

MODULE-1**EVOLUTION OF AUTOMOTIVE ELECTRONICS**

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

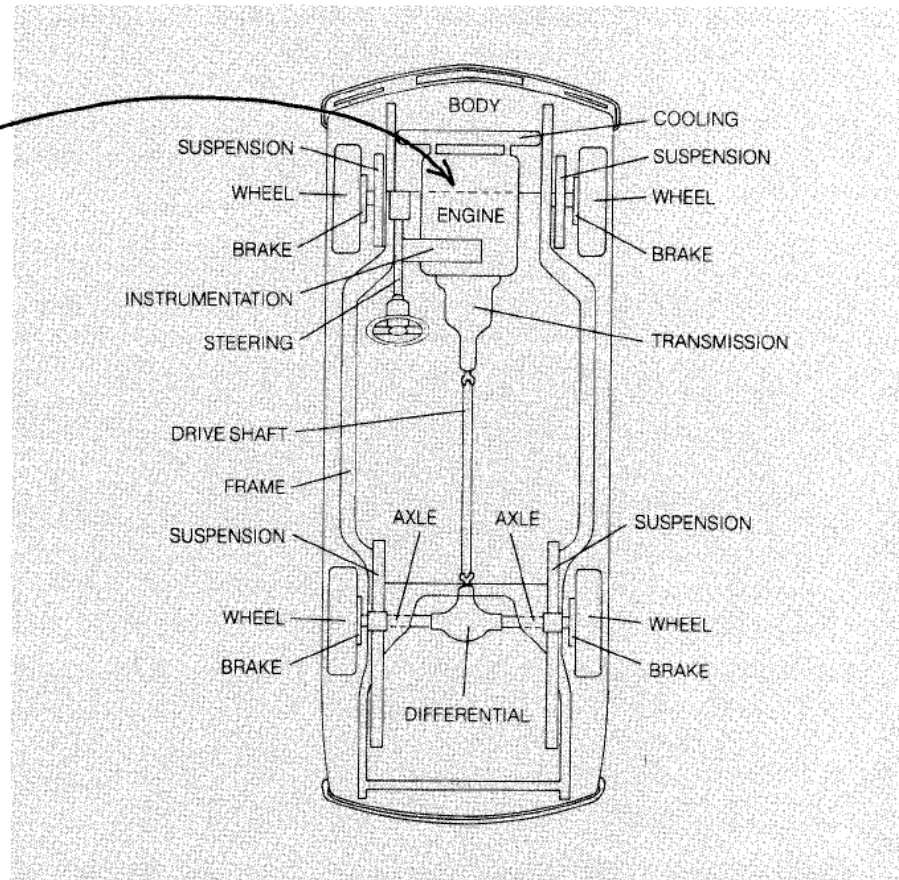
The earliest automobiles consisted of carriages (similar to those drawn by horses) to which a primitive engine and drive train and steering controls were added. Typically, such cars had a strong steel frame that supported the body of the car. The wheels were attached to this frame by a set of springs 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. This early configuration is depicted in Figure 1.1, in which many of the important automotive systems are illustrated. These systems include the following:

1. Engine
2. Drive train (transmission, differential, axle)
3. Suspension
4. Steering
5. Brakes
6. Instrumentation
7. Electrical/electronic
8. Motion control
9. Safety
10. Comfort/convenience
11. Entertainment/communication/navigation

Figure 1.1
Systems of the Automobile

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

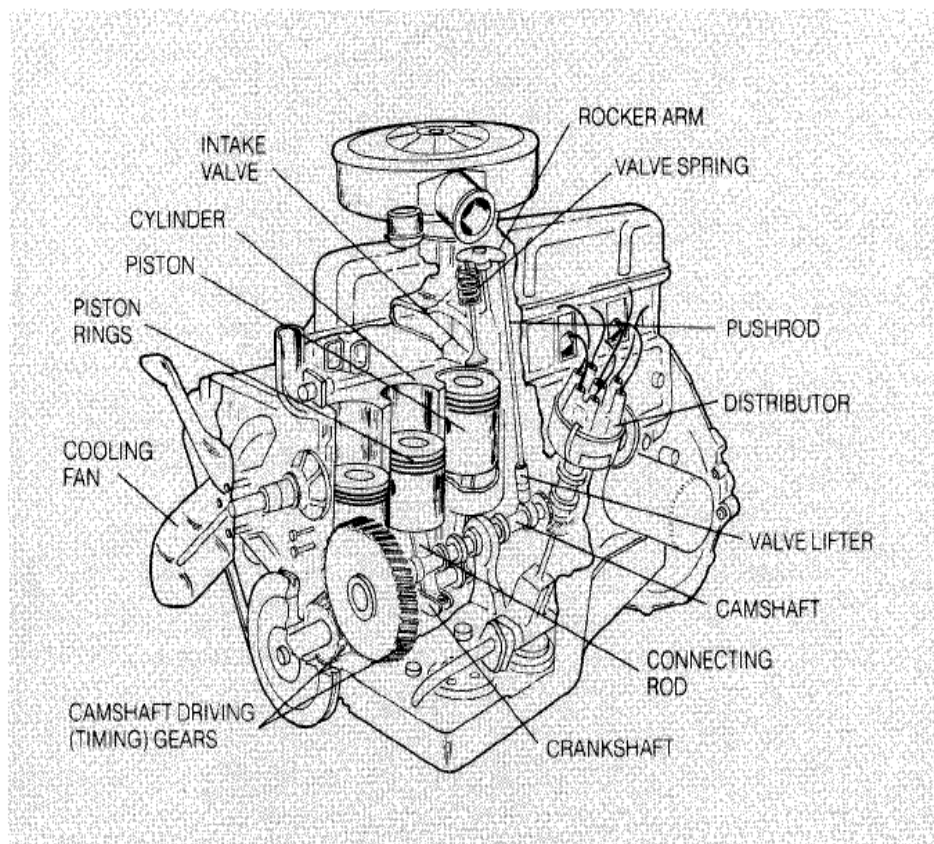


THE ENGINE

The engine in an automobile provides all the power for moving the automobile, for the hydraulic and pneumatic systems, and for the electrical system. A variety of engine types have been produced, but one class of engine is used most: the internal combustion, piston-type, 4-stroke/cycle, gasoline-fueled, spark-ignited, liquid-cooled engine. Although rapid technological advances in the control of the SI engine have been achieved through the use of electronics, the fundamental mechanical configuration has remained unchanged since this type of power plant was first

invented. In addition, the introduction of modern materials has greatly improved the packaging, size, and power output per unit weight or per unit volume. In order that the reader may fully appreciate the performance improvements that have been achieved through electronic controls.

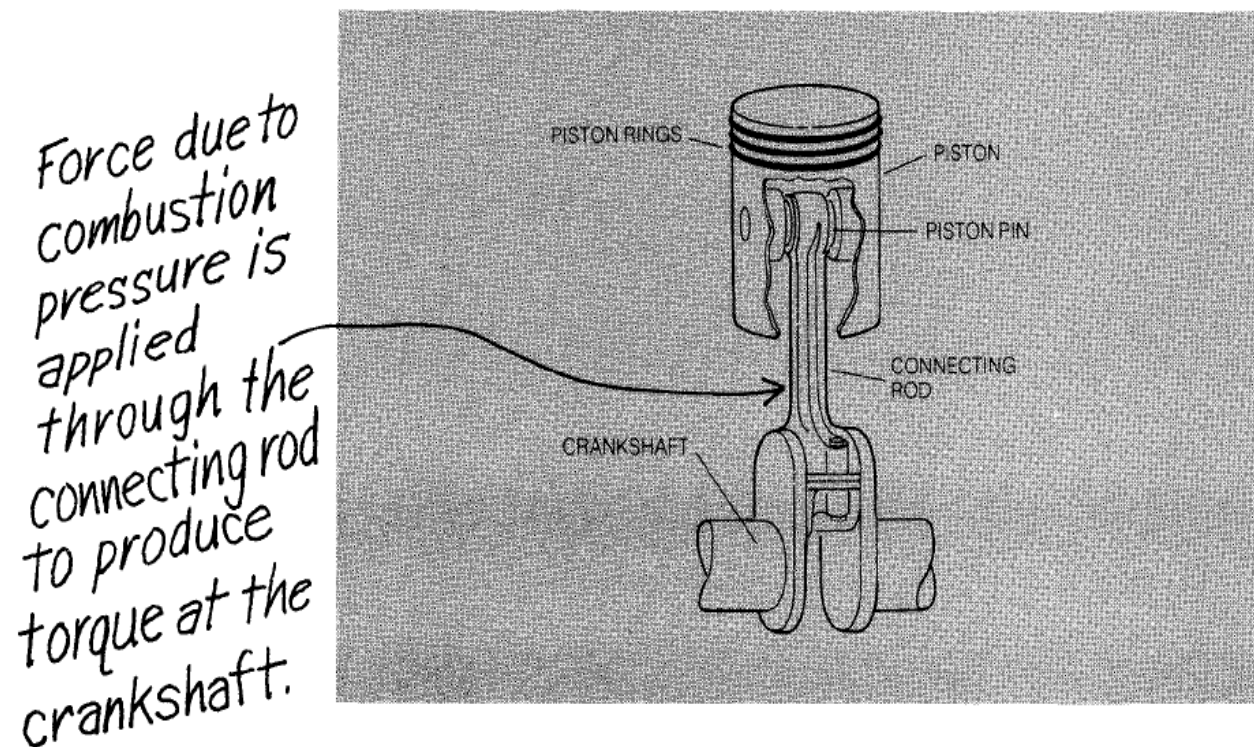
Figure 1.2
Cutaway View of a 6-
Cylinder, Overhead-
Valve, Inline Engine
(Source: Crouse)



ENGINE BLOCK

Mechanical rotary power is produced in an engine through the combustion of gasoline inside cylinders in the engine block and a mechanism consisting of pistons (in the cylinders) and a linkage (connecting rod) coupled to the crankshaft. Mechanical power is available at the crankshaft. The cylinders are cast in the engine block and machined to a smooth finish. The pistons fit tightly into the cylinder and have rings that provide a tight sliding seal against the cylinder wall. The pistons are connected to the crankshaft by connecting rods, as shown in Figure 1.3. The crankshaft converts the up and down motion of the pistons to the rotary motion and the torque needed to drive the wheels.

Figure 1.3
Piston Connection to Crankshaft (Source: Crouse)



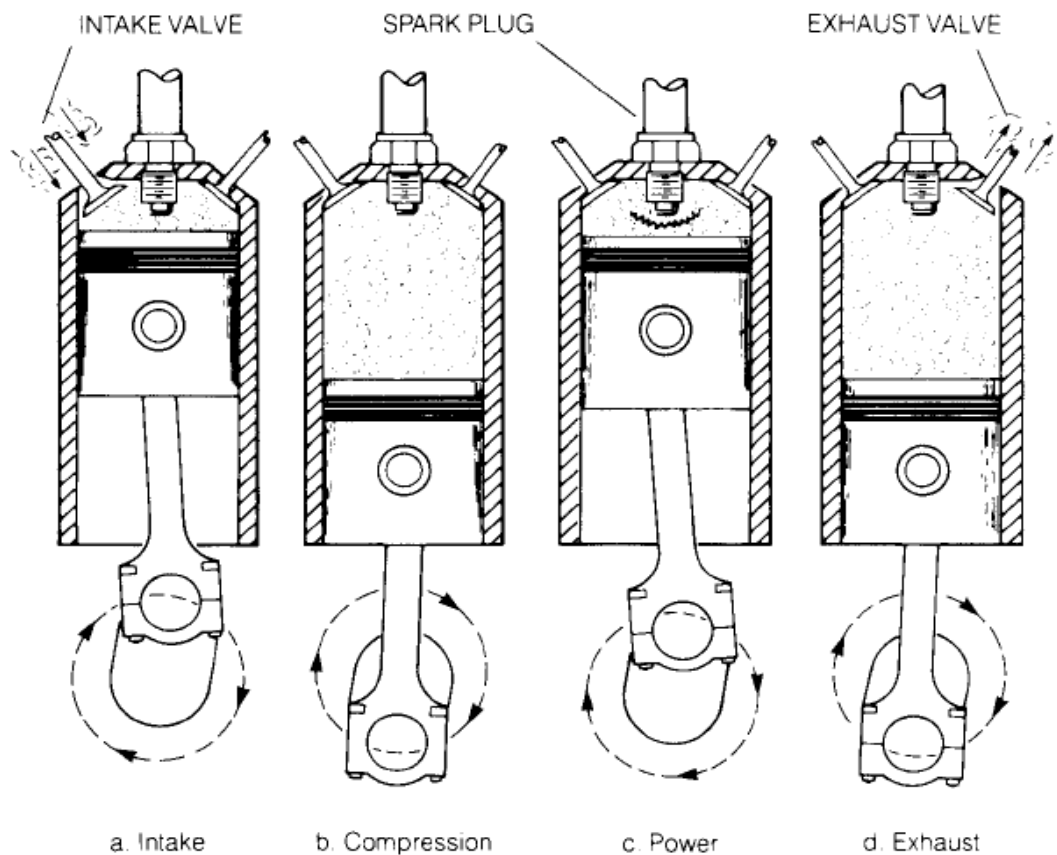
The 4-Stroke Cycle

The operation of the engine can be understood by considering the actions in any one cylinder during a complete cycle of the engine. One complete cycle in the 4-stroke/cycle SI engine requires two complete rotations of the crankshaft. As the crankshaft rotates, the piston moves up and down in the cylinder. In the two complete revolutions of the crankshaft that make up one cycle, there are four separate strokes of the piston from the top of the cylinder to the bottom or from the bottom to the top. Figure 1.5 illustrates the four strokes for a 4-stroke/cycle SI engine, which are called:

1. Intake
2. Compression
3. Power
4. Exhaust

There are two valves for each cylinder. The left valve in the drawing is called the *intake valve* and the right valve is called the *exhaust valve*. The intake valve is normally larger than the exhaust

valve. Note that the crankshaft is assumed to be rotating in a clockwise direction. The action of the engine during the four strokes is described in the following sections.



