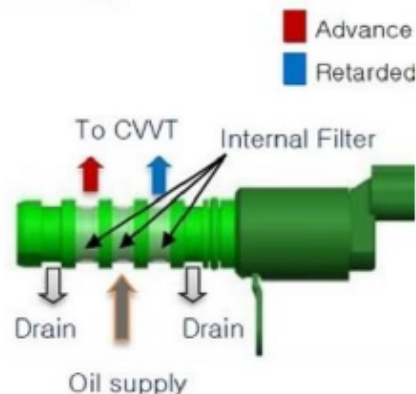

Fig: - Oil Control Valve

Engine Oil Solenoid Valve/Oil control valve is controlled by the engine control module, or PCM/ECM. The oil control valve is basically what controls the flow of oil into the camshaft of the engine (especially upper portion of the engine). This allows the internal moving parts of the engine to sustain their functionality.

Cooling Fan

The cooling fan is located a bit after the radiator, which is closest to the engine. the part is designed to protect fingers and direct airflow. It blows air to the radiator to cool the hot fluid while the engine is running, so the fan helps to cool down the temperature of the radiator.
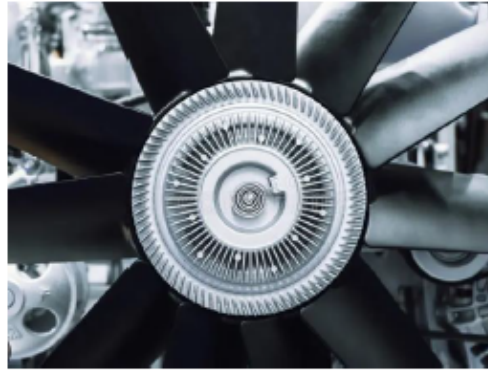
Fig: - Cooling fan

A temperature sensor detects the coolant temperature in the engine cooling system and sends these signals to the control unit of the cooling system. The controller analyzes these signals and determines the required speed of the motors for the coolant pump and cooling fan.

MIL, Indicators

The Malfunction Indicator Light (MIL) is also known as the Check Engine Light. The purpose of this warning light is to indicate a detected problem with the car and alert the driver about the issue.

Fig:- MIL Indicators

The MIL is part of the vehicle's onboard diagnostics system, known as OBD-II (On-Board Diagnostics II). It monitors various sensors, systems, and components of the vehicle, including the engine, fuel system, emission control system, and other important systems. When the system detects a problem that could potentially affect emissions or engine performance, it triggers the MIL to inform the driver that further inspection or repair may be needed.

Set of Switches and Relay:

Air conditioner clutch engaged switch

The air conditioner clutch engaged switch, commonly referred to as the AC clutch switch, is a component found in automobiles with air conditioning systems. It is responsible for controlling the engagement and disengagement of the air conditioner compressor clutch.
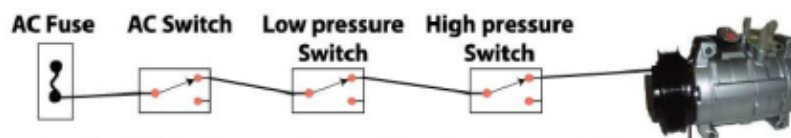

Fig: - Air conditioner clutch engaged switch

Purpose: The AC clutch switch is designed to activate or deactivate the air conditioner compressor clutch based on the driver's input or specific conditions. It allows the driver to manually control the operation of the air conditioning system.

Brake on/off

The brake on/off switch, also known as the brake light switch, is a component that controls the activation and deactivation of the brake lights when the brake pedal is pressed.
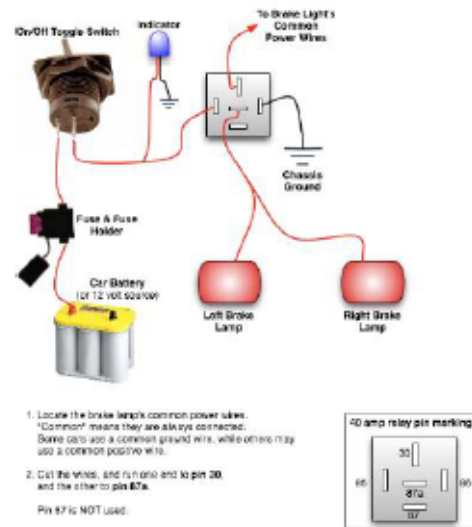
Fig: Brake On/Off

Purpose: The brake on/off switch is responsible for signaling the vehicle's brake lights to turn on or off, indicating to other drivers that the vehicle is slowing down or coming to a stop. It is an essential safety feature that helps alert drivers behind the vehicle of its braking actions.

Wide open throttle

Wide Open Throttle (WOT) refers to a situation in which the accelerator pedal of an automobile is fully depressed, causing the throttle valve to open completely, allowing maximum airflow into the engine.

Closed throttle

A "closed throttle" refers to the position of the throttle valve when the accelerator pedal is not being pressed, resulting in minimal airflow into the engine.

Reed switch

A reed switch is a magnetic switch that is sometimes used in automobiles for specific applications. It consists of two ferromagnetic reeds enclosed in a glass tube, with contacts at their ends.
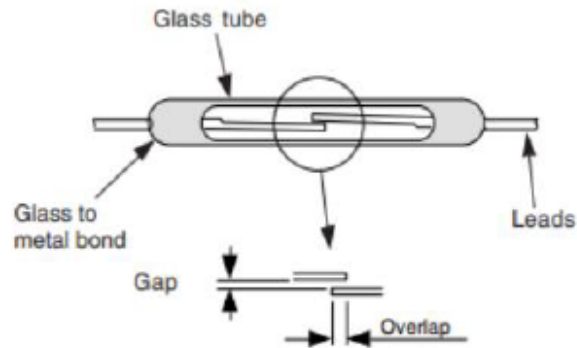
Fig: -Reed Switch

The reed switch operates based on the proximity of a magnetic field. When a magnetic field is applied to the reed switch, the magnetic force causes the reeds to come into contact, completing the electrical circuit. When the magnetic field is removed, the reeds separate, breaking the circuit.

Main Relay

The main relay, also known as the fuel pump relay or primary relay, is an electrical component found in many automobiles. It is responsible for controlling the flow of electrical power to critical systems and components in the vehicle.

Purpose: The main relay acts as a switch that controls the electrical power supply to important systems or components in the vehicle, such as the fuel pump, engine control unit (ECU), ignition system, or other high-demand electrical systems.
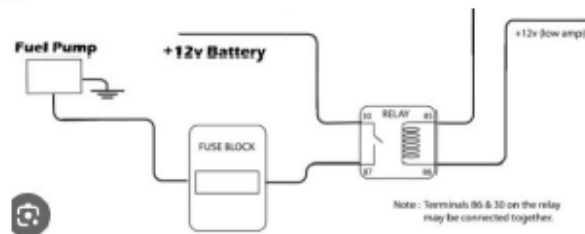

Fig: - Main Relay

Fuel Pump Relay

In many vehicles, the main relay also serves as the fuel pump relay. It controls the operation of the fuel pump, which is responsible for supplying fuel from the tank to the engine. When the main relay is energized, it activates the fuel pump, enabling proper fuel delivery.
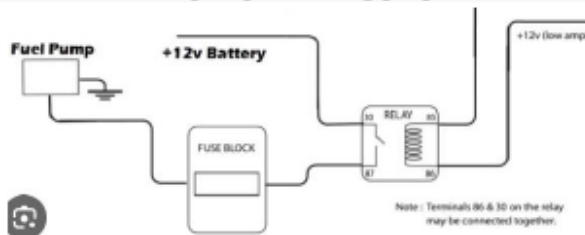

Fig: - Main Relay

AC Blower Switch

The AC blower switch, also known as the fan switch or blower motor switch, is a component found in automobile air conditioning systems. It controls the operation and speed of the blower motor, which is responsible for circulating air through the AC system and into the vehicle's cabin.
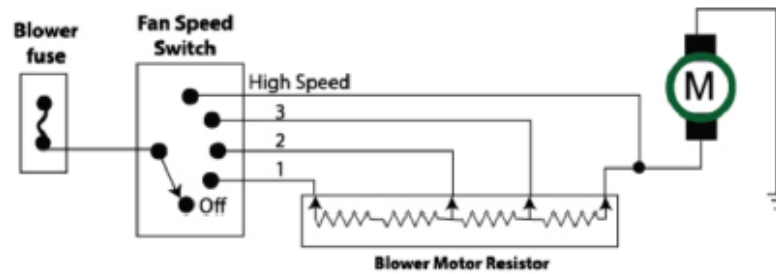

Fig: AC blower switch configuration

Purpose: The AC blower switch enables the driver or occupants to adjust the speed of the blower motor, which affects the airflow and temperature control within the vehicle's interior. It provides control over the amount of air and the intensity at which it is delivered.

*****Thank You*****

<u>Contents</u>
Introduction
Digital Engine Control Features
Control Modes for Fuel Control
- Engine Crank
- Engine Warm-Up
- Open-Loop Control
- Closed-Loop Control
- EGR Control

Integrated Engine Control System
- Secondary Air Management
- Evaporative Emissions Canister Purge
- Torque Converter Lock-up Control
- Automatic System Adjustment

Improvements in Electronic Engine Control
- Integrated Engine Control System
- Oxygen Sensor Improvements
- Fuel Injection Timing

<u>Introduction</u>

Traditionally, the term *powertrain* has been thought to include the engine, transmission, differential, and drive axle/wheel assemblies. With the advent of electronic controls, the powertrain also includes the electronic control system. In addition to engine control functions for emissions regulation, fuel economy, and performance, electronic controls are also used in the automatic transmission to select shifting as a function of operating conditions.
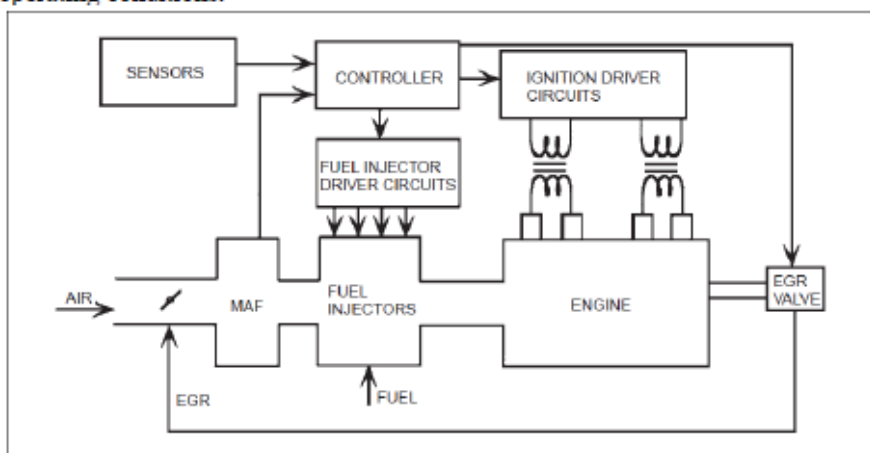
**Figure: - Components of an Electronically Controlled Engine**

A typical engine control system incorporates a microprocessor and is essentially a special-purpose computer (or microcontroller). Electronic engine control has evolved from a relatively rudimentary fuel control

system employing discrete analog components to the highly precise fuel and ignition control through 32-bit (sometimes more) microprocessor based integrated digital electronic power train control. A multimode controller operates in one of many possible modes, and, among other tasks, changes the various calibration parameters as operating conditions change in order to optimize performance.