Intake

During the intake stroke (Figure 1.5a), the piston is moving from top to bottom and the intake valve is open. As the piston moves down, a partial vacuum is created, which draws a mixture of air and vaporized gasoline through the intake valve into the cylinder. It will be shown in Chapters 5, 6, and 7 that, in modern, electronically controlled engines, fuel is injected into the intake port and is timed to coincide with the intake stroke. The intake valve is closed after the piston reaches the bottom. This position is normally called bottom dead center (BDC).

Compression

During the compression stroke (Figure 1.5b), both valves are closed, and the piston moves upward and compresses the fuel and air mixture against the cylinder head. When the piston is near the top of this stroke, the ignition system produces an electrical spark at the tip of the spark plug. (The top

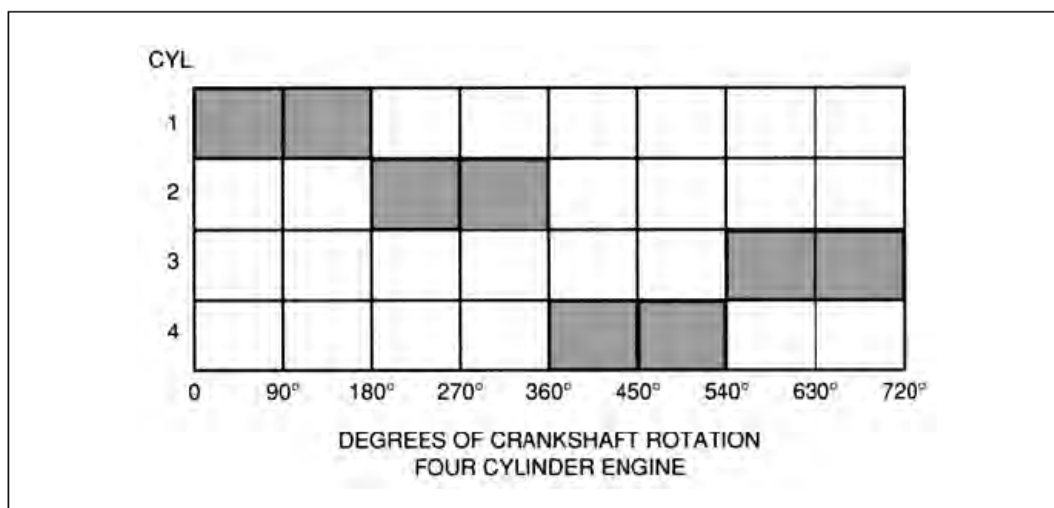
of the stroke is normally called top dead center—TDC.) The spark ignites the air–fuel mixture and the mixture burn quickly, causing a rapid rise in the pressure in the cylinder.

Power

During the power stroke (Figure 1.5c), the high pressure created by the burning mixture forces the piston downward. The cylinder pressure creates the force on the piston that results in the torque on the crankshaft as described above. It is only during this stroke that actual usable power is generated by the engine.

Exhaust

During the exhaust stroke (Figure 1.5d), the piston is again moving upward. The exhaust valve is open and the piston forces the burned gases from the cylinder through the exhaust port into the exhaust system and out the tailpipe into the atmosphere. This 4-stroke cycle is repeated continuously as the crankshaft rotates. In a single-cylinder engine, power is produced only during the power stroke, which is only one-quarter of the cycle. Modern automotive engines have multiple cylinders, each of which contributes power during its associated power stroke. In a multi cylinder engine, the power strokes are staggered so that power is produced during a larger fraction of the cycle than for a single-cylinder engine. In a 4-cylinder engine, for example, power is produced almost continually by the separate power strokes of the four cylinders. The shaded regions of Figure 1.6 indicate which cylinder is producing power for each 180 degrees of crankshaft rotation.



(Remember that one complete engine cycle requires two complete crankshaft rotations of 360 degrees each, for a total of 720 degrees.)

ENGINE CONTROL

Control of the engine in any car means regulating the power that it produces at any time in accordance with driving needs. The driver controls engine power via the accelerator pedal, which, in turn, determines the setting of the throttle plate via a mechanical linkage system. The throttle plate is situated in the air intake system and is, in effect, a rotary valve that impedes the air flowing past it (Figure 1.7). The intake system is an assembly of pipes or passageways through which the air flows from outside into each cylinder. The air flowing into the engine flows past the throttle plate, which, in fact, controls the amount of air being drawn into the engine during each intake stroke. As we will show in later chapters, the power produced by the engine is proportional to the mass flow rate of air into the engine. The driver then controls engine power directly by controlling this air mass flow rate with the throttle plate. As the accelerator pedal is depressed, the throttle plate rotates, permitting air to flow at an increased rate. Of course, the power produced by the engine depends on fuel being present in the correct proportions. Fuel is delivered to each cylinder at a rate that is proportional to air flow. The fuel flow rate is determined by fuel injectors (one for each cylinder), which are operated by an electronic engine control system as explained in Chapters 5 and 7. There it is shown that fuel flow rate is regulated so as to minimize exhaust gas pollutant concentration. It should be noted that before the advent of electronic engine controls fuel flow was regulated by a device known as a carburetor (as depicted in Figure 1.7).

Figure 1.6
Power Pulses from a
4-Cylinder Engine

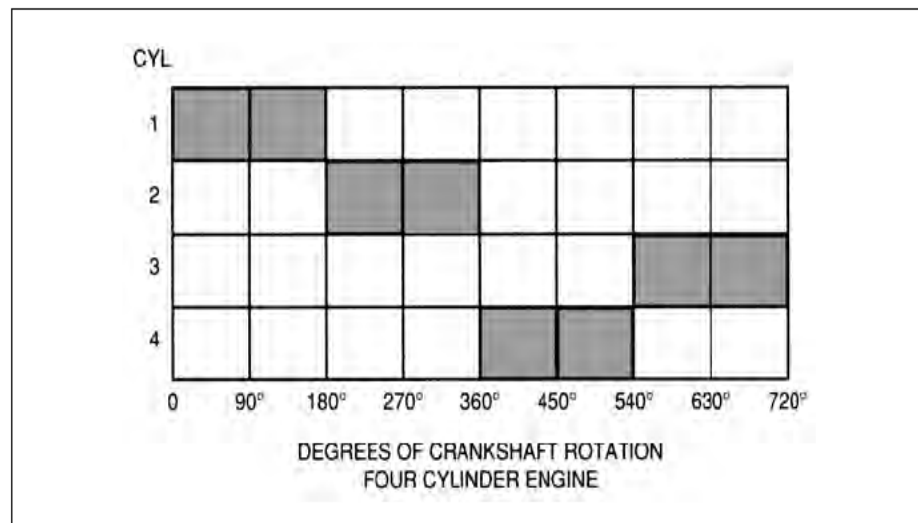
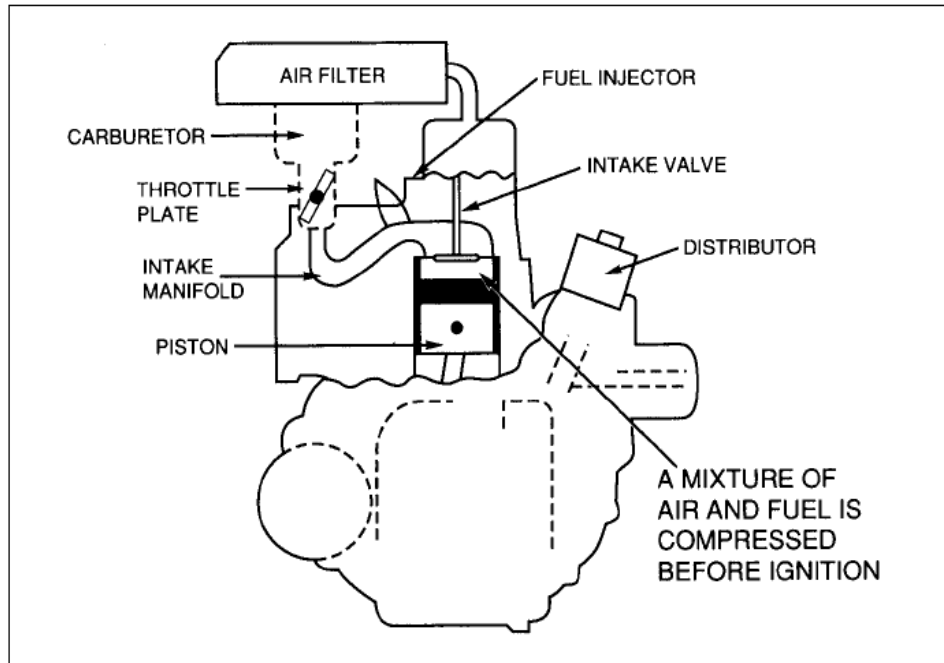


Figure 1.7
Intake Manifold and
Fuel Metering



IGNITION SYSTEM

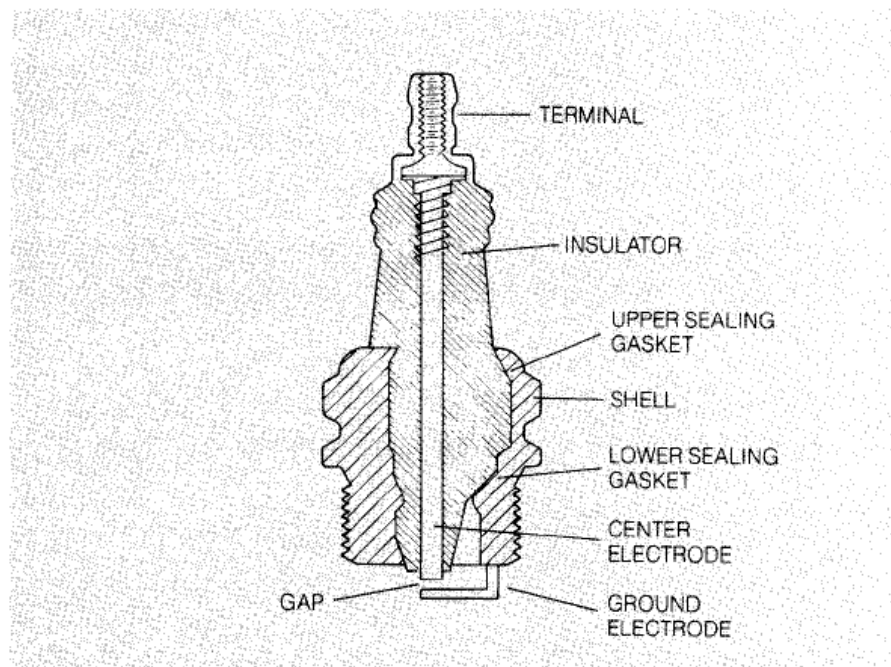
To produce power, the gasoline engine must not only have a correct mixture of fuel and air, but also some means of initiating combustion of the mixture. Essentially the only practical means is with an electric spark produced across the gap between a pair of electrodes of a spark plug. The electric arc or spark provides sufficient energy to cause combustion. This phenomenon is called ignition. Once a stable combustion has been initiated, there is no further need for the spark during any engine cycle. Typically, the spark must persist for a period of about a millisecond (one thousandth of a second). This relatively short period makes spark ignition possible using highly efficient pulse transformer circuits in which a circuit having a relatively low average current can deliver a very high-voltage (high peak power) pulse to the spark plug. The ignition system itself consists of several components: the spark plug, one or more pulse transformers (typically called coils), timing control circuitry, and distribution apparatus that supplies the high-voltage pulse to the correct cylinder.

Spark Plug

The spark is produced by applying a high-voltage pulse of from 20kV to 40kV (1 kV is 1,000 volts) between the center electrode and ground. The actual voltage required to start the arc varies with the size of the gap, the compression ratio, and the air-fuel ratio. Once the arc is started, the

voltage required to sustain it is much lower because the gas mixture near the gap becomes highly ionized. (An ionized gas allows current to flow more freely.) The arc is sustained long enough to ignite the air–fuel mixture. A typical spark plug configuration is shown in Figure 1.8. The spark plug consists of a pair of electrodes, called the center and ground electrodes, separated by a gap. The gap size is important and is specified for each engine. The gap may be 0.025 inch (0.6 mm) for one engine and 0.040 inch (1mm) for another engine. The center electrode is insulated from the ground electrode and the metallic shell assembly. The ground electrode is at electrical ground potential because one terminal of the battery that supplies the current to generate the high-voltage pulse for the ignition system is connected to the engine block and frame.

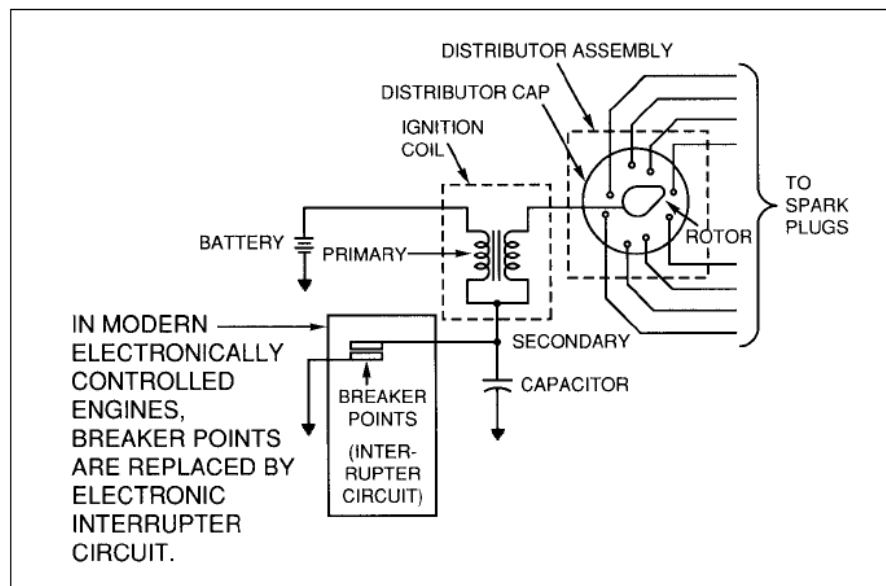
Figure 1.8
Spark Plug
Configuration



High-Voltage Circuit and Distribution

The ignition system provides the high-voltage pulse that initiates the arc. Figure 1.9 is a schematic of the electrical circuit for the ignition system as it existed before electronic control systems. The high-voltage pulse is generated by inductive discharge of a special high-voltage transformer commonly called an ignition coil. The high-voltage pulse is delivered to the appropriate spark plug at the correct time for ignition by a distribution circuit. In a modern engine, the breaker points have been replaced with an electronic control.

Figure 1.9
Schematic of the
Ignition Circuit

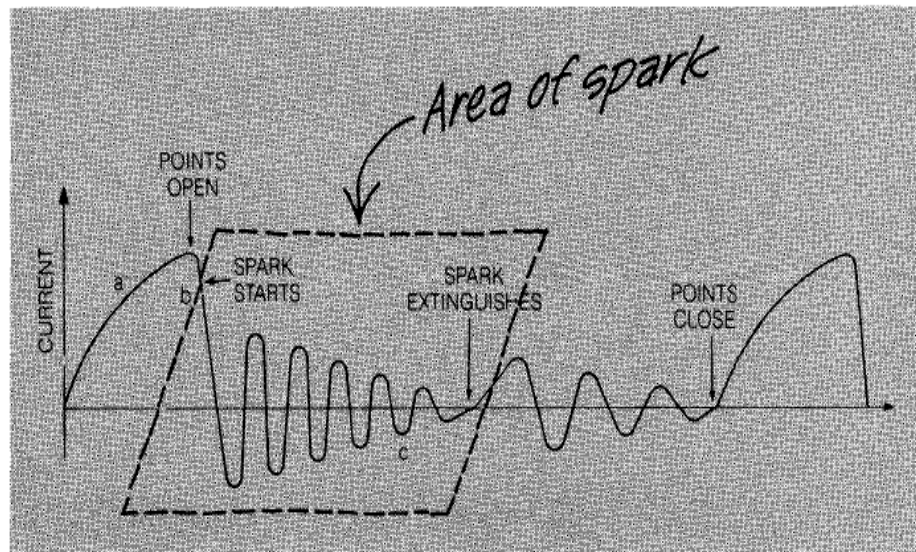


Spark Pulse Generation

The actual generation of the high-voltage pulse is accomplished by switching the current through the primary circuit (see Figure 1.9). The mechanism in the distributor of a traditional ignition system for switching the primary circuit of the coil consists of opening and closing the breaker points (of a switch) by a rotary-cam in the distributor (explained later). During the intervals between ignition pulses (i.e., when the rotor is between contacts), the breaker points are closed (known as dwell). Current flows through the primary of the coil, and a magnetic field is created that links the primary and secondary of the coil. At the instant the spark pulse is required, the breaker points are opened. This interrupts the flow of current in the primary of the coil and the magnetic field collapses rapidly. The rapid collapse of the magnetic field induces the high-voltage pulse in the secondary of the coil. This pulse is routed through the distributor rotor, the terminal in the distributor cap, and the spark plug wire to the appropriate spark plug. The capacitor absorbs the primary current, which continues to flow during the short interval in which the points are opening, and limits arcing at the breaker points. The waveform of the primary current is illustrated in Figure 1.11. The primary current increases with time after the points close (point a on waveform). At the instant the points open, this current begins to fall rapidly. It is during this rapid drop in primary current that the secondary high-voltage pulse occurs (point b). The primary current

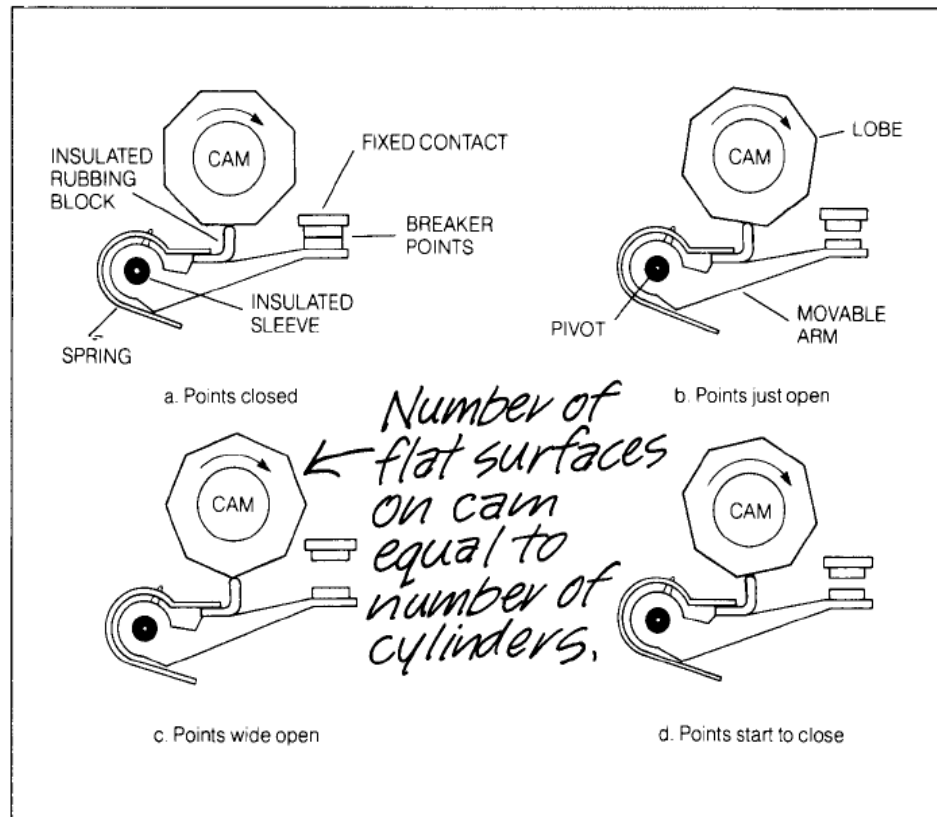
oscillates (the “wavy” portion; point c) because of the resonant circuit formed between the coil and capacitor.

Figure 1.11
Primary Current
Waveform



The mechanism for opening and closing the breaker points of a conventional distributor is illustrated in Figure 1.12. A cam having a number of lobes equal to the number of cylinders is mounted on the distributor shaft. As this cam rotates, it alternately opens and closes the breaker points. The movable arm of the breaker points has an insulated rubbing block that is pressed against the cam by a spring. When the rubbing block is aligned with a flat surface on the cam, the points are closed (i.e., dwell period), as shown in Figure 1.12a. As the cam rotates, the rubbing block is moved by the lobe (high point) on the cam as shown in Figure 1.12b. At this time, the breaker points open (corresponding to point b of Figure 1.11) and spark occurs. The rotary switch that connects the coil to the appropriate spark plug wire is connected to the same shaft as the cam, thereby synchronizing the actions of spark creation with the switching of the high-voltage pulse to each spark plug. The distributor shaft is coupled to the camshaft and rotates at the same speed and is positioned relative to the camshaft so that the spark occurs at the correct time during each engine cycle to produce optimum combustion. This relative position of distributor and camshaft is known as “ignition timing.”

Figure 1.12
Breaker Point
Operation



ALTERNATIVE ENGINES

The vast majority of automobile engines in North America are SI engines. Alternative engines such as the diesel have simply not been able to compete effectively with the SI engine in the United States. Diesel engines are used mostly in heavy-duty vehicles such as large trucks, ships, railroad locomotives, and earth-moving machinery. However, there is some use of these engines in light-duty trucks and some passenger cars.

Diesel Engine

Physically, the diesel engine is nearly identical to the gasoline engine and can be either 4 stroke or 2 stroke/cycle. It consists of cylinders cast into a block with pistons, connecting rods, crank shaft, camshaft, and valves (4-stroke engine). Torque and power are produced during the 4 strokes as in the case of the 4-stroke gasoline engine. The diesel engine fuel is supplied via a fuel injection system that injects fuel either directly into the cylinder (direct injection system) or into the intake port during the intake stroke (indirect injection system). Diesel engines are subject to exhaust

emission regulations similar to those applied to gasoline engines. Emissions are influenced by the timing of fuel injection relative to the compression and power strokes.

Another alternative to the SI engine has been the Wankel, or rotary, engine. As in the case of the diesel engine, the number of Wankel engines has been very small compared to the SI engine. One limitation to its application has been somewhat poorer exhaust emissions relative to the SI engine. Still another potential competitor to current automotive engines is the 2-stroke/cycle engine. This engine, which is similar in many respects to the traditional engine, is a gasoline-fueled, spark-ignited, reciprocating engine. It has achieved widespread use in lawnmowers, small motorcycles, and some outboard marine engines. It had (at one time) even achieved limited automotive use, though it suffered from poor exhaust emissions. Just as in the case of the 4-stroke/cycle engine, electronic controls have significantly improved 2-stroke/cycle engine performance relative to mechanical controls. At the present time, it does not appear likely that the 2-stroke/cycle engine will have sufficient passenger car application in the foreseeable future to justify its discussion in this book. An alternative to the internal combustion engine as an automotive power plant is electric propulsion in which the mechanical power required to move the car comes from an electric motor. Electric propulsion of automobiles is not new. Electric motors were used to propel cars in the early part of the twentieth century. The necessary electric energy required was supplied by storage batteries. However, the energy density (i.e., the energy per unit weight) of storage cells has been and continues to be significantly less than gasoline or diesel fuel. Consequently, the range for an electrically powered car has been much less than that for a comparably sized IC engine-powered car. On the other hand, the exhaust emissions coming from an electrically powered car are (theoretically) zero, making this type of car very attractive from a pollution standpoint. At the time of this writing, only a handful of relatively expensive electrically powered cars are in operation, and generally their performance and range are inferior to those of gasoline-fueled cars. One attractive option for electrically powered cars is a combination of a gasoline-fueled engine with an electric propulsion system. Such cars are known as hybrid cars and can be operated either as purely electric propulsion (with energy supplied by storage cells) or as a combination of an engine driving a generator to supply the electric power for the motor. A hybrid car can be operated with electric propulsion in urban areas where exhaust emissions are required to be low (or zero) and as a gasoline fueled, engine-driven car in rural areas where the range advantage of the gasoline-fueled

option is superior to the electric propulsion and where exhaust emissions are somewhat less of an issue. The efficiency of electric propulsion is improved by raising the operating voltage from the present-day 14-volt systems (i.e., using 12-volt-rated batteries). This efficiency gain is responsible in part for the evolution of car electrical systems from the present 14-volt to 42-volt systems. In the early years following the introduction of cars with 42-volt electrical systems, there will be two separate electrical buses, one at 14 volts and the other at 42 volts. The 14-volt bus will be tied to a single 12-volt (nominal) battery. The 42-volt electrical bus will be tied to three 12-volt batteries connected in series. The 14-volt bus will supply power to those components and subsystems that are found in present-day vehicles including, for example, all lighting systems and electronic control systems. The 42-volt bus will be associated with the electric drive system of the hybrid car where it can provide more efficient propulsion than would be possible with a 14-volt system.

DRIVETRAIN

The engine drive train system of the automobile consists of the engine, transmission, drive shaft, differential, and driven wheels.

Transmission

The transmission is a gear system that adjusts the ratio of engine speed to wheel speed. Essentially, the transmission enables the engine to operate within its optimal performance range regardless of the vehicle load or speed. It provides a gear ratio between the engine speed and vehicle speed such that the engine provides adequate power to drive the vehicle at any speed.

To accomplish this with a manual transmission, the driver selects the correct gear ratio from a set of possible gear ratios (usually three to five for passenger cars). An automatic transmission selects this gear ratio by means of an automatic control system. The configuration for an automatic transmission consists of a fluid coupling mechanism, known as a torque converter, and a system of planetary gear sets. The torque converter is formed from a pair of structures of a semi-toroidal shape (i.e., a donut-shaped object split along the plane of symmetry). Figure 1.14a is a schematic sketch of a torque converter showing the two semi-toroids. One of the toroids is driven by the engine by the input shaft. The other is in close proximity and is called the turbine. Both the pump and the turbine have vanes that are essentially in axial planes. In addition, a series of vanes are fixed to the frame and are called the reactor. The entire structure is mounted in a fluid, tight

chamber and is filled with a hydraulic fluid (i.e., transmission fluid). As the pump is rotated by the engine, the hydraulic fluid circulates as depicted by the arrows in Figure 1.14a. The fluid impinges on the turbine blades, imparting a torque to it. The torque converter exists to transmit engine torque and power to the turbine from the engine. However, the properties of the torque converter are such that when the vehicle is stopped corresponding to a nonmoving turbine, the engine can continue to rotate (as it does when the vehicle is stopped with the engine running). The planetary gear system consists of a set of three types of gears connected together as depicted in Figure 1.14b. The inner gear is known as the sun gear. There are three gears meshed with the sun gear at equal angles, which are known as planetary gears. These three gears are tied together with a cage that supports their axles. The third gear, known as a ring gear, is a section of a cylinder with the gear teeth on the inside. The ring gear meshes with the three planetary gears. In operation, one or more of these gear systems are held fixed to the transmission housing via a set of hydraulically actuated clutches. The action of the planetary gear system is determined by which set or sets of clutches are activated. For example, if the ring gear is held fixed and input power (torque) is applied to the sun gear, the planetary gears rotate in the same direction as the sun gear but at a reduced rate and at an increased torque. If the planetary gear cage is fixed, then the sun gear drives the ring gear in the opposite direction as is done when the transmission is in reverse. If all three sets of gears are held fixed to each other rather than the transmission housing, then direct drive (gear ratio = 1) is achieved. A typical automatic transmission has a cascade connection of a number of planetary gear systems, each with its own set of hydraulically actuated clutches. In an electronically controlled automatic transmission, the clutches are electrically or electro hydraulically actuated. Most automatic transmissions have three forward gear ratios, although a few have two and some have four.