Digital Engine Control Features

The primary purpose of the electronic engine control system is to regulate the mixture (i.e., air–fuel), the ignition timing, and EGR. In this figure, the engine control system is a microcontroller, typically implemented with a specially designed microprocessor and operating under program control. Typically, the controller incorporates hardware multiply and ROM.

Figure 7.2
Digital Engine Control System Diagram
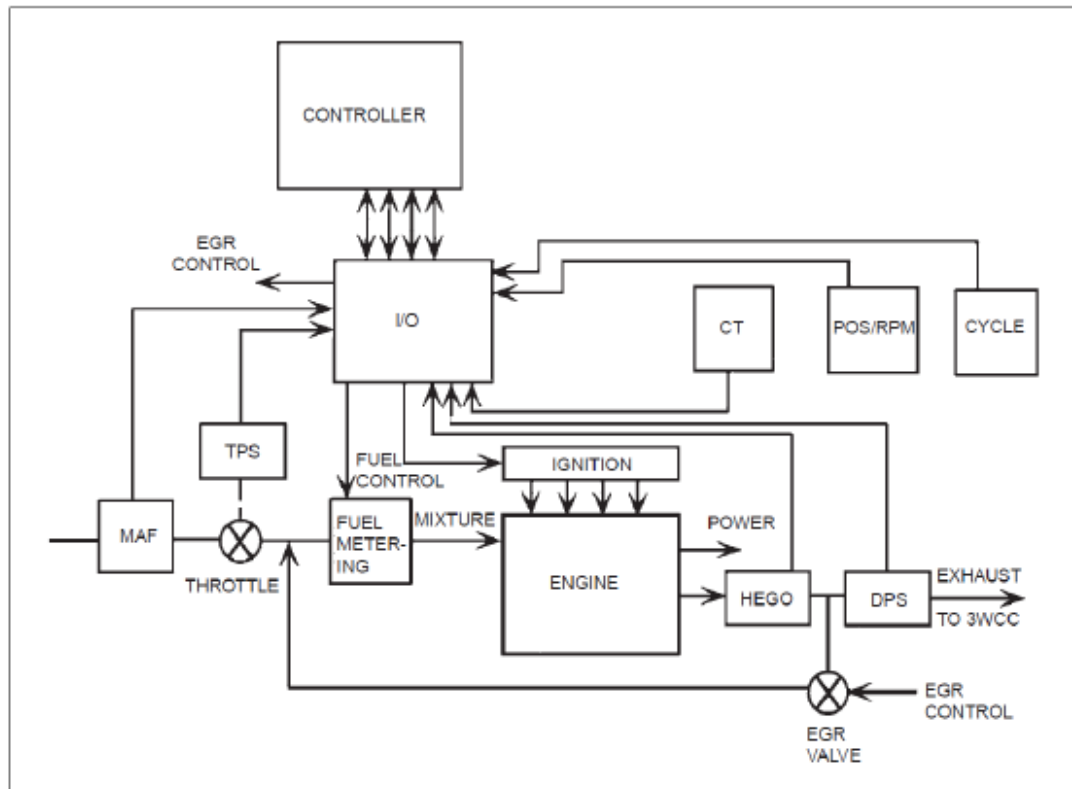
The hardware multiply greatly speeds up the multiplication operation required at several stages of engine control relative to software multiplication routines, which are generally cumbersome and slow.
The associated ROM contains the program for each mode as well as calibration parameters and lookup tables.

The microcontroller under program control generates output electrical signals to operate the fuel injectors so as to maintain the desired mixture and ignition to optimize performance.

In determining the correct fuel flow, the controller obtains a measurement or estimate of the mass air flow rate into the cylinder.

This estimate can be found from measurement of the intake manifold absolute pressure (MAP), the RPM, and the inlet air temperature.

The quantity of fuel to be delivered is determined by the controller in accordance with the instantaneous control mode.

The quantity of fuel delivered by the fuel injector is determined by the operation of the fuel injector.

A fuel injector is essentially a solenoid-operated valve. Fuel that is supplied to each injector from the fuel pump is supplied to each fuel injector at a regulated fuel pressure.

When the injector valve is opened, fuel flows at a rate R_f (in gal/sec) that is determined by the (constant) regulated pressure and by the geometry of the fuel injector valve. The quantity of fuel F delivered to any cylinder is proportional to the time T that this valve is opened:

$$F = R_f T$$

The engine control system, then, determines the correct quantity of fuel to be delivered to each cylinder (for a given operating condition) via measurement of mass air flow rate.

The controller then generates an electrical signal that opens the fuel injector valve for the appropriate time interval T to deliver this desired fuel quantity to the cylinder such that a stoichiometric air/fuel ratio is maintained.

The controller also determines the correct time for fuel delivery to correspond to the intake stroke for the relevant cylinder. This timing is determined by measurements of crankshaft and camshaft position using sensors.

CONTROL MODES FOR FUEL CONTROL

Engines have different modes of operation as the operating conditions change. Seven different modes of operation commonly affect fuel control.

During engine crank and engine warm-up modes, the controller holds the air/fuel ratio to a purposely low value (a rich fuel mixture).

After warm-up, the controller switches to open-loop control until accurate readings can be obtained from the EGO sensor. The controller then changes to, and remains in, closed-loop mode under ordinary driving conditions.

During conditions of hard acceleration or deceleration, the controller adjusts the air/fuel ratio as needed. During idle periods, the controller adjusts engine speed to reduce engine roughness and stalling.

- **Engine Crank**

    While the engine is being cranked, the fuel control system must provide an intake air/fuel ratio of anywhere from 2: 1 to 12: 1, depending on engine temperature. The correct air/fuel ratio (i.e., $[A/F]_d$) is selected from a ROM lookup table as a function of coolant temperature. Low temperatures affect the ability of the fuel metering system to atomize or mix the incoming air and fuel. At low temperatures, the fuel tends to form into large droplets in the air, which do not burn as efficiently as tiny droplets. The larger fuel droplets tend to increase the apparent air/fuel ratio, because the amount of usable fuel (on the surface of the droplets) in the air is reduced; therefore, the fuel metering system must provide a decreased air/fuel ratio to provide the engine with a more combustible air/fuel mixture. During engine crank the primary issue is to achieve engine start as rapidly as possible. Once the engine is started the controller switches to an engine warm-up mode.

- **Engine Warm-Up**

While the engine is warming up, an enriched air/fuel ratio is still needed to keep it running smoothly, but the required air/fuel ratio changes as the temperature increases. Therefore, the fuel control system stays in the open-loop mode, but the air/fuel ratio commands continue to be altered due to the temperature changes. The emphasis in this control mode is on rapid and smooth engine warm-up. Fuel economy and emission control are still a secondary concern. The controller selects a warm-up time from a lookup table based on the temperature of the coolant. During engine warm-up the air/fuel ratio is still rich, but it is changed by the controller as the coolant temperature increases.

- **Open-Loop Control**

For a warmed-up engine, the controller will operate in an open loop if the closed-loop mode is not available for any reason. For example, the engine may be warmed sufficiently but the EGO sensor may not provide a usable signal. The base pulse width T_b is computed as, except that the desired air/fuel ratio $(A/F)_d$ is 14.7. (stoichiometry):

After engine warm-up, open-loop control is used. The most popular method uses the mass density equation to calculate the amount of air entering the intake manifold.

$$T_b = \frac{MAF}{r(N/2)(14.7)R_f} \qquad \text{base pulse width}$$

Figure 7.4
Engine Control System Using the Speed-Density Method
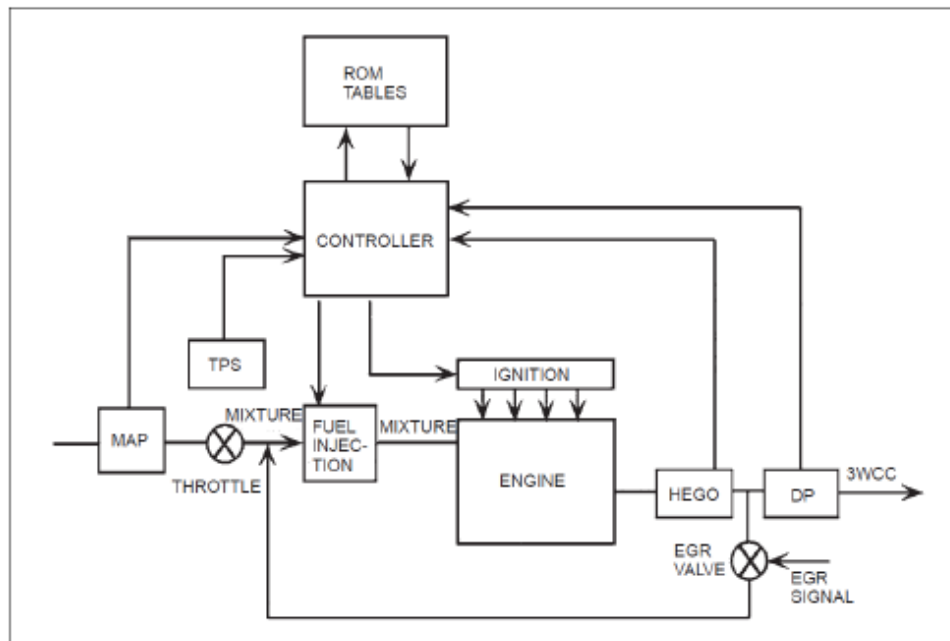
Corrections of the base pulse width occur whenever anything affects the accuracy of the fuel delivery. For example, low battery voltage might affect the pressure in the fuel rail that delivers fuel to the fuel injectors. Corrections to the base pulse width are then made using the actual battery voltage.

This method, which is illustrated in Figure 7.4, is based on measurements of manifold absolute pressure (MAP), RPM, and intake air temperature T_i. The air density d_a is computed from MAP and

T_t, and the volume flow rate R_v of combined air and EGR is computed from RPM and volumetric efficiency, the latter being a function of MAP and RPM. The volume rate for air is found by subtracting the EGR volume flow rate from the combined air and EGR. Finally, the mass air flow rate is computed as the product of the volume flow rate for air and the intake air density. Given the complexity of the speed density method it is easy to see why automobile manufacturers would choose the direct mass air flow measurement once a cost-effective mass air flow sensor became available.

- **Closed-Loop Control**

  Perhaps the most important adjustment to the fuel injector pulse duration comes when the control is in the closed-loop mode.

  In the open-loop mode the accuracy of the fuel delivery is dependent on the accuracy of the measurements of the important variables. However, any physical system is susceptible to changes with either operating conditions (e.g., temperature) or with time (aging or wear of components).

Figure 7.8b
Closed-Loop Control
System
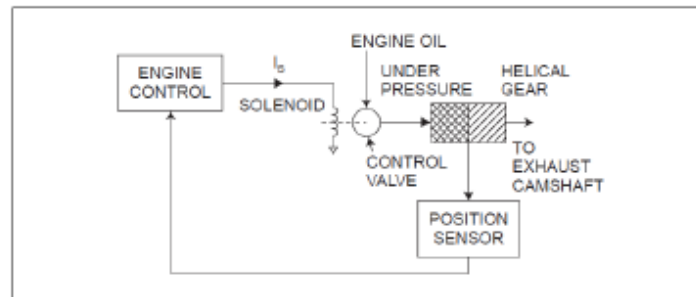
  In any closed-loop control system a measurement of the output variables is compared with the desired value for those variables. *In the case of fuel control*, the variables being regulated are exhaust gas concentrations of HC. CO, and NO_x.

- **EGR Control**

  A second electronic engine control subsystem is the control of exhaust gas that is recirculated back to the intake manifold. Under normal operating conditions, engine cylinder temperatures can reach more than 3,000°F. The higher the temperature, the more chance the exhaust will have NO_x emissions. The control mode selection logic determines when EGR is turned off or on. EGR is turned off during cranking, cold engine temperature (engine warm-up), idling, acceleration, or other conditions demanding high torque.

  Since exhaust gas recirculation was first introduced as a concept for reducing NO_x exhaust emissions, its implementation has gone through considerable change.

  Fundamental to all EGR schemes is a passageway or port connecting the exhaust and intake manifolds. A valve is positioned along this passageway whose position regulates EGR from zero to some maximum value. Typically, the valve is operated by a diaphragm connected to a variable vacuum source.

  In many EGR control systems the controller monitors the differential pressure between the exhaust and intake manifold via **a differential pressure sensor (DPS)**. With the signal from this sensor the controller can calculate the valve opening for the desired EGR level. The amount of EGR required is a predetermined function of the load on the engine (i.e., power produced).

Figure 7.8a
EGR Control
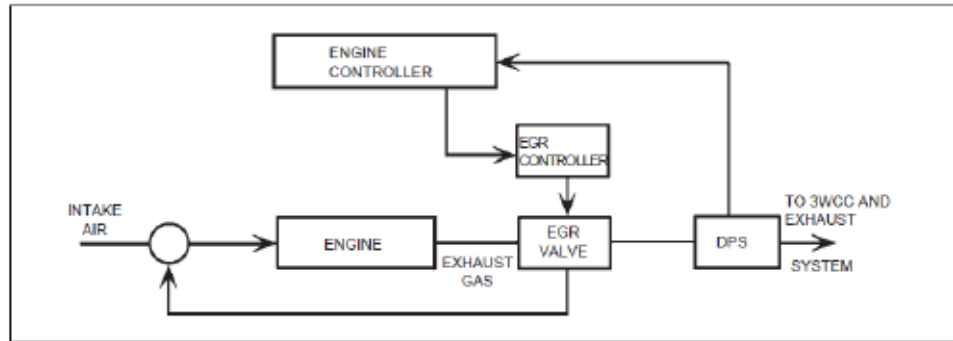
Integrated Engine Control System

A fully integrated electronic engine control system can include fuel control, spark control, and EGR subsystems and provide additional functions. (Usually, the flexibility of the digital control system allows such expansion quite easily because the computer program can be changed to accomplish the expanded functions.)

- **Secondary Air Management**

  Secondary air management is used to improve the performance of the catalytic converter by providing extra (oxygen-rich) air to either the converter itself or to the exhaust manifold. The catalyst temperature must be above about 200°C to efficiently oxidize HC and CO and reduce NOx. During engine warm-up when the catalytic converter is cold, HC and CO are oxidized in the exhaust manifold by routing secondary air to the manifold. This creates extra heat to speed warm-up of the converter and EGO sensor, enabling the fuel controller to go to the closed-loop mode more quickly. **The converter** can be damaged if too much heat is applied to it. This can occur if large amounts of HC and CO are oxidized in the manifold during periods of heavy loads, which call for fuel enrichment, or during severe deceleration. In such cases, the secondary air is directed to the air cleaner, where it has no effect on exhaust temperatures.

Figure 7.17
Secondary Air Control System

Secondary air either to intake, exhaust, or converter.
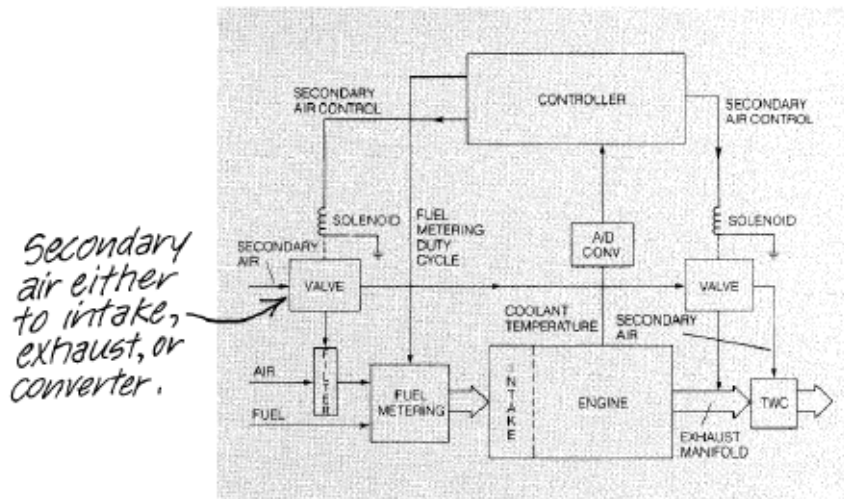
After warm-up, the main use of secondary air is to provide an oxygen rich atmosphere in the second chamber of the three-way catalyst, dual chamber converter system. In a dual-chamber converter,

the first chamber contains rhodium, palladium, and platinum to reduce NO_x and to oxidize HC and CO. The second chamber contains only platinum and palladium. The extra oxygen from the secondary air improves the converter's ability to oxidize HC and CO in the second converter chamber.

The computer program for the control mode selection logic can be modified to include the conditions for controlling secondary air. The computer controls secondary air by using two solenoid valves similar to the EGR valve. One valve switches air flow to the air cleaner or to the exhaust system. The other valve switches air flow to the exhaust manifold or to the converter.

- **Evaporative Emissions Canister Purge**

  During engine-off conditions, the fuel stored in the fuel system tends to evaporate into the atmosphere. To reduce these HC emissions, the fuel tank is sealed and evaporative gases are collected by a charcoal filter in a canister. The collected fuel is released into the intake through a solenoid valve controlled by the computer. This is done during closed-loop operation to reduce fuel calculation complications in the open-loop mode.

- **Torque Converter Lock-up Control**

  Automatic transmissions use a hydraulic or fluid coupling to transmit engine power to the wheels. Because of slip, the fluid coupling is less efficient than the nonslip coupling of a pressure-plate manual clutch used with a manual transmission. Thus, fuel economy is usually lower with an automatic transmission than with a standard transmission. This problem has been partially remedied by placing a clutch functionally similar to a standard pressure-plate clutch inside the torque converter of the automatic transmission and engaging it during periods of steady cruise. This enables the automatic transmission to provide fuel economy near that of a manual transmission and still retain the automatic shifting convenience. Here is a good example of the ease of adding a function to the electronic engine control system. The torque converter locking clutch (TCC) is activated by a lock-up solenoid controlled by the engine control system computer. The computer determines when a period of steady cruise exists from throttle position and vehicle speed changes. It pulls in the locking clutch and keeps it engaged until it senses conditions that call for disengagement.

- **Automatic System Adjustment**

  Another important feature of microcomputer engine control systems is their ability to be programmed to adapt to parameter changes. Many control systems use this feature to enable the computer to modify lookup table values for computing open-loop air/fuel ratios. While the computer is in the closed-loop mode, the computer checks its open-loop calculated air/fuel ratios and compares them with the closed-loop average limit-cycle values. If they match closely, the open-loop lookup tables are unchanged. If the difference is large, the system controller corrects the lookup tables so that the open-loop values more closely match the closed-loop values. This updated open-loop lookup table is stored in separate memory (RAM), which is always powered directly by a car battery so that the new values are not lost while the ignition key is turned off. The next time the engine is started, the new lookup table values will be used in the open loop mode and will provide more accurate control of the air/fuel ratio. This feature is very important because it allows the system controller to adjust to long-term changes in engine and fuel system conditions. This feature can be applied in individual subsystem control systems or in the fully integrated control system. If not available initially, it may be added to the system by modifying its control program.