Figure 1.14a
Schematic Cross
Section of a Torque
Converter

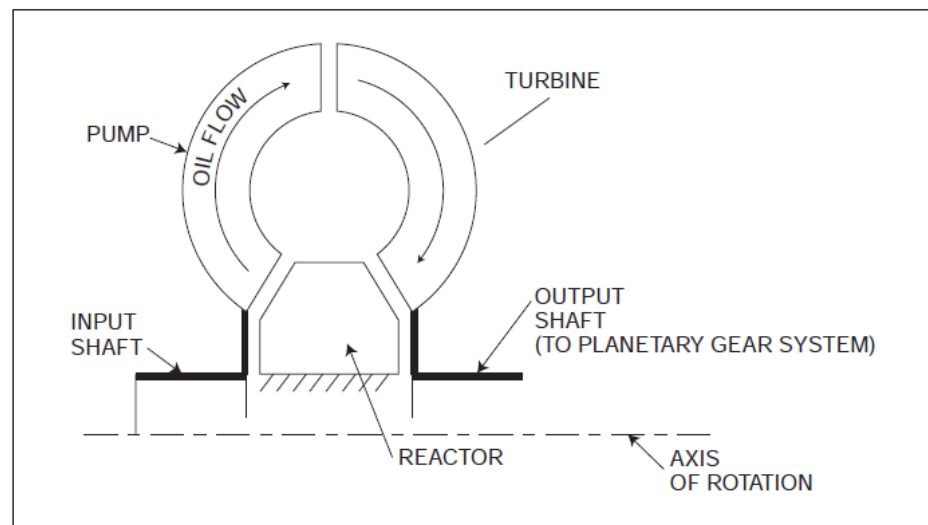


Figure 1.14b
Planetary Gear
System

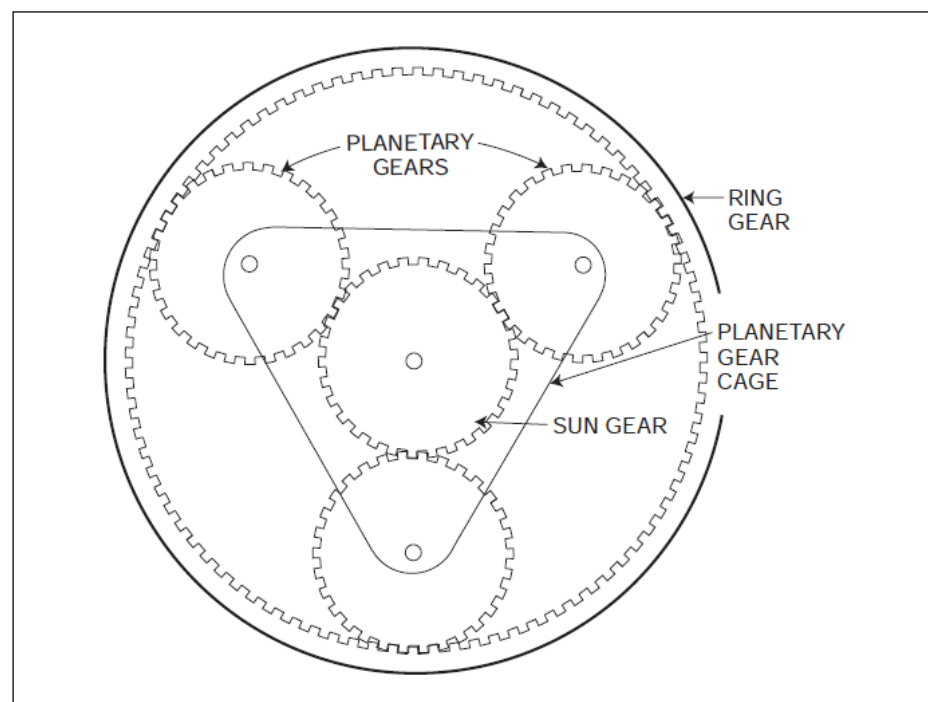
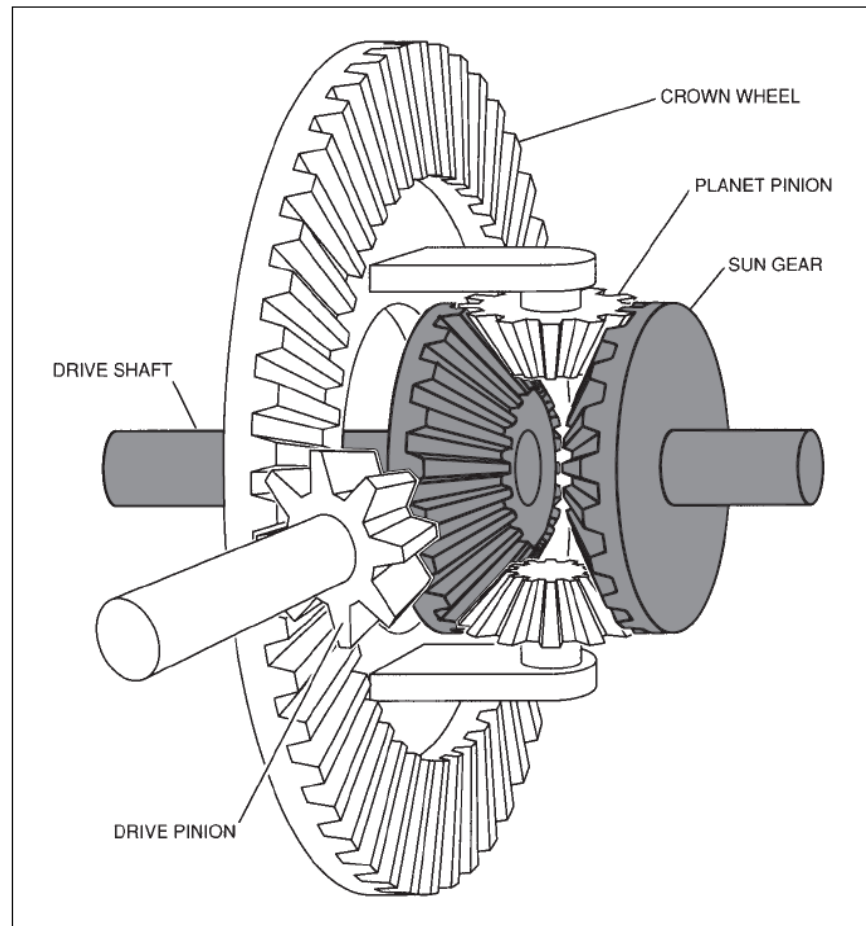


Figure 1.14c
Schematic of a
Differential



Drive Shaft

The drive shaft is used on front-engine, rear wheel drive vehicles to couple the transmission output shaft to the differential input shaft. Flexible couplings, called universal joints, allow the rear axle housing and wheels to move up and down while the transmission remains stationary. In front wheel drive automobiles, a pair of drive shafts couples the transmission to the drive wheels through flexible joints known as constant velocity (CV) joints.

Differential

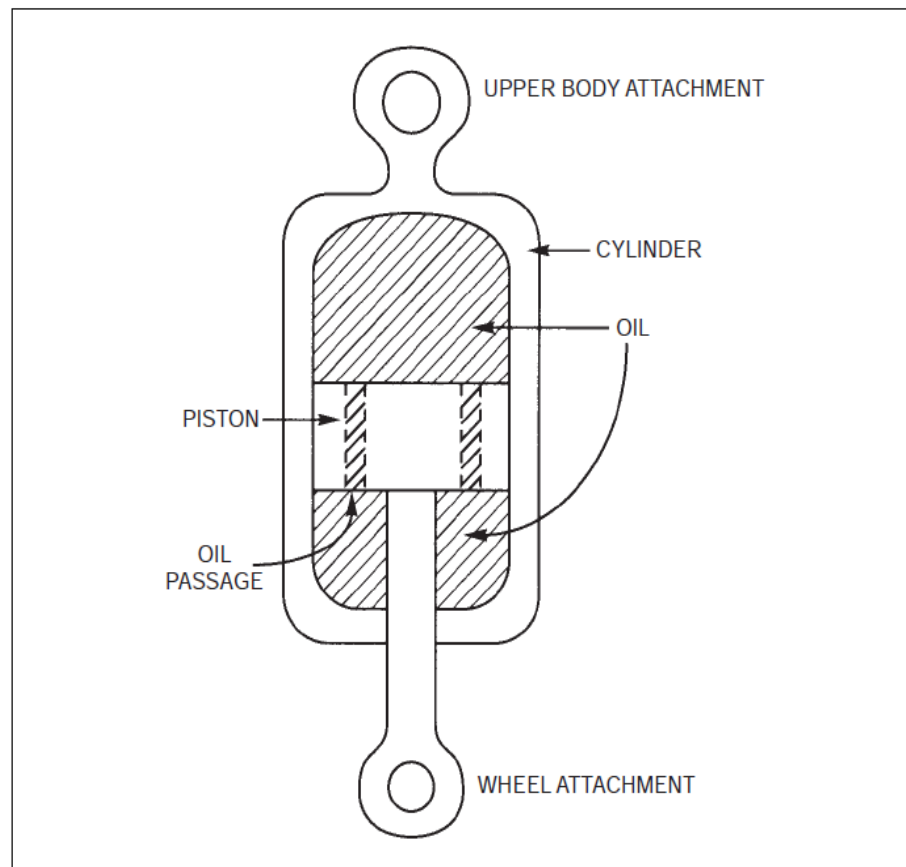
The differential serves three purposes (see Figure 1.14c). The most obvious is the right-angle transfer of the rotary motion of the drive shaft to the wheels. The second purpose is to allow each driven wheel to turn at a different speed. This is necessary because the “outside” wheel must turn faster than the “inside” wheel when the vehicle is turning a corner. The third purpose is the torque

increase provided by the gear ratio. This gear ratio can be changed in a repair shop to allow different torque to be delivered to the wheels while using the same engine and transmission. The gear ratio also affects fuel economy. In front wheel drive cars, the transmission differential and drive shafts are known collectively as the transaxle assembly.

SUSPENSION

Another major automotive subsystem is the suspension system, which is the mechanical assembly that connects each wheel to the car body. The primary purpose of the suspension system is to isolate the car body from the vertical motion of the wheels as they travel over the rough road surface. The suspension system can be understood with reference to Figure 1.15, which illustrates the major components.

Figure 1.16
Shock Absorber
Assembly



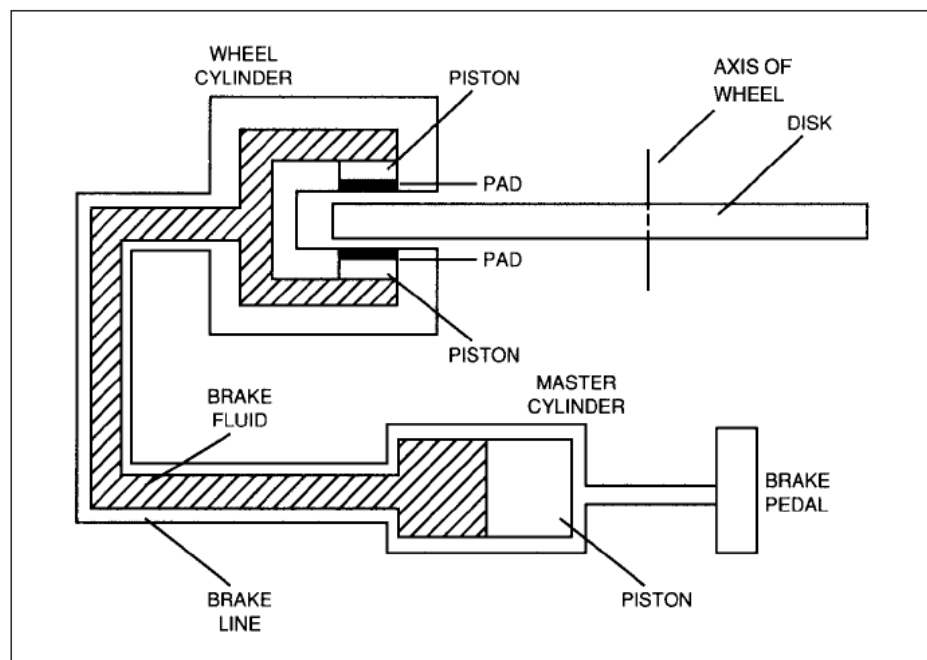
Notice that the wheel assembly is connected through a movable assembly to the body. The weight of the car is supported by springs. In addition, there is a so-called shock absorber (sometimes a

strut), which is in effect a viscous damping device. There is a similar assembly at each wheel, although normally there are differences in the detailed configuration between front and rear wheels. The mass of the car body is called the sprung mass, that is, the mass that is supported by springs. The mass of the wheel assemblies at the other end of the springs is called unsprung mass. All springs have the property that the deflection of the spring is proportional to the applied axial force. The proportionality constant is known as the spring rate. The springs are selected for each car such that the car body height is as desired for the unloaded car. Typically, the weight on the front wheels is greater than on the rear wheels, therefore, the front springs normally have a higher spring rate than the rear.

BRAKES

Brakes are as basic to the automobile as the engine drive train system and are responsible for slowing and stopping the vehicle. Most of the kinetic energy of the car is dissipated by the brakes during deceleration and stopping (with the other contributions coming from aerodynamic drag and tire rolling resistance). There are two major types of automotive brakes: drum and disk brakes. Drum brakes are an extension of the types of brakes used on early cars and horse drawn wagons. Increasingly, automobile manufacturers are using disk brakes. Consequently, it is this type that we discuss here. Disk brakes are illustrated in Figure 1.17.

Figure 1.17
Disk Brake System



A flat disk is attached to each wheel and rotates with it as the car moves. A wheel cylinder assembly (often called a caliper) is connected to the axle assembly. A pair of pistons having brake pad material are mounted in the caliper assembly and are close to the disk. Under normal driving conditions, the pads are not in contact with the hydraulic pressure is applied through the brake fluid to force the brake pads against the disk. The braking force that decelerates the car results from friction between the disk and the pads. Electronic control of braking benefits safety by improving stopping performance in poor or marginal braking conditions. Chapter 8 explains the operation of the so-called antilock braking system (ABS).

STEERING SYSTEM

A steering system is one of the major automotive subsystems required for operation of the car (see Figure 1.18). It provides the driver control of the path of the car over the ground. Steering functions by rotating the plane of the front wheels in the desired direction of the turn. The angle between the front wheel plane and the longitudinal axis of the car is known as the steering angle. This angle is proportional to the rotation angle of the steering wheel. Traditionally, automotive steering systems have consisted solely of mechanical means for rotating the wheels about a nominally vertical axis in response to rotation of the steering wheel. The inclination of this axis gives rise to a restoring torque that tends to return the wheels to planes that are parallel to the vehicle's longitudinal axis so that the car will tend to travel straight ahead. This restoring torque provides a steering stability for the car. When steering the car, the driver must provide sufficient torque to overcome the restoring torque. Because the restoring torque is proportional to the vehicle weight for any given steering angle, considerable driver effort is required for large cars, particularly at low speeds and when parking. In order to overcome this effort in relatively large cars, a power steering system is added. This system consists of an engine-driven hydraulic pump, a hydraulic actuator, and control valve. Whenever the steering wheel is turned, a proportioning valve opens, allowing hydraulic pressure to activate the actuator. The high-pressure hydraulic fluid pushes on one side of the piston. The piston, in turn, is connected to the steering linkage and provides mechanical torque to assist the driver in turning. This hydraulic force is often called steering boost. The desired boost varies with vehicle speed, as depicted in Figure 1.19.

Figure 1.18
One Type of Steering
Mechanism

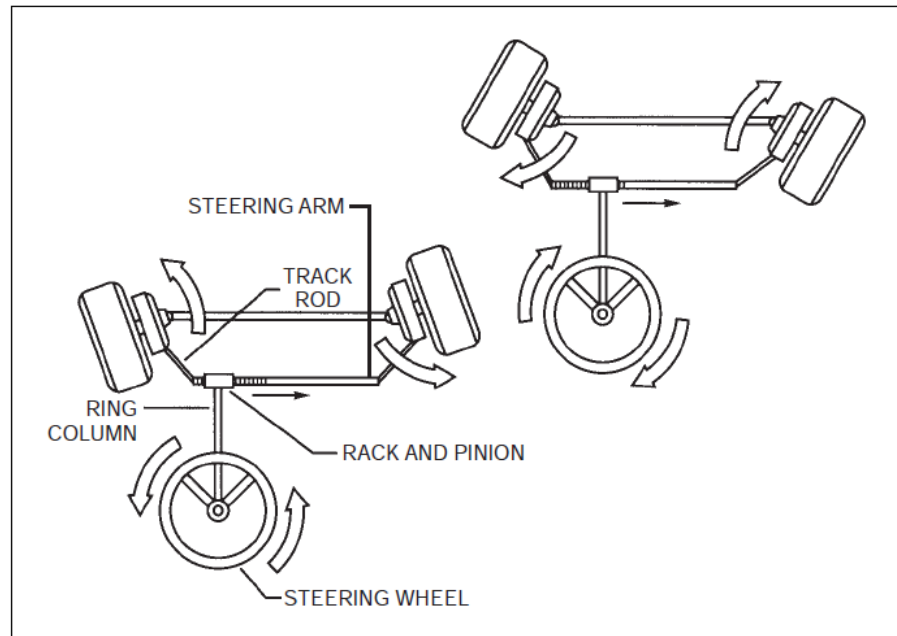
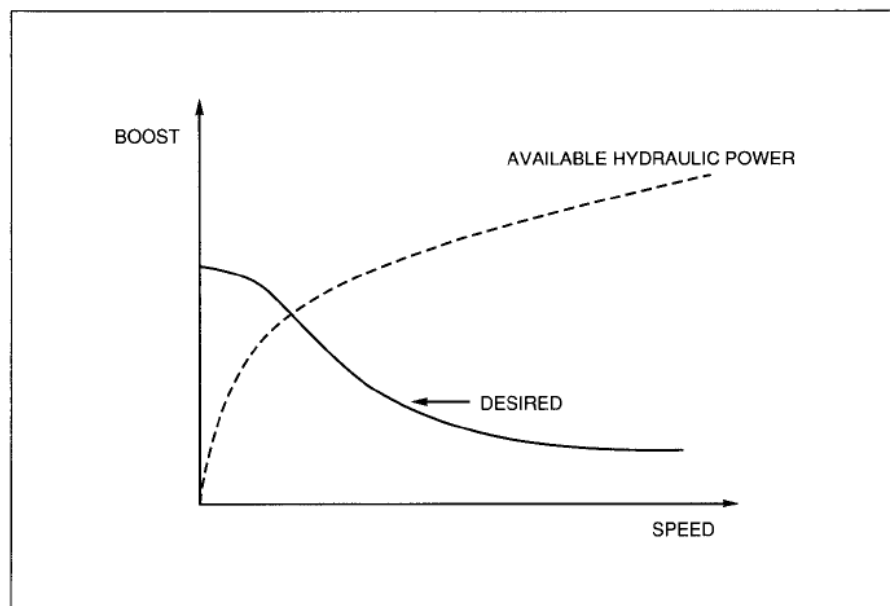


Figure 1.19
Desired Boost Versus
Speed



The Basics of Electronic Engine Control

Engine control in the vast majority of engines means regulating fuel and air intake as well as spark timing to achieve desired performance in the form of torque or power output. Until the late 1960s, control of the engine output torque and RPM was accomplished through some combination of

mechanical, pneumatic, or hydraulic systems. Then, in the 1970s, electronic control systems were introduced.

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 (CO₂) and water (H₂O), 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 CO₂ and H₂O, 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. Automotive exhaust emission control requirements started in the United States in 1966 when the California state regulations became effective. Since then, the federal government has imposed emission control limits for all states, and the standards became progressively tighter throughout the remainder of the twentieth century and will continue to tighten in the twenty-first century. Auto manufacturers found that the traditional engine controls could not control the engine sufficiently to meet these emission limits and maintain adequate engine performance at the same time, so they turned to electronic controls.

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. The government fuel economy standards are not based on just one car, but are stated in terms of the average rated miles per gallon fuel mileage for the production of all models by a manufacturer for any year. This latter requirement is known in the automotive industry by the acronym CAFÉ (corporate average fuel economy). It is a somewhat complex requirement and is based on measurements of the fuel used during a prescribed simulated standard driving cycle.

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 that will be encountered in this chapter.

Inputs to Controllers

Figure 5.6 identifies the major physical quantities that are sensed and provided to the electronic controller as inputs. They are as follows:

1. Throttle position sensor (TPS)
2. Mass air flow rate (MAF)
3. Engine temperature (coolant temperature) (CT)
4. Engine speed (RPM) and angular position
5. Exhaust gas recirculation (EGR) valve position
6. Exhaust gas oxygen (EGO) concentration

Outputs from Controllers

Figure 5.7 identifies the major physical quantities that are outputs from the controller. These outputs are

1. Fuel metering control
2. Ignition control
3. Ignition timing
4. Exhaust gas recirculation control

Figure 5.6
Major Controller
Inputs from Engine

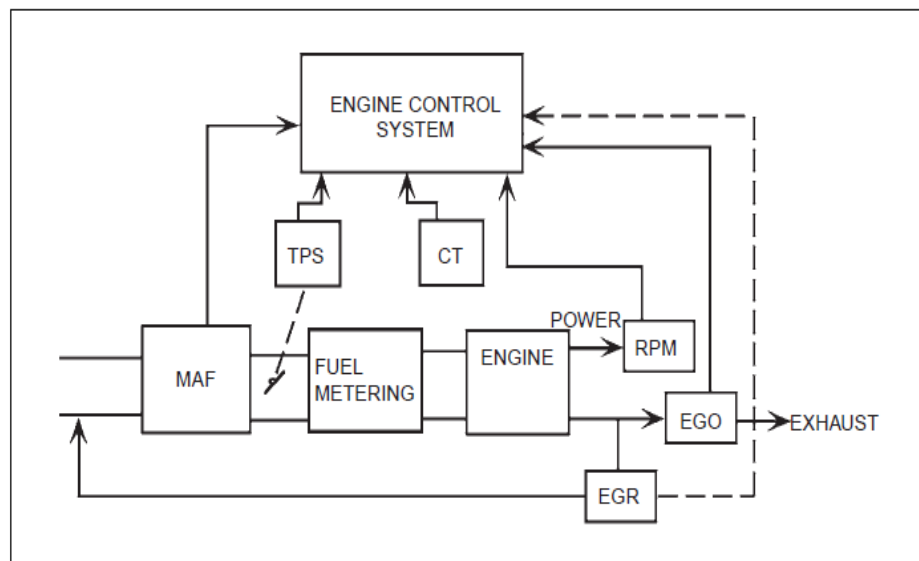
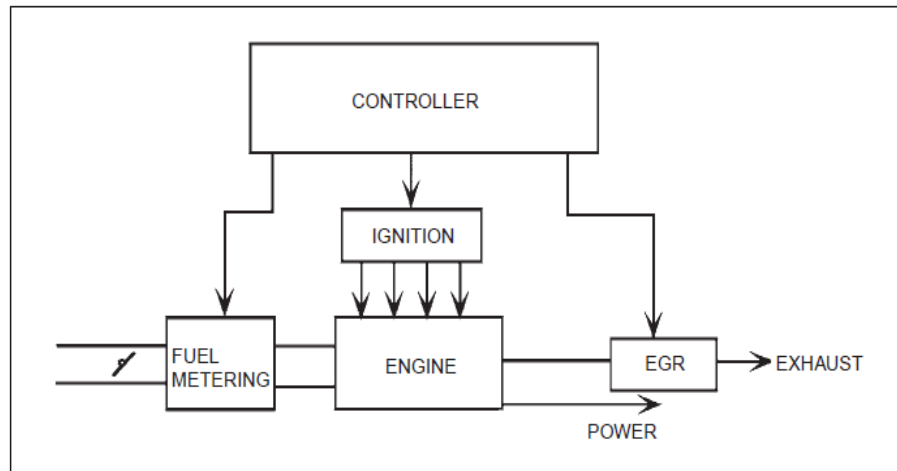


Figure 5.7
Major Controller
Outputs to Engine



DEFINITION OF ENGINE PERFORMANCE TERMS

Several common terms are used to describe an engine's performance. Here are a few.

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. Power may be measured at the drive wheels or at the engine output shaft. It is more convenient and useful to the designer of an electronic engine control system to know the output power of only the engine than the power delivered to the wheels. This permits realistic comparisons of engine data as engine controls are varied. To make such measurements, an engine dynamometer is used. This dynamometer is similar to the one in Figure 5.1 except that the engine output shaft drives the dynamometer directly instead of coupling the output through wheels and rollers. The power delivered by the engine to the dynamometer is called the brake power and is designated P_b . The brake power of an engine is always less than the total amount of power that is actually developed in the engine. This developed power is called the indicated power of the engine and is denoted P_i . The indicated power differs from the brake power by the loss of power in the engine due to friction between cylinders and pistons, and other friction losses. That is,

$$P_b = P_i - \text{friction and other losses}$$

BSFC

Fuel economy can be measured while the engine delivers power to the dynamometer. 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. By improving the BSFC of the engine, the fuel economy of the vehicle in which it is installed is also improved. Electronic controls help to improve BSFC.