Improvements in Electronic Engine Control

The digital engine control system in this chapter has been made possible by a rapid evolution of the state of technology. Some of this technology has been briefly mentioned in this chapter. It is worthwhile to review some of the technological improvements that have occurred in digital engine control in greater detail

to fully appreciate the capabilities of modern digital engine control. *Although major improvements have been made in electronic engine control, the fuel strategy continues to maintain stoichiometry.*

- **Integrated Engine Control System**

    One of the developments that has occurred since the introduction of digital engine control technology is the integration of the various functions into a single control unit. This trend has been made possible, in part, by improvements in digital hardware and in computational algorithms and software.
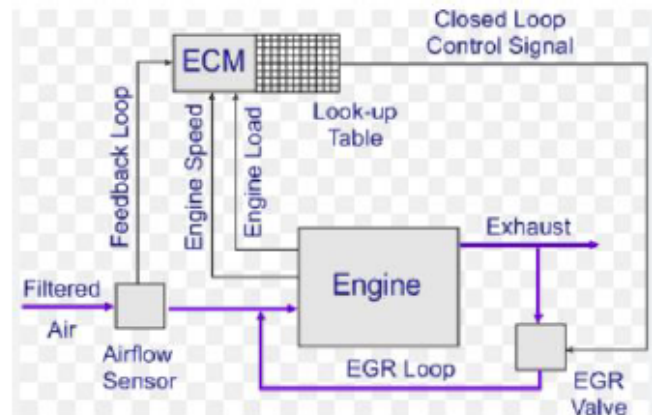

Fig: - Integrated Engine Control System

For example, one of the hardware improvements that has been achieved is the operation of the microprocessor (MPU) at higher clock frequencies. This higher frequency results in a reduction of the time for any given MPU computation, thereby permitting greater computational capability. This increased computational capability has made it possible, in turn, to have more precise control of fuel delivery during rapid transient engine operation.

- **Oxygen Sensor Improvements**

    Improvements have also been made in the exhaust gas oxygen sensor, which remains today as the primary sensor for closed-loop operation in cars equipped with the three-way catalyst.
   The signal from the oxygen sensor is not useful for closed-loop control until the sensor has reached a temperature of about 300°C.
    Typically, the temperature of the sensor is too low during the starting and engine warm-up phase, but it can also be too low during relatively long periods of deceleration. It is desirable to return to closed loop operation in as short a time as possible. Thus, the oxygen sensor must reach its minimum operating temperature in the shortest possible time.
    An improved exhaust gas oxygen sensor has been developed that incorporates an electric heating element inside the sensor, as shown in Figure below. This EGO sensor is known as the heated exhaust gas oxygen, or HEGO, sensor.
    The heat current is automatically switched on and off depending on the engine operating condition. The operating regions in which heating is applied are determined by the engine control system as derived from engine RPM and MAP sensors.

Figure 7.18
Heated Exhaust Gas
Oxygen Sensor
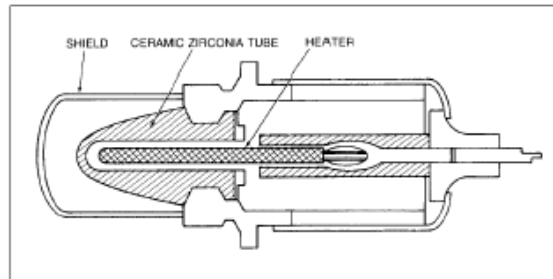
The heating element is made from resistive material and derives heat from the power dissipated in the associated resistance. The HEGO sensor is packaged in such a way that this heat is largely maintained within the sensor housing, thereby leading to a relatively rapid temperature rise. Normally, the heating element need only be turned on for cold-start operations. Shortly after engine start the exhaust gas has sufficient heat to maintain the EGO sensor at a suitable temperature.

- **Fuel Injection Timing**
In this fuel control system, a separate fuel injector is provided for each cylinder. The fuel injector for each cylinder is typically mounted in the intake manifold such that fuel is sprayed directly into the intake port of the corresponding cylinder during the intake stroke.

During the intake stroke, the intake valve is opened and the piston is moving down from top dead center (TDC). Figure 7.19 illustrates the timing for the fuel injectors for a 4-cylinder engine. It can be seen that in two complete engine revolutions (as indicated by the No. 1 cylinder position), all four injectors have been switched on for a time $T(n)$. This pulse duration results in delivery of the desired quantity of fuel for the nth engine cycle. This system provides for highly uniform fueling of all the cylinders and is superior in performance to either carburetors or throttle body fuel injectors.

Figure 7.19
Injector Timing for
4-Cylinder Engine
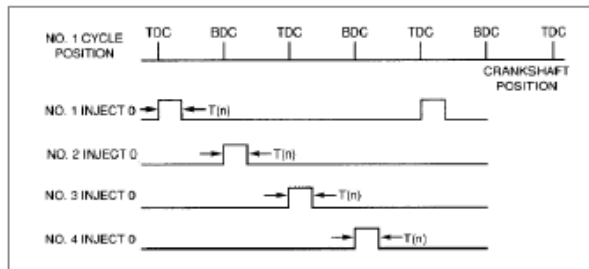
Notes below shows the summary of different control modes. Below given summaries are mentioned as reference for boosting student's understandings.

SUMMARY OF CONTROL MODES

Now that a typical electronic engine control system has been discussed, let's summarize what happens in an integrated system operating in the various modes.

Engine Crank (Start)

The following list is a summary of the engine operations in the engine crank (starting) mode. Here, the primary control concern is reliable engine start.

1. Engine RPM at cranking speed.
2. Engine coolant at low temperature.
3. Air/fuel ratio low.
4. Spark retarded.
5. EGR off.
6. Secondary air to exhaust manifold.
7. Fuel economy not closely controlled.
8. Emissions not closely controlled.

Engine Warm-Up

While the engine is warming up, the engine temperature is rising to its normal operating value. Here, the primary control concern is rapid and

smooth engine warm-up. A summary of the engine operations during this period follows:

1. Engine RPM above cranking speed at command of driver.
2. Engine coolant temperature rises to minimum threshold.
3. Air/fuel ratio low.
4. Spark timing set by controller.
5. EGR off.
6. Secondary air to exhaust manifold.
7. Fuel economy not closely controlled.
8. Emissions not closely controlled.

Open-Loop Control

The following list summarizes the engine operations when the engine is being controlled with an open-loop system. This is before the EGO sensor has reached the correct temperature for closed-loop operation. Fuel economy and emissions are closely controlled.

1. Engine RPM at command of driver.
2. Engine temperature above warm-up threshold.
3. Air/fuel ratio controlled by an open-loop system to 14.7.
4. EGO sensor temperature less than minimum threshold.
5. Spark timing set by controller.
6. EGR controlled.
7. Secondary air to catalytic converter.
8. Fuel economy controlled.
9. Emissions controlled.

Closed-Loop Control

For the closest control of emissions and fuel economy under various driving conditions, the electronic engine control system is in a closed loop. Fuel economy and emissions are controlled very tightly. The following is a summary of the engine operations during this period:

1. Engine RPM at command of driver.
2. Engine temperature in normal range (above warm-up threshold).
3. Average air/fuel ratio controlled to 14.7, ±0.05.
4. EGO sensor's temperature above minimum threshold detected by a sensor output voltage indicating a rich mixture of air and fuel for a minimum amount of time.
5. System returns to open loop if EGO sensor cools below minimum threshold or fails to indicate rich mixture for given length of time.
6. EGR controlled.
7. Secondary air to catalytic converter.

8. Fuel economy tightly controlled.
9. Emissions tightly controlled.

Hard Acceleration

When the engine must be accelerated quickly or if the engine is under heavy load, it is in a special mode. Now, the engine controller is primarily concerned with providing maximum performance. Here is a summary of the operations under these conditions:

1. Driver asking for sharp increase in RPM or in engine power, demanding maximum torque.
2. Engine temperature in normal range.
3. Air/fuel ratio rich mixture.
4. EGO not in loop.
5. EGR off.
6. Secondary air to intake.
7. Relatively poor fuel economy.
8. Relatively poor emissions control.

Deceleration and Idle

Slowing down, stopping, and idling are combined in another special mode. The engine controller is primarily concerned with reducing excess emissions during deceleration, and keeping idle fuel consumption at a minimum. This engine operation is summarized in the following list.

1. RPM decreasing rapidly due to driver command or else held constant at idle.
2. Engine temperature in normal range.
3. Air/fuel ratio lean mixture.
4. Special mode in deceleration to reduce emissions.
5. Special mode in idle to keep RPM constant at idle as load varies due to air conditioner, automatic transmission engagement, etc.
6. EGR on.
7. Secondary air to intake.
8. Good fuel economy during deceleration.
9. Poor fuel economy during idle, but fuel consumption kept to minimum possible.

******Thank You******

Automotive Electronics-I

Unit 5
Vehicle Motion Control

Contents

Typical Cruise Control System

- Speed Response Curves
- Digital Cruise Control
- Throttle Actuator

Cruise Control Electronics

- Stepper Motor-Based Actuator
- Vacuum-Operated Actuator

Antilock Braking System

- Hydraulic Modulator
- Solenoids
- Electronic Parking Brake (EPB)
- Electronic Brake force Distribution (EBD)

Electronic Suspension System

Electronic Steering Control

- Electrostatic Column Lock
- Electronic Power steering
- Electronic Stability Program (ESP)

Air Bag system

- Impact Sensors
- SRS Control Module
- Clock Spring Operation
- Passenger Air Bag Operation
- Driver Air Bag Operation
- Curtain Air Bag Operation
- Seat Belt Pretensioners
- Seat Belt Operation

Introduction To Vehicle Motion Control

The term *vehicle motion* refers to its translation along and rotation about all three axes (i.e., longitudinal, lateral, and vertical). By the term *longitudinal axis*, we mean the axis that is parallel to the ground (vehicle at rest) along the length of the car. The lateral axis is orthogonal to the longitudinal axis and is also parallel to the ground (vehicle at rest). The vertical axis is orthogonal to both the longitudinal and lateral axes.

Rotations of the vehicle around these three axes correspond to angular displacement of the car body in roll, yaw, and pitch. *Roll* refers to angular displacement about the longitudinal axis; *yaw* refers to angular displacement about the vertical axis; and *pitch* refers to angular displacement about the lateral axis.