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

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

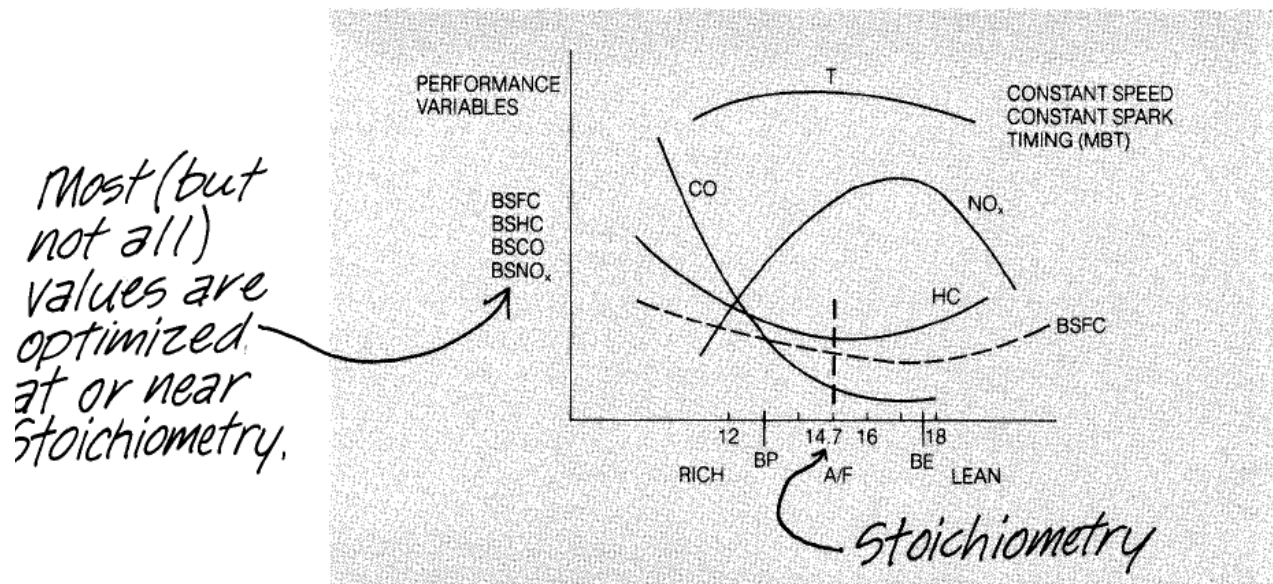
The development of any control system comes from knowledge of the plant, or system to be controlled. In the case of the automobile engine, this knowledge of the plant (the engine) comes primarily from a process called engine mapping. For engine mapping, the engine is connected to a dynamometer and operated 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. The control system designer must select a control configuration, control variables, and control strategy that will satisfy all performance requirements (including stability) as computed from this model and that are within the other design limits such as cost, quality, and reliability. To understand a typical engine control system, it is instructive to consider the influence of control variables 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.

Figure 5.8

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



This is a standard way to characterize exhaust gases whose absolute emission levels are

BSHC = brake-specific HC concentration

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

BSCO = brake-specific CO concentration

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

BSNO_x = brake-specific NO_x concentration

$$= \frac{r_{\text{NO}_x}}{P_b}$$

where

r_{HC} = HC rate of flow

r_{CO} = CO rate of flow

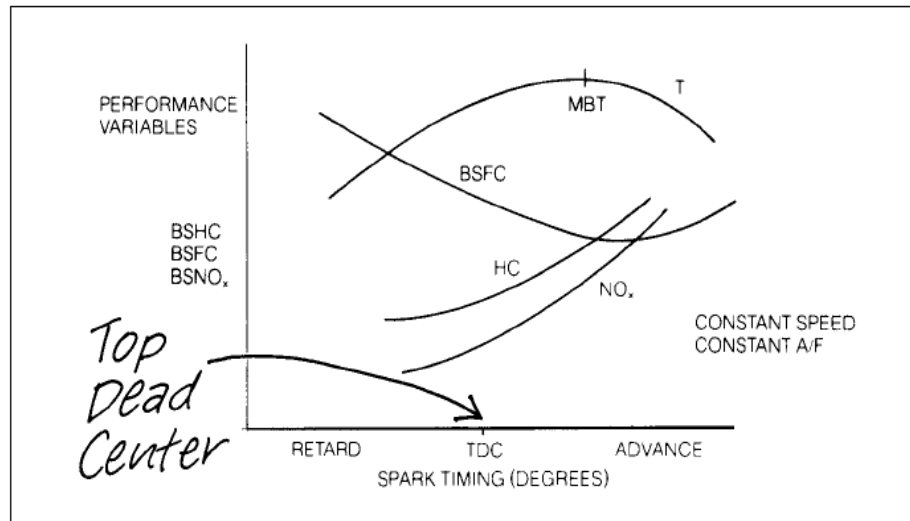
r_{NO_x} = NO_x rate of flow

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

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

Figure 5.9
Typical Variation of
Performance with
Spark Timing



Effect of Exhaust Gas Recirculation on Performance

Up to this point in the discussion, 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. 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 5.10
NO_x Emission as a
Function of EGR at
Various Air/Fuel
Ratios

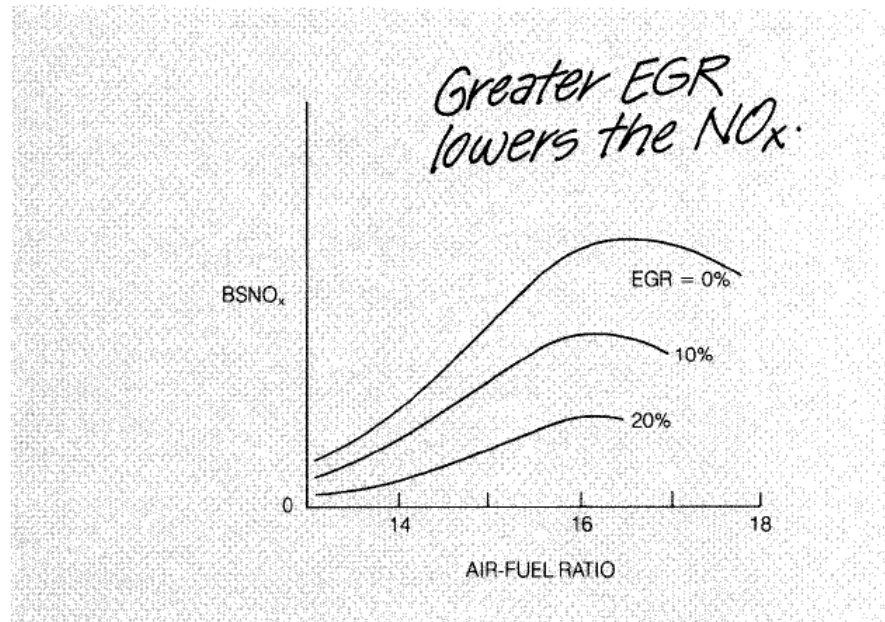
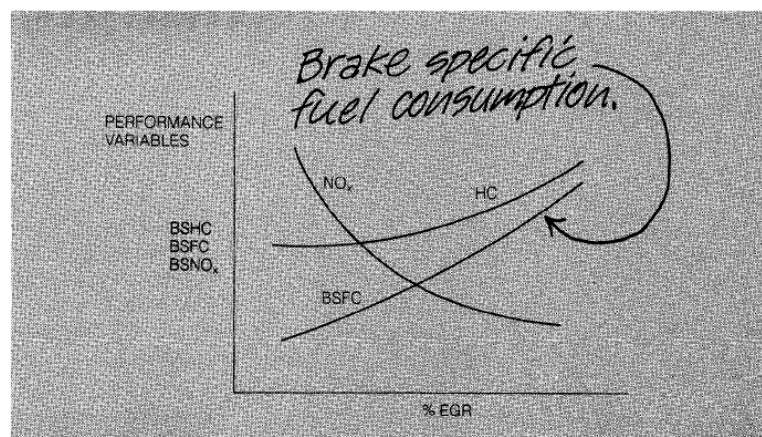


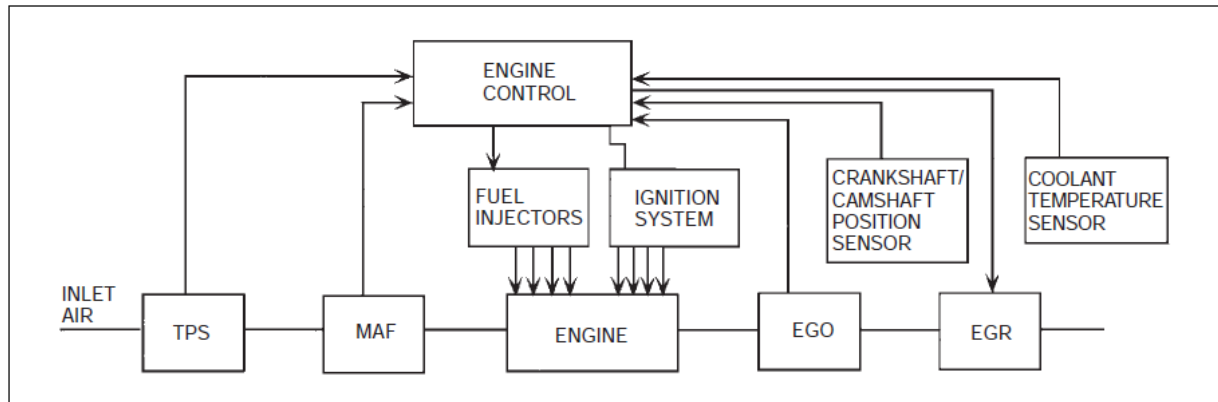
Figure 5.11
Typical Variation of
Engine Performance
with EGR



MODULE -2**Automotive Sensors & actuators****AUTOMOTIVE CONTROL SYSTEM APPLICATIONS OF SENSORS AND ACTUATORS**

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. 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. However, because of the large potential production run for automotive control systems, it is often worthwhile to develop a sensor for a particular application, even though it may take a long and expensive research project to do so. Although there are many subsystems on automobiles that operate with sensors and actuators, we begin our discussion with a survey of the devices for power train control. To motivate the discussion of engine control sensors and actuators it is helpful to review the variables measured (sensors) and the controlled variables (actuators). Figure 6.1 is a representative block diagram of a typical electronic engine control system illustrating most of the relevant sensors used for engine control. The position of the throttle plate, sensed by the throttle position sensor (TPS), directly regulates the air flow into the engine, thereby controlling output power. A set of fuel injectors (one for each cylinder) delivers the correct amount of fuel to a corresponding cylinder during the intake stroke under control of the electronic engine controller. A fuel injector is, as will presently be shown, one of the important actuators used in automotive electronic application. The ignition control system fires each spark plug at the appropriate time under control of the electronic engine controller. The exhaust gas recirculation (EGR) is controlled by yet another output from the engine controller. All critical engine control functions are based on measurements made by various sensors connected to the engine in an appropriate way.

Figure 6.1
Typical Electronic Engine Control System



AIR FLOW RATE SENSOR

The majority of cars produced since the early 1990s use a relatively simple and inexpensive mass air flow rate (MAF) sensor. This is normally mounted as part of the air cleaner assembly, where it measures air flow into the intake manifold. It is a ruggedly packaged, single-unit sensor that includes solid-state electronic signal processing. In operation, the MAF sensor generates a continuous signal that varies nearly linearly with true mass air flow R_m . The MAF sensor is a variation of a classic air flow sensor that was known as a hot wire anemometer and was used, for example, to measure wind velocity for weather forecasting. In the MAF, the hot-wire, or sensing, element is replaced by a hot-film structure mounted on a substrate. On the air inlet side is mounted a honeycomb flow straightener that “smooths” the air flow (causing nominally laminar air flow over the film element). At the lower portion of the structure is the signal processing circuitry. The film element is electrically heated to a constant temperature above that of the inlet air. The latter air temperature is sensed using a solid-state temperature sensor (explained later in this chapter). The hot-film element is incorporated in a Wheatstone bridge circuit (Figure 6.2a). The power supply for the bridge circuit comes from an amplifier. The Wheatstone bridge consists of three fixed resistors R_1 , R_2 , and R_3 and a hot-film element having resistance R_{HW} . With no air flow the resistors R_1 , R_2 , and R_3 are chosen such that voltage v_a and v_b are equal (i.e., the bridge is said to be balanced). As air flows across the hot film, heat is carried away from the film by the moving air. The amount of heat carried away varies in proportion to the mass flow rate of the air. The heat lost by the film to the air tends to cause the resistance of the film to vary, which unbalances the bridge circuit, thereby producing an input voltage to the amplifier. The output of

the amplifier is connected to the bridge circuit and provides the power for this circuit. The amplified voltage changes the resistance in such a way as to maintain a fixed hot-film temperature relative to the inlet temperature. The amplifier output voltage V_c varies with MAF and serves as a measure of R_m . Typically the conversion of MAF to voltage is slightly nonlinear, as indicated by the calibration curve depicted in Figure 6.2b. Fortunately, a modern digital engine controller can convert the analog bridge output voltage directly to mass air flow by simple computation.

$$B = f t$$

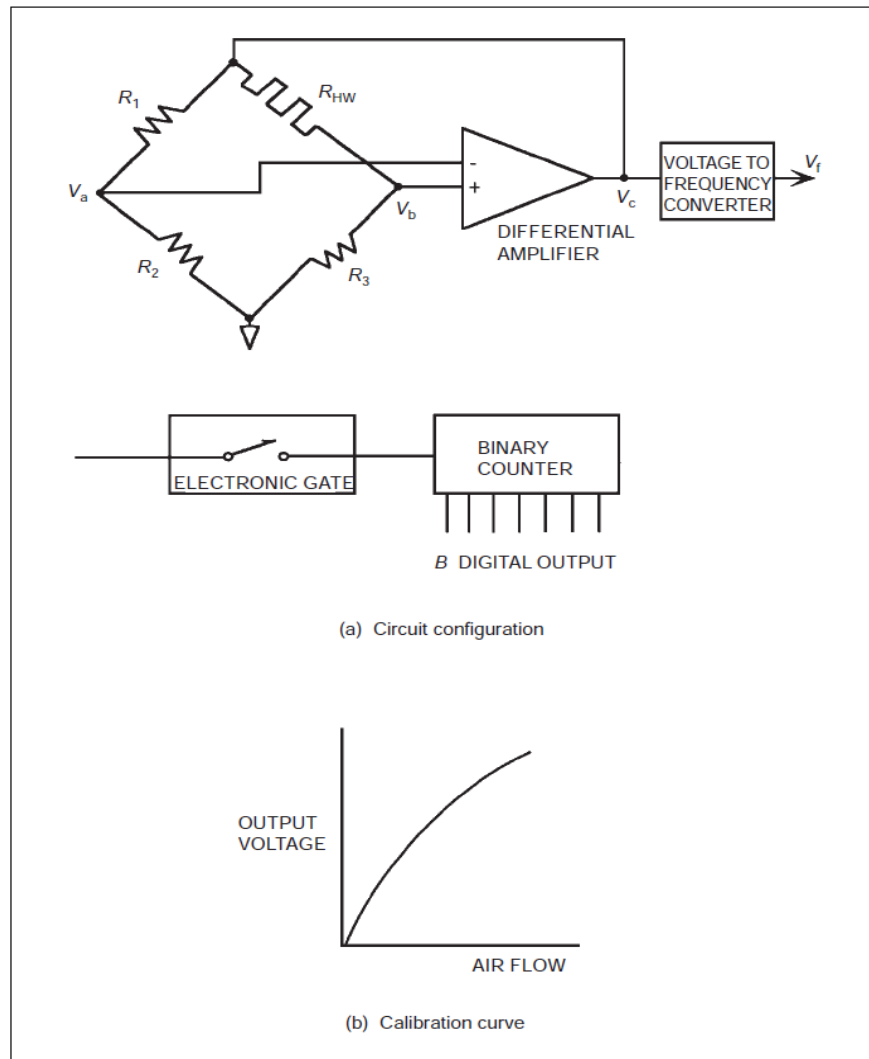
where

B = BC count

f = frequency of v/f

t = duration of closure of electronic gate

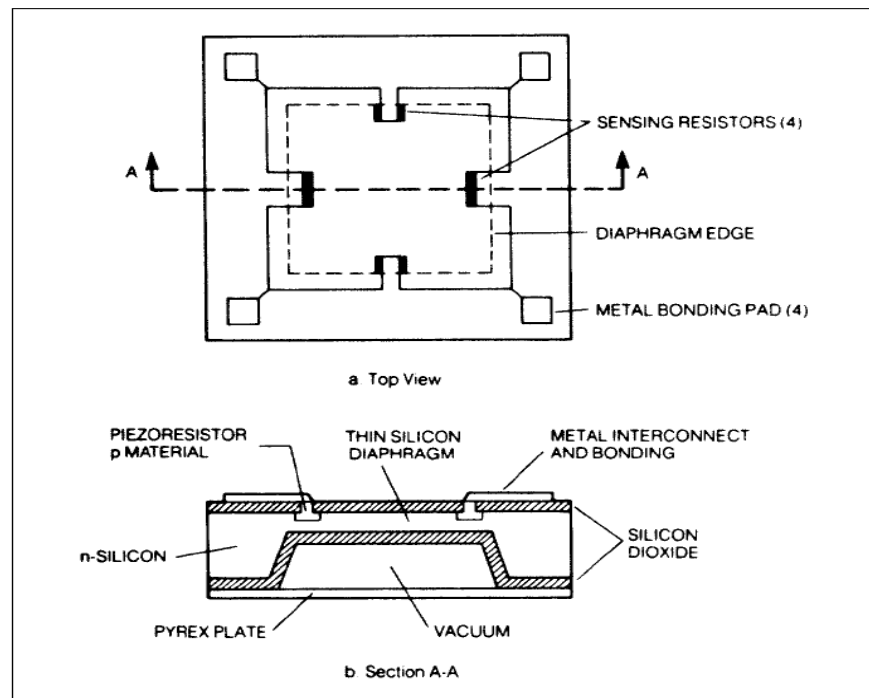
Figure 6.2
Mass Air Flow Sensor



Strain Gauge MAP Sensor

One relatively inexpensive MAP sensor configuration is the silicon diaphragm diffused strain gauge sensor shown in Figure 6.3. This sensor uses a silicon chip that is approximately 3 millimeters square. Along the outer edges, the chip is approximately 250 micrometers (1 micrometer = 1 millionth of a meter) thick, but the center area is only 25 micrometers thick and forms a diaphragm. The edge of the chip is sealed to a Pyrex plate under vacuum, thereby forming a vacuum chamber between the plate and the center area of the silicon chip. A set of sensing resistors is formed around the edge of this chamber, as indicated in Figure 6.3. The resistors are formed by diffusing a doping impurity into the silicon. External connections to these resistors are made through wires connected to the metal bonding pads. This entire assembly is placed in a sealed housing that is connected to the intake manifold by a small diameter tube. Manifold pressure applied to the diaphragm causes it to deflect. The resistance of the sensing resistors changes in proportion to the applied manifold pressure by a phenomenon that is known as piezo-resistivity. Piezo-resistivity occurs in certain semiconductors so that the actual resistivity (a property of the material) changes in proportion to the strain (fractional change in length). The strain induced in each resistor is proportional to the diaphragm deflection, which, in turn, is proportional to the pressure on the outside surface of the diaphragm. This pressure is the manifold pressure.

Figure 6.3
Typical Silicon-
Diaphragm Strain
Gauge MAP Sensor



ENGINE CRANKSHAFT ANGULAR POSITION SENSOR

Besides pressure, the position of shafts, valves, and levers must be sensed for automotive control systems. Measurements of the angular position or velocity of shafts are common in automotive electronics. It is highly desirable that these measurements be made without any mechanical contact with the rotating shaft. Such non contacting measurements can be made in a variety of ways, but the commonest of these in automotive electronics use magnetic or optical phenomena as the physical basis. Magnetic means of such measurements are generally preferred in engine applications since they are unaffected by oil, dirt, or other contaminants. The principle involved in measuring rotating shafts can be illustrated by one of the most significant applications for engine control: the measurement of crankshaft angular position or angular velocity (i.e., RPM). Imagine the engine as viewed from the rear, as shown in Figure 6.5. On the rear of the crankshaft is a large, heavy, circular steel disk called the flywheel that is connected to and rotates with the crankshaft. Let's mark a point on the flywheel, as shown in Figure 6.5, and draw a line through this point and the axis of rotation. Let's draw another line through the axis of rotation parallel to the horizontal center line of the engine as a reference line. The crankshaft angular position is the angle between the reference line and the mark on the flywheel. Imagine that the flywheel is rotated so that the mark is directly on the reference line. This is an angular position of zero degrees. For our purposes, assume that this angular position corresponds to the No. 1 cylinder at TDC (top dead center). As the crankshaft rotates, this angle increases from zero to 360° in one revolution. However, one full engine cycle from intake through exhaust requires two complete revolutions of the crankshaft. That is, one complete engine cycle corresponds to the crankshaft angular position going from zero to 720° . During each cycle, it is important to measure the crankshaft position with reference to TDC for each cylinder. This information is used by the electronic engine controller to set ignition timing and, in most cases, to set the fuel injector pulse timing.

Figure 6.4
Circuit Diagram for
MAP Sensor Using
Strain Gauges

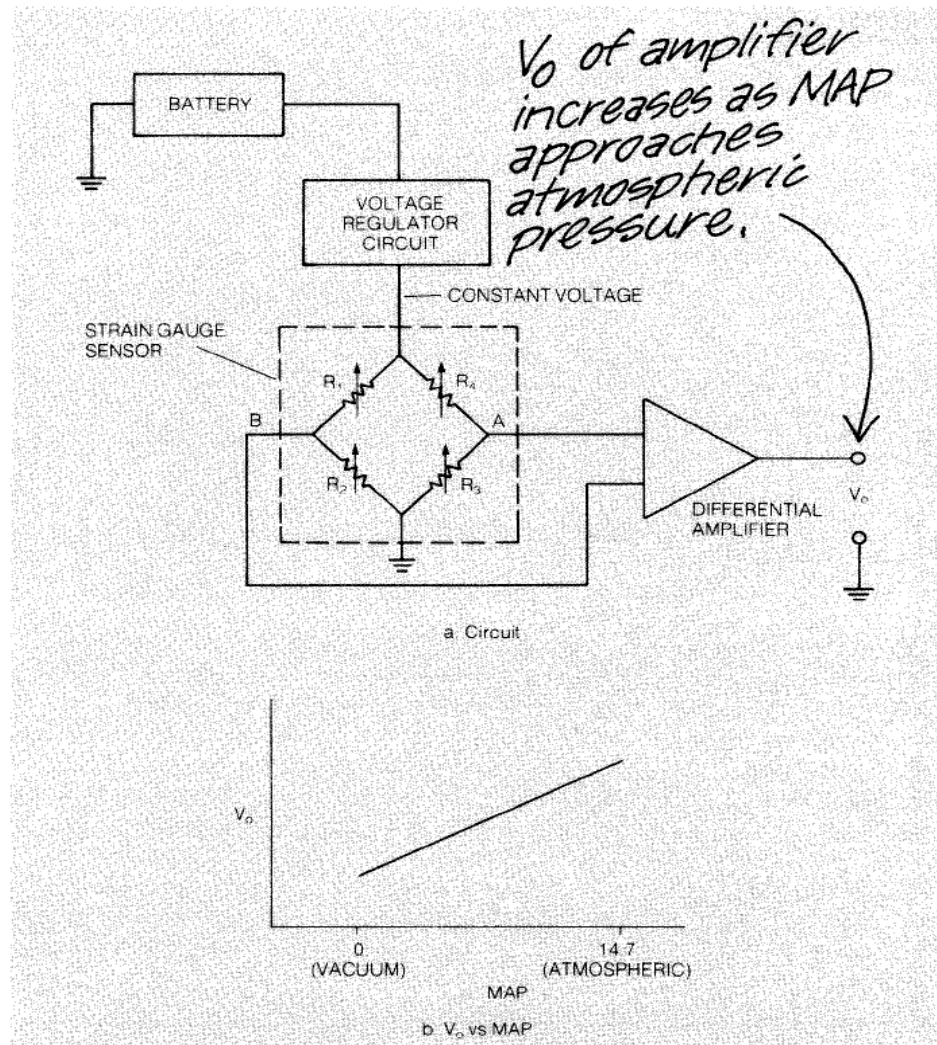
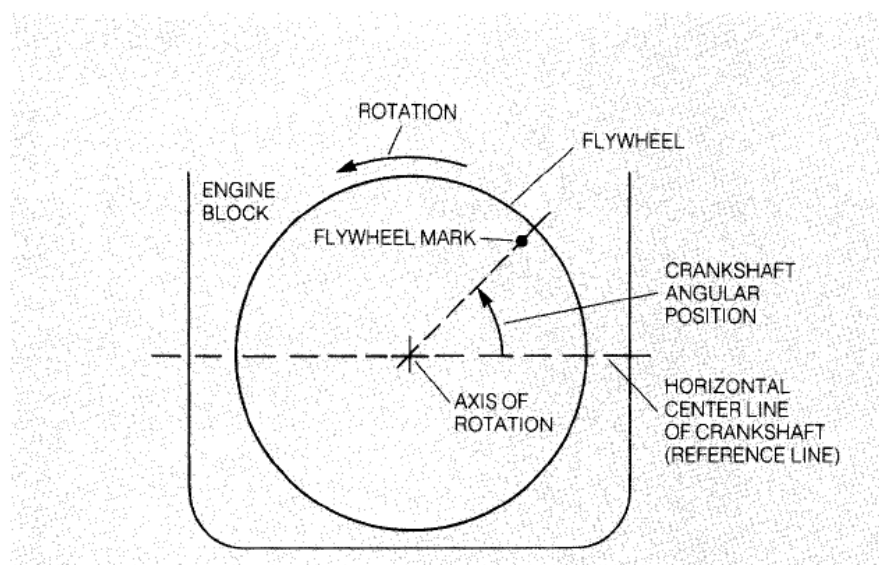


Figure 6.5
Engine Crankshaft
Angular Position
Measurement



Magnetic Reluctance Position Sensor

One engine sensor configuration that measures crankshaft position directly (using magnetic phenomena) is illustrated in Figure 6.6. 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. In Figure 6.6, the steel disk has four protruding tabs, which is appropriate for an 8-cylinder engine. The passage of each tab can correspond to the TDC position of a cylinder on its power stroke, although other reference positions are also possible. This sensor is of the magnetic reluctance type and is based on the concept of a magnetic circuit. A magnetic circuit is a closed path through a magnetic material (e.g., iron, cobalt, nickel, or synthetic magnetic material called ferrite). In the case of the sensor in Figure 6.6, the magnetic circuit is the closed path through the magnet material and across the gap between the pole pieces. The magnetic field in a magnetic circuit is described by a pair of field quantities that can be compared to the voltage and current of an ordinary electric circuit. One of these quantities is called the magnetic field intensity. It 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. A line of constant magnetic flux is a closed path through the magnetic material. The magnetic flux is similar to the current that flows when a resistor is connected across a battery to form a closed electrical circuit. As we shall see, the voltage generated by the reluctance sensor is determined by the strength of this magnetic flux. The strength of the magnetic flux is, in turn, determined by the reluctance of the magnetic circuit. Reluctance is to a magnetic circuit what resistance is to an electrical circuit. The path for the magnetic flux of the reluctance sensor is illustrated in Figure 6.7. The reluctance of a magnetic circuit is inversely proportional to the magnetic permeability of the material along the path. The magnetic permeability of steel is a few thousand times larger than air; therefore, the reluctance of steel is much lower than air. Note that when one of the tabs of the steel disk is located between the pole pieces of the magnet, a large part of the gap between the pole pieces is filled by the steel. Since the steel has a lower reluctance than air, the “flow” of magnetic flux increases to a relatively large value. On the other hand, when a tab is not between the magnet pole pieces, the gap is filled by air only. This creates a high-reluctance circuit for which the magnetic flux is relatively small. Thus, the magnitude of the magnetic flux that “flows” through the magnetic circuit depends on the

position of the tab, which, in turn, depends on the crankshaft angular position. The magnetic flux is least when none of the tabs is near the magnet pole pieces. As a tab begins to pass through the gap, the magnetic flux increases. It reaches a maximum when the tab is exactly between the pole pieces, and then decreases as the tab passes out of the pole piece region. In most control systems, the position of maximum magnetic flux has a fixed relationship to TDC for one of the cylinders.