Electronic controls have been recently developed with the capability to regulate the motion along and about all three axes. Individual car models employ various selected combinations of these controls.

The forces that influence vehicle motion along the longitudinal axis include the powertrain (including, in selected models, traction control), the brakes, the aerodynamic drag, and tire-rolling resistance, as well as the influence of gravity when the car is moving on a road with a nonzero

inclination (or grade). In a traditional cruise control system, the tractive force due to the powertrain is balanced against the total drag forces to maintain a constant speed. In an advanced cruise control system, brakes are also automatically applied as required to maintain speed when going down a hill of sufficiently steep grade.

Typical Cruise Control System

Automotive cruise control is an excellent example of the type of electronic feedback control system. The components of a control system include the plant, or system being controlled, and a sensor for measuring the plant variable being regulated. It also includes an electronic control system that receives inputs in the form of the desired value of the regulated variable and the measured value of that variable from the sensor.

In the case of a cruise control, the variable being regulated is the vehicle speed. The driver manually sets the car speed at the desired value via the accelerator pedal. Upon reaching the desired speed the driver activates a momentary contact switch that sets that speed as the command input to the control system. From that point on, the cruise control system maintains the desired speed automatically by operating the throttle via a throttle actuator.

Figure 8.1
Cruise Control Configuration
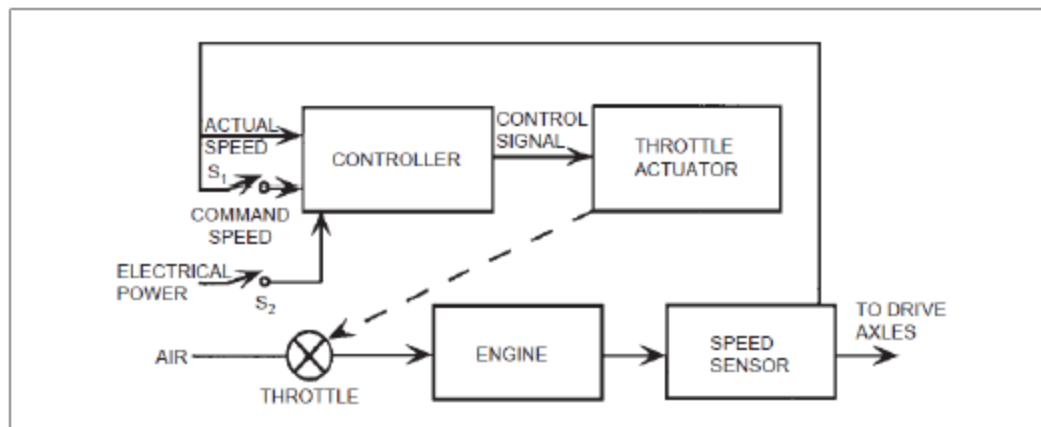
The configuration for a typical automotive cruise control is shown in Figure 8.1. The momentary contact (pushbutton) switch that sets the command speed is denoted S_1 in Figure 8.1. Also shown in this figure is a disable switch that completely disengages the cruise control system from the power supply such that throttle control reverts back to the accelerator pedal. This switch is denoted S_2 in Figure 8.1 and is a safety feature. In an actual cruise control system, the disable function can be activated in a variety of ways, including the master power switch for the cruise control system, and a brake pedal–activated switch that disables the cruise control any time that the brake pedal is moved from its rest position. The throttle actuator opens and closes the throttle in response to the error between the desired and actual speed. Whenever the actual speed is less than the desired speed the throttle opening is increased by the actuator, which increases vehicle speed until the error is zero, at which point the throttle opening remains fixed until either a disturbance occurs or the driver calls for a new desired speed.

- **Speed Response Curves**

  The curves of Figure below show the response of a cruise control system with a PI control strategy to a sudden disturbance. *These curves are all for the same car cruising initially at 60 mph along a level road and encountering an upsloping hill. The only difference in the response of these curves is the controller gain parameters.*

  <u>When a new speed is requested, the time required for the vehicle to reach that speed is affected by the control system's damping coefficient.</u>

  Consider, first, the curve that initially drops to about 30 mph and then increases, overshooting the desired speed and oscillating above and below the desired speed until it eventually decays to the desired 60 mph. This curve has a relatively low damping ratio as determined by the controller parameters KP and KI and takes more time to come to the final steady value.

  Next, consider the curve that drops initially to about 40 mph, then increases with a small overshoot and decays to the desired speed. The numerical value for this damping ratio is about 0.7, whereas the first curve had a damping ratio of about 0.4. Finally, consider the solid *curve of Figure 8.3c*. This curve corresponds to critical damping. This situation involves the most rapid response of the car to a disturbance, with no overshoot.
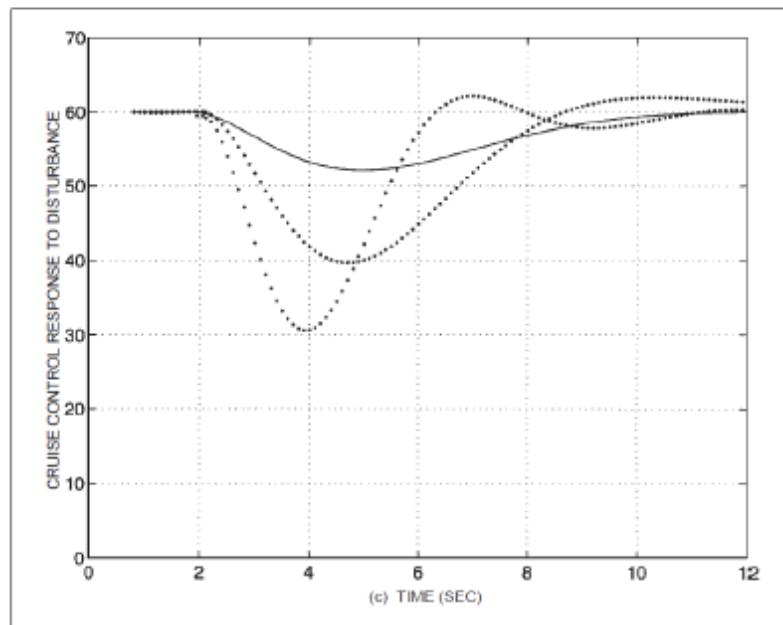
  Figure 8.3
  Continued

  Fig: - speed Response Curve

  The importance of these performance curves is that they demonstrate how the performance of a cruise control system is affected by the controller gains. These gains are simply parameters that are contained in the control system. They determine the relationship between the error, the integral of the error, and the actuator control signal.

- **Digital Cruise Control**

  Cruise control is now mostly implemented digitally using a microprocessor-based computer. For such a system, proportional and integral control computations are performed numerically in the computer.

A block diagram for a typical digital cruise control is shown in Figure 8.4. The vehicle speed sensor is digital.

When the car reaches the desired speed, S_d, the driver activates the speed set switch. At this time, the output of the vehicle speed sensor is transferred to a storage register.

The computer continuously reads the actual vehicle speed, S_a, and generates an error, e_n, at the sample time, t_n (n is an integer). $e_n = S_d - S_a$ at time t_n. A control signal, d, is computed that has the following form:

$$d_n = K_p e_n + K_I \sum_{m=1}^{M} e_{n-m}$$

Figure 8.4
Digital Cruise Control
System
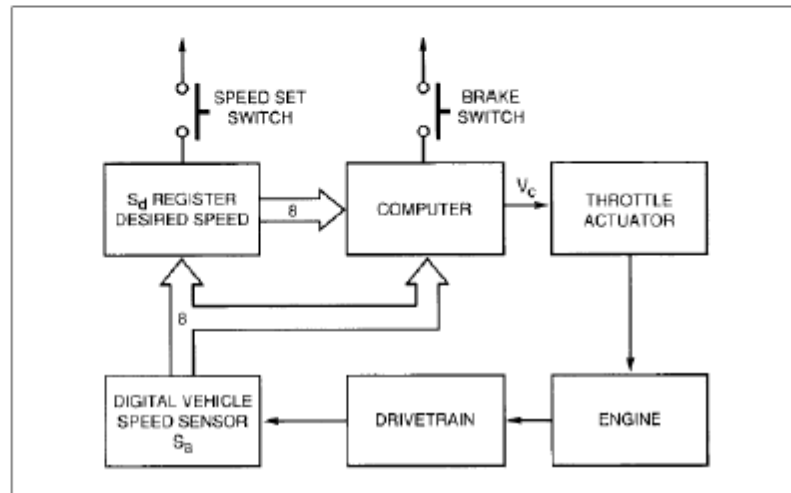
(*Note:* The symbol S in this equation means to add the M previously calculated errors to the present error.) This sum, which is computed in the cruise control computer, is then multiplied by the integral gain KI and added to the most recent error multiplied by the proportional gain KP to form the control signal.

This control signal is actually the duty cycle of a square wave (Vc) that is applied to the throttle actuator (as explained later). The throttle opening increases or decreases as d increases or decreases due to the action of the throttle actuator.
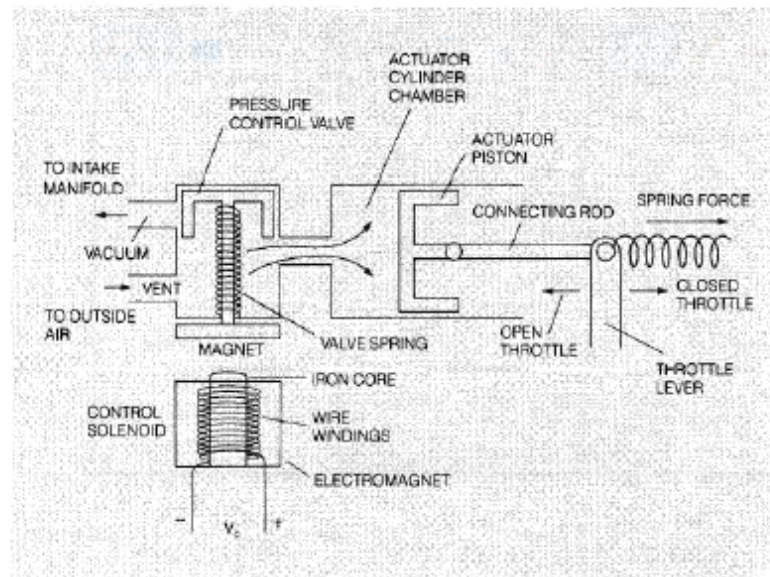
- **Throttle Actuator**
  The throttle actuator is an electromechanical device that, in response to an electrical input from the controller, moves the throttle through some appropriate mechanical linkage.
  Two relatively common throttle actuators operate either from manifold vacuum or with a stepper motor.

- **Vacuum-Operated Actuator**

  The throttle actuator that is operated by manifold vacuum through a solenoid valve is similar to that used for the EGR valve.

**Figure 8.7
Vacuum-Operated
Throttle Actuator**

During cruise control operation the throttle position is set automatically by the throttle actuator in response to the actuator signal generated in the control system. This type of manifold-vacuum operated actuator is illustrated in Figure above.

Throttle actuators use manifold vacuum to pull a piston that is mechanically linked to the throttle. The amount of vacuum provided is controlled by a solenoid valve that is turned on and off rapidly.

Cruise Control Electronics

Cruise control can be implemented electronically in various ways, including with a microcontroller with special-purpose digital electronics or with analog electronics. It can also be implemented (in proportional control strategy alone) with an electromechanical speed governor. A microprocessor-based cruise control system performs all of the required control law computations digitally under program control.
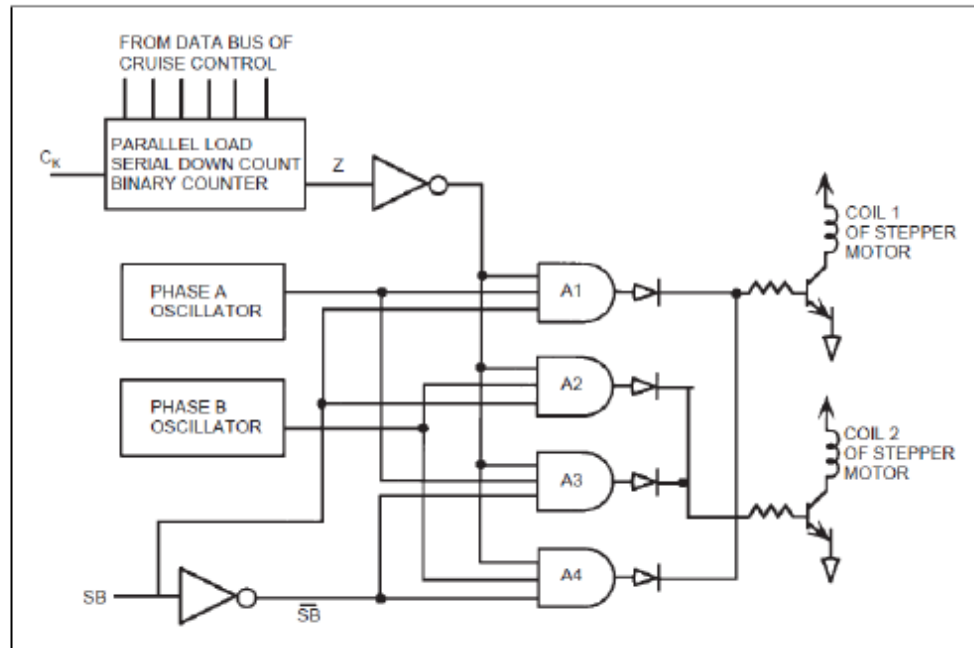
- **Stepper Motor-Based Actuator**

  In the case of a stepper motor actuator, the actuator driver electronics reads this number and then generates a sequence of pulses to the pair of windings on the stepper motor (with the correct relative phasing) to cause the stepper motor to either advance or retard the throttle setting as required to bring the error toward zero.

  The throttle opening is either increased or decreased by the stepper motor in response to the sequences of pulses sent to the two windings depending on the relative phase of the two sets of pulses

  An illustrative example of driver circuitry for a stepper motor actuator is shown in Figure below.

Figure 8.9
Stepper Motor Actuator for Cruise Control

The basic idea for this circuitry is to continuously drive the stepper motor to advance or retard the throttle in accordance with the control signal that is stored in memory. Just as the controller periodically updates the actuator control signal, the stepper motor driver electronics continually adjusts the throttle by an amount determined by the actuator signal.

This signal is, in effect, a signed number (i.e., a positive or negative numerical value). A sign bit indicates the direction of the throttle movement (advance or retard). The numerical value determines the amount of advance or retard.

A signal is applied to coil 1 and phase B to coil 2. To retard the throttle these phases are each switched to the opposite coil. The amount of movement in either direction is determined by the number of cycles of A and B, one step for each cycle.

The number of cycles of these two phases is controlled by a logical signal (Z in Figure).

Antilock Braking System

One of the most readily accepted applications of electronics in automobiles has been the antilock brake system (ABS).

In ABS-equipped cars, the wheel is prevented from locking by a mechanism that automatically regulates braking force to an optimum for any given low-friction condition. The physical configuration for an ABS is shown in Figure 8.12. In addition to the normal brake components, including brake pedal, master cylinder, vacuum boost, wheel cylinders, calipers/disks, and brake lines, this system has a set of angular speed sensors at each wheel, an electronic control module, and a hydraulic brake pressure modulator (regulator).
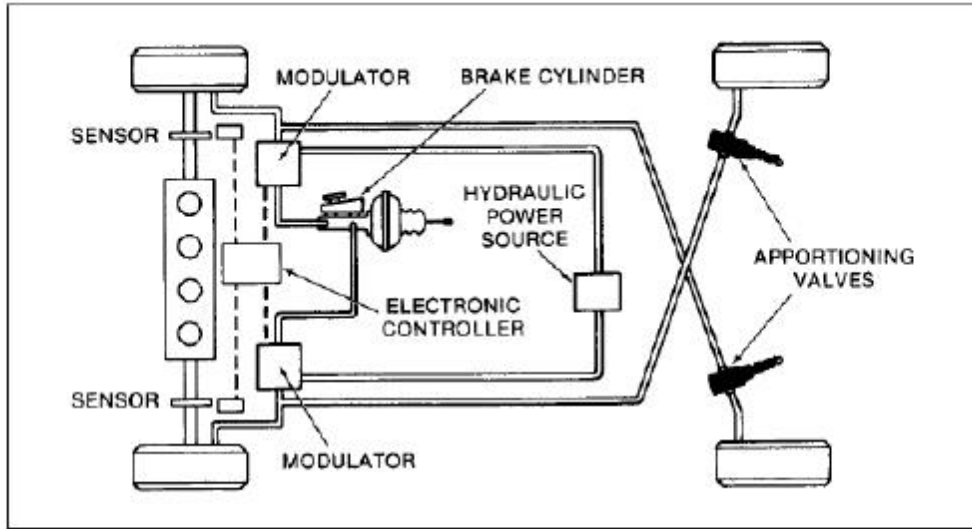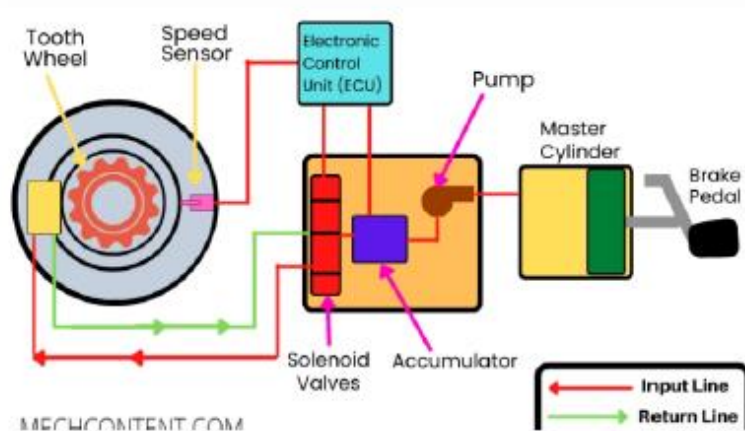
Fig: -Schematic of ABS

- **Hydraulic Modulator**

  The hydraulic modulator is a key component of the ABS system. It consists of valves that control the brake fluid pressure to the individual wheel brakes. When the ABS system detects impending wheel lockup during hard braking, it rapidly opens and closes the valves in the hydraulic modulator to regulate the brake fluid pressure to each wheel. By doing so, the system prevents the wheels from fully locking up, allowing the driver to maintain control and steer the vehicle while braking.

- **Solenoids**

  Solenoids are electromagnetic devices used to control the flow of brake fluid in the hydraulic modulator. They act as on-off valves that open and close rapidly based on the signals from the ABS control module. The solenoids play a crucial role in modulating brake pressure and preventing wheel lockup during ABS activation.

Tooth Wheel • Speed Sensor • Electronic Control Unit (ECU) • Pump • Master Cylinder • Brake Pedal • Solenoid Valves • Accumulator

Input Line
Return Line

MECHCONTENT.COM

ABS System with Solenoid

- **Electronic Parking Brake (EPB)**

  The Electronic Parking Brake is an electronic alternative to the conventional handbrake lever or foot pedal used to engage the parking brake. It is often operated through a button or switch inside the vehicle. The EPB is electronically controlled and typically utilizes electric motors or actuators to apply and release the parking brake. This system offers various features such as automatic engagement when the engine is turned off, automatic release when the vehicle starts moving, and integration with other vehicle systems.