Figure 6.6
Magnetic Reluctance
Crankshaft Position
Sensor

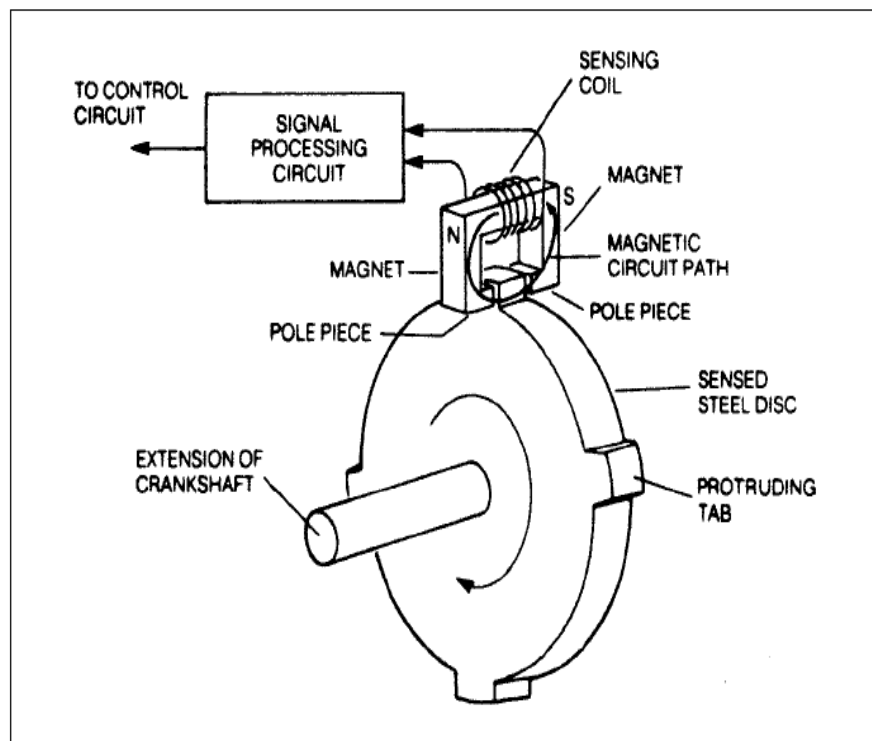


Figure 6.7
Magnetic Circuit of
the Reluctance
Sensor

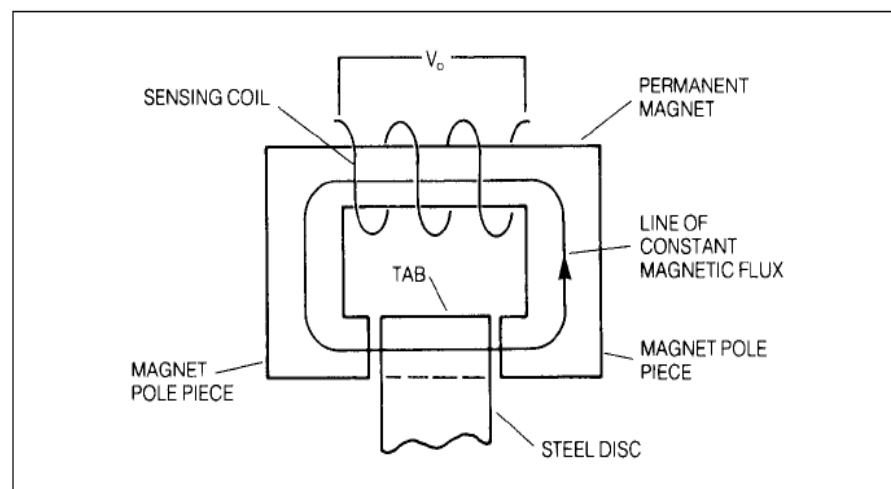
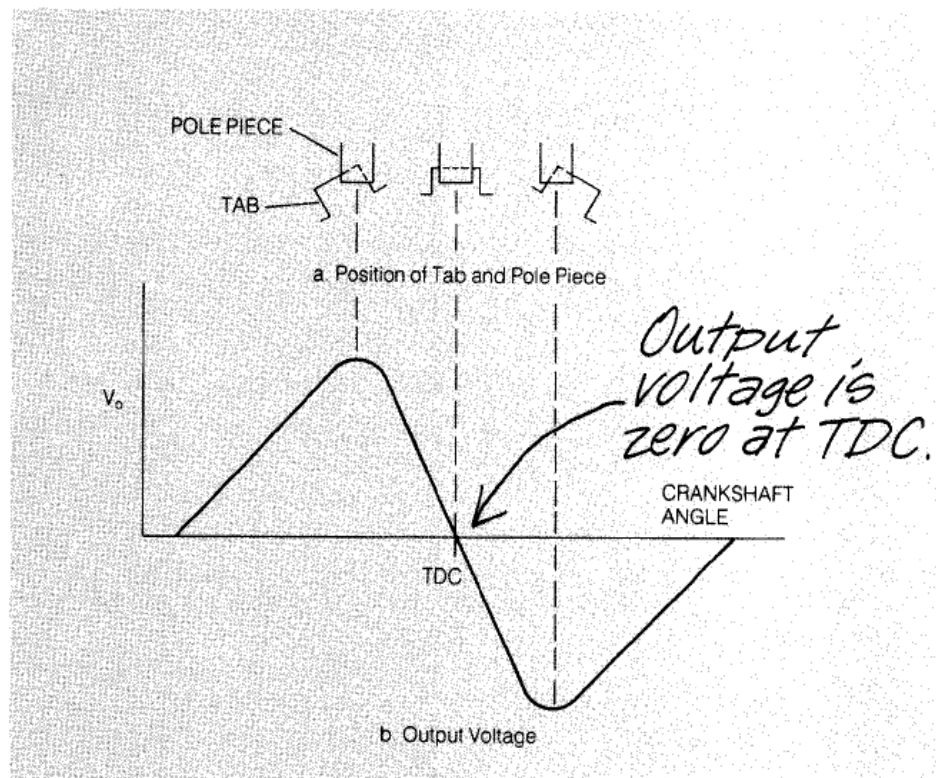


Figure 6.8
Output Voltage
Waveform from the
Magnetic Reluctance
Crankshaft Position
Sensor Coil



Hall-Effect Position Sensor

A crankshaft position sensor that avoids this problem is the 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 6.10. 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. Another similarity is that the steel disk varies the reluctance of the magnetic path as the tabs pass between the magnet pole pieces. The Hall Effect The Hall element is a small, thin, flat slab of semiconductor material. When a current, I , is passed through this slab by means of an external circuit as shown in Figure 6.11a, a voltage is developed across the slab perpendicular to the direction of current flow and perpendicular to the direction 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 6.11b, 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 6.11b, the Lorentz force direction is such that the electrons are deflected toward the lower sense electrode. Thus, this electrode is more negative than the upper electrode and a voltage exists between the electrodes, having the polarity shown in Figure 6.11b. As the strength of the magnetic flux density increases, more of the electrons are deflected downward. If the current, I , is held constant, then the voltage, V_o , is proportional to the strength of the magnetic flux density, which, in turn, is determined by the position of the tabs. This voltage tends to be relatively weak so it is amplified, as shown in Figure 6.10. Output Waveform It was shown in the discussion of the reluctance crankshaft position sensor that the magnetic flux density for this configuration depends on the position of the tab. Recall that the magnetic flux is largest when one of the tabs is positioned symmetrically between the magnet pole pieces and that this position normally corresponds closely to TDC of one of the cylinders. The voltage waveform V_o that is produced by the Hall element in the position sensor of Figure 6.10 is illustrated in Figure 6.12. Since V_o is proportional to the magnetic flux density, it reaches maximum when any of the tabs is symmetrically located between the magnet pole pieces (corresponding to TDC of a cylinder). If the disk is driven by the camshaft, then the disk must have as many tabs as the engine has cylinders. Therefore, the disk shown would be for a 4-cylinder engine. It is important to realize that voltage output versus crankshaft angle is independent of engine speed. Thus, this sensor can be used for setting the engine timing when the engine is not running (e.g., when it is being motored at the end of an assembly line).

Figure 6.10
Hall-Effect Position
Sensor

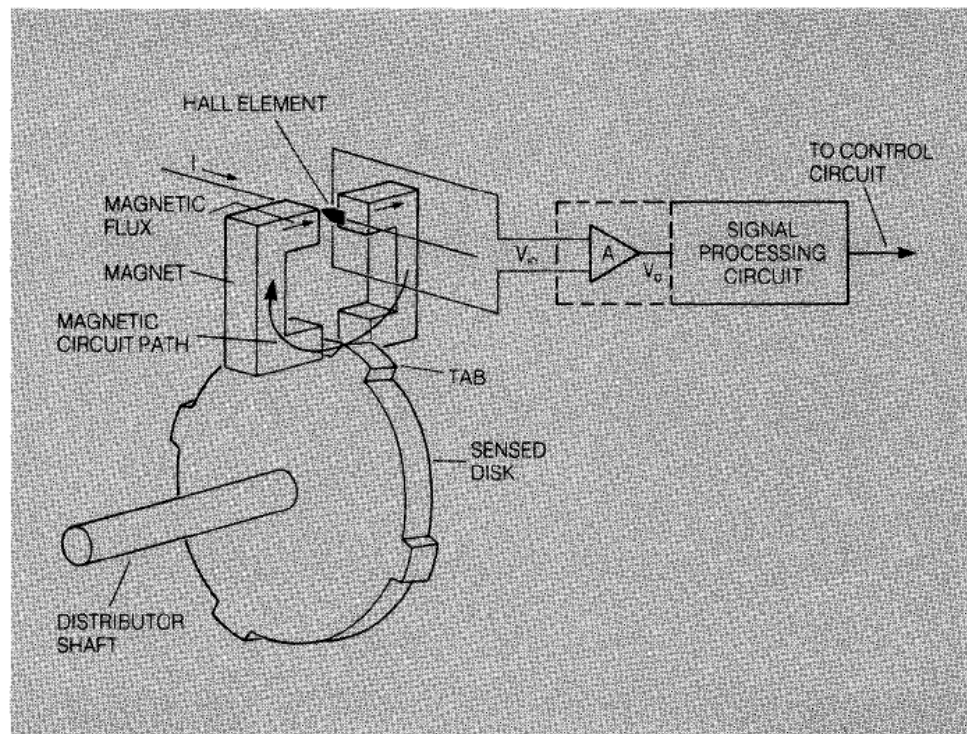
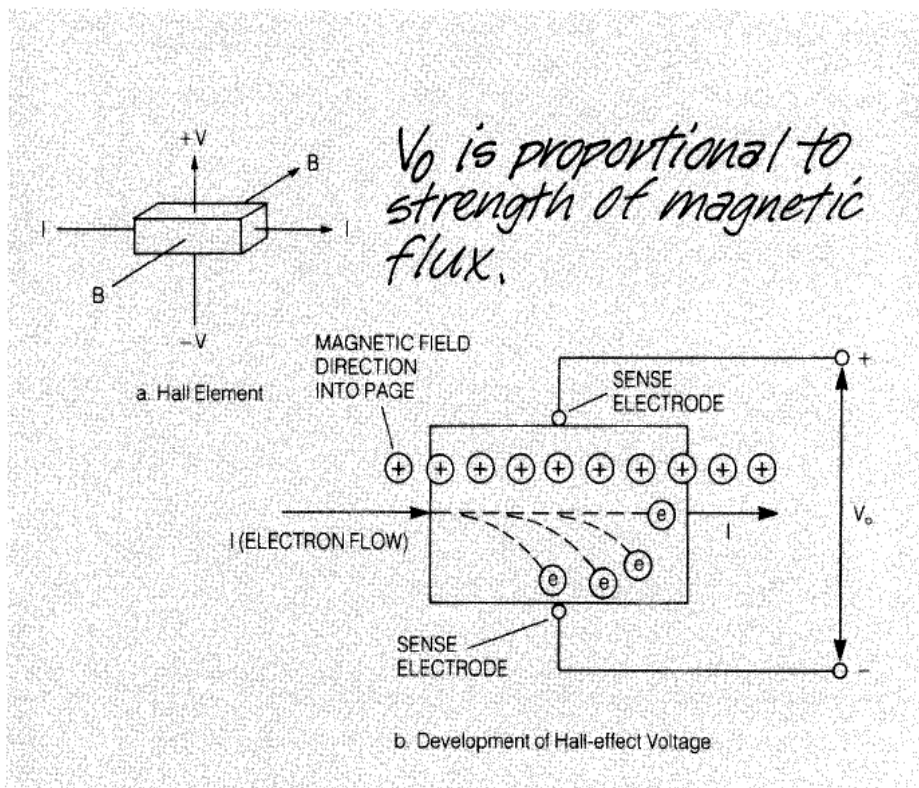