EPB Brake Caliper & Motor

Brake Caliper • EPB Motor • Rotor
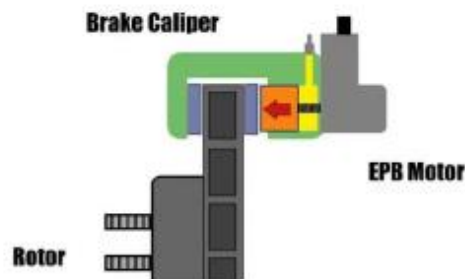
Schematic of EBP

- **Electronic Brake force Distribution (EBD)**

  EBD is a system that works in conjunction with the ABS to optimize brake force distribution between the front and rear wheels. It takes into account various factors such as vehicle load, weight distribution, and braking conditions. By adjusting the brake force applied to each wheel, EBD helps ensure maximum braking efficiency, stability, and control during braking maneuvers.
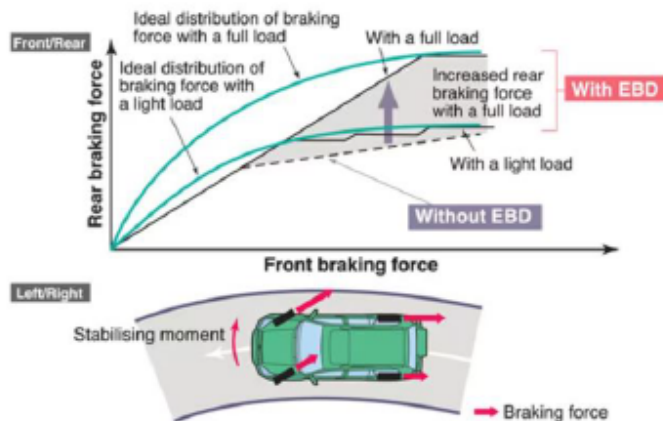
Electronic Suspension System

The control system for a typical electronic suspension system is depicted in the block diagram of Figure. The control system configuration in

Figure is generic and not necessarily representative of the system for any production car. This system includes sensors for measuring vehicle speed; steering input (i.e., angular deflection of steered wheels); relative displacement of the wheel assembly and car body/chassis; lateral acceleration; and yaw rate.

There are two major classes of electronic suspension control systems active and semiactive. The semiactive suspension system is purely dissipative (i.e., power is absorbed by the shock absorber under control of a microcontroller). In this system, the shock absorber damping is regulated to absorb the power of the wheel motion in accordance with the driving conditions. The primary purpose of the semiactive suspension system is to provide a good ride for as much of the time as possible without sacrificing handling. A semiactive suspension controls the shock absorber damping to achieve the best possible ride.
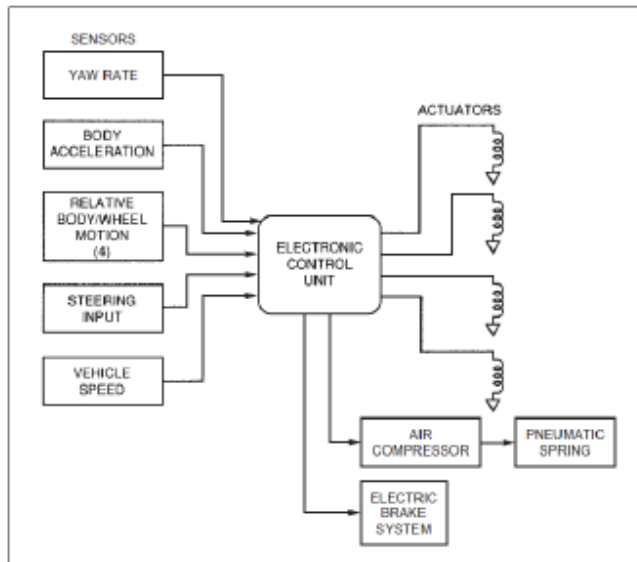
Figure 8.22
Electronic
Suspension System

Fig: - Electronic Suspension System

In an active suspension system, power is added to the suspension system via a hydraulic or pneumatic power source. *Commercial suspension systems are primarily semiactive. The active suspension system is just beginning to appear in production vehicles.*

Electronic Steering Control

Electronic Steering Control refers to the various electronic systems used to control and enhance the steering performance and stability of a vehicle. These systems use electronic components and sensors to assist the driver in steering the vehicle more effectively and safely.
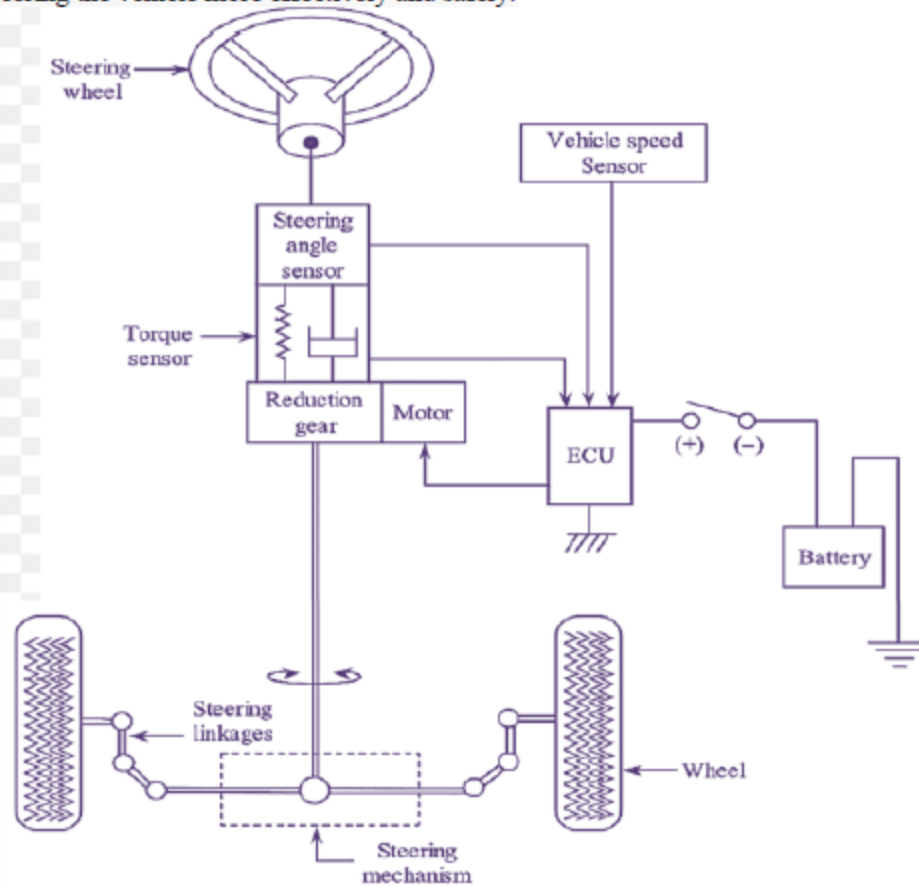
Fig: -Electronic Steering Control

An example of an electronically controlled steering system that has had commercial production is for four-wheel steering systems (4WS). In the 4WSequipped vehicles, the front wheels are directly linked mechanically to the steering wheel, as in traditional vehicles. There is a power steering boost for the front wheels as in a standard two-wheel steering system. The rear wheels are steered under the control of a microcontroller via an actuator. Figure below is an illustration of the 4WS configuration.
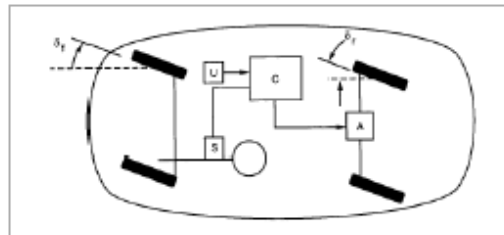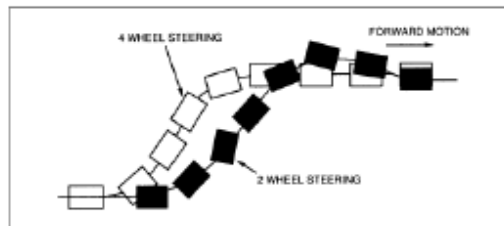
Figure 8.23
4WS Configuration

Figure 8.24
Lane Change
Maneuver

In this illustration, the front wheels are steered to a steering angle d_f by the driver's steering wheel input. A sensor (S) measures the steering angle and another sensor (U) gives the vehicle speed. The microcontroller (C) determines the desired rear steering angle d_r under program control as a function of speed and front steering angle

- **Electrostatic Column Lock**

    This system is designed to prevent the unauthorized use of a vehicle by electronically locking the steering column. It acts as a security feature to prevent theft. When the vehicle is turned off and the ignition key is removed, the electrostatic column lock engages, making it difficult to turn the steering wheel without the correct key or electronic authorization.
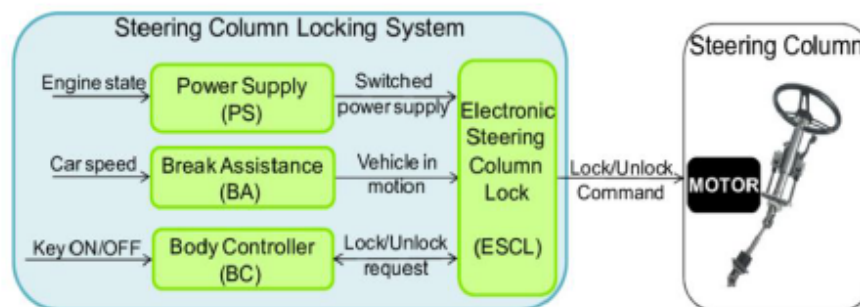

Fig: - Electrostatic Column Lock

- **Electronic Power steering**

    EPS is a type of power steering system that uses electronic control instead of traditional hydraulic assistance. It typically consists of an electric motor that assists the driver in turning the steering wheel. The level of assistance provided by the motor is adjusted based on vehicle speed, steering wheel position, and other factors, making it easier for the driver to steer the vehicle, especially at low speeds or during parking.
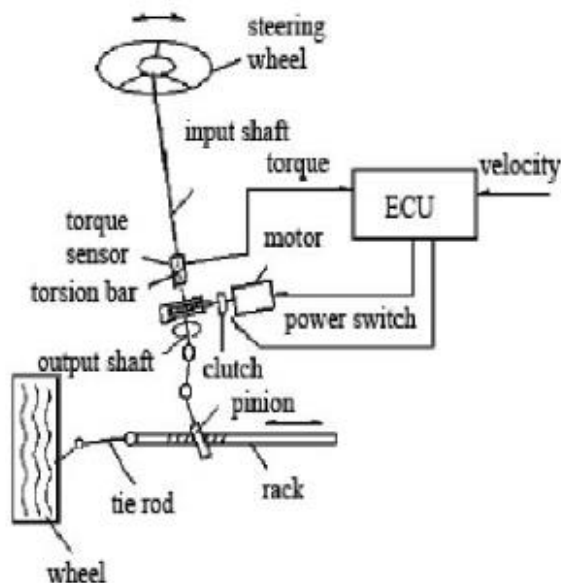
Fig: - Electronic Power Steering

- **Electronic Stability Program (ESP)**

  ESP, also known as Electronic Stability Control (ESC), is a crucial safety feature in modern vehicles. It uses various sensors to monitor the vehicle's stability and compare the driver's intended direction with the vehicle's actual behavior. If the system detects that the vehicle is deviating from the intended path, it can automatically apply selective braking to individual wheels and reduce engine power to help the driver regain control and prevent skidding or loss of control during cornering or emergency maneuvers. ESP significantly enhances vehicle stability and reduces the risk of accidents caused by oversteering or understeering.
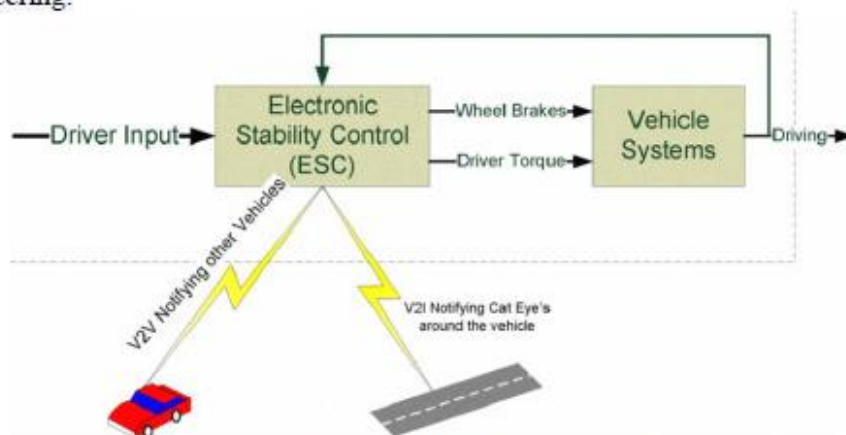

Fig: - Electronic Stability Program/Control

Air Bag system

The airbag system is a critical safety feature in modern vehicles designed to protect occupants during a collision or impact. It deploys airbags strategically placed throughout the vehicle's interior to help reduce the risk of injury to the driver and passengers.

An **airbag** is a vehicle occupant-restraint system using a bag designed to inflate extremely quickly, then quickly deflate during a collision. It consists of the airbag cushion, a flexible fabric bag, an inflation module, and an impact sensor. The purpose of the airbag is to provide a vehicle occupant with soft cushioning and restraint during a collision. It can reduce injuries between the flailing occupant and the interior of the vehicle.
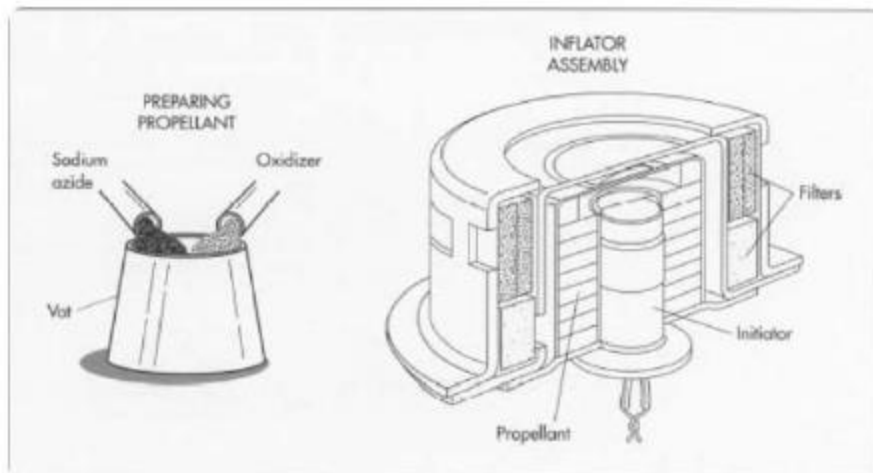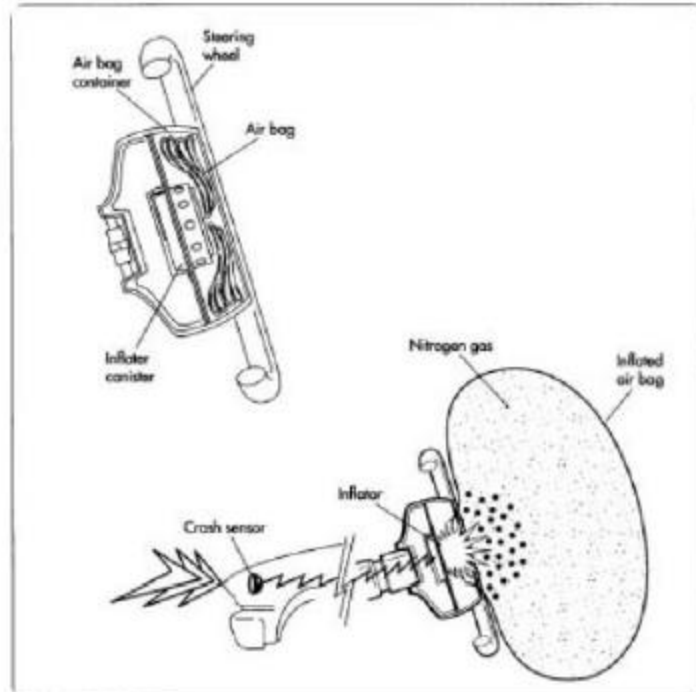
The airbag provides an energy-absorbing surface between the vehicle's occupants and a steering wheel, instrument panel, body pillar, headliner, and windshield, for example. Modern vehicles may contain up to 10 airbag modules in various configurations, including: driver, passenger, side-curtain, seat-mounted, door-mounted, B and C-pillar mounted side-impact, knee bolster, inflatable seat belt, and pedestrian airbag modules.

During a crash, the vehicle's crash sensors provide crucial information to the airbag electronic controller unit (ECU), including collision type, angle, and severity of impact. Using this information, the airbag ECU's crash algorithm determines if the crash event meets the criteria for deployment and triggers various firing circuits to deploy one or more airbag modules within the vehicle.
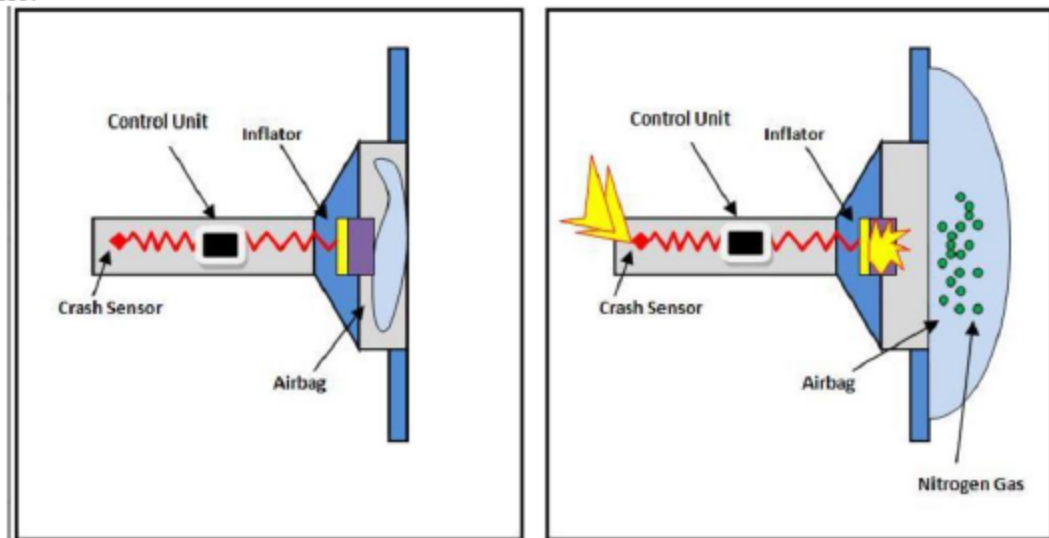
- **Impact Sensors**

  Impact sensors, also known as crash sensors, are devices that detect sudden deceleration or changes in vehicle speed that occur during a collision. These sensors send signals to the SRS (Supplemental Restraint System) control module when a significant impact is detected.

- **SRS (Supplemental Restraint System) Control Module**

  The SRS control module is the brain of the airbag system. It receives input from the impact sensors and other relevant sensors in the vehicle, such as seat occupancy sensors and seat belt sensors. Based on this information, the SRS control module determines if airbag deployment is necessary and triggers the appropriate airbags when a collision occurs.

- **Clock Spring Operation**

  The clock spring, also called the spiral cable, is a mechanism that allows electrical connections to be maintained while the steering wheel is being turned. It enables communication between the driver's airbag, horn, and other steering wheel controls. The clock spring ensures that these components continue to function properly even as the steering wheel is turned.

- **Passenger Air Bag Operation**

The passenger airbag is usually located in the dashboard on the front passenger side of the vehicle. When the SRS control module detects a significant impact and determines that airbag deployment is necessary, it triggers the passenger airbag to inflate rapidly. This helps protect the front passenger from impact with the dashboard.

- **Driver Air Bag Operation**

The driver's airbag is located in the center of the steering wheel. When the SRS control module senses a collision, it sends a signal to the driver's airbag, causing it to rapidly inflate. This provides a cushioning effect for the driver's upper body, reducing the risk of impact with the steering wheel.

- **Curtain Air Bag Operation**

Curtain airbags, also known as side airbags or side-curtain airbags, are typically mounted in the roof rails above the windows. They deploy in the event of a side-impact collision or a rollover, providing protection to the occupants' heads and reducing the risk of injury from side-impact forces.

- **Seat Belt Pretensioners**

Seat belt pretensioners are devices integrated into the seat belt system. They activate during a collision and rapidly retract the seat belt, removing any slack from the belt. This action helps secure the occupants firmly in their seats before the airbags deploy, maximizing the effectiveness of the airbag protection.

- **Seat Belt Operation**

Seat belts are the primary safety restraint system in a vehicle. When worn correctly, they secure the occupants to their seats, preventing them from being thrown forward in a collision. Seat belts work in conjunction with airbags and other safety features to provide comprehensive protection during an accident.

*****Thank You*****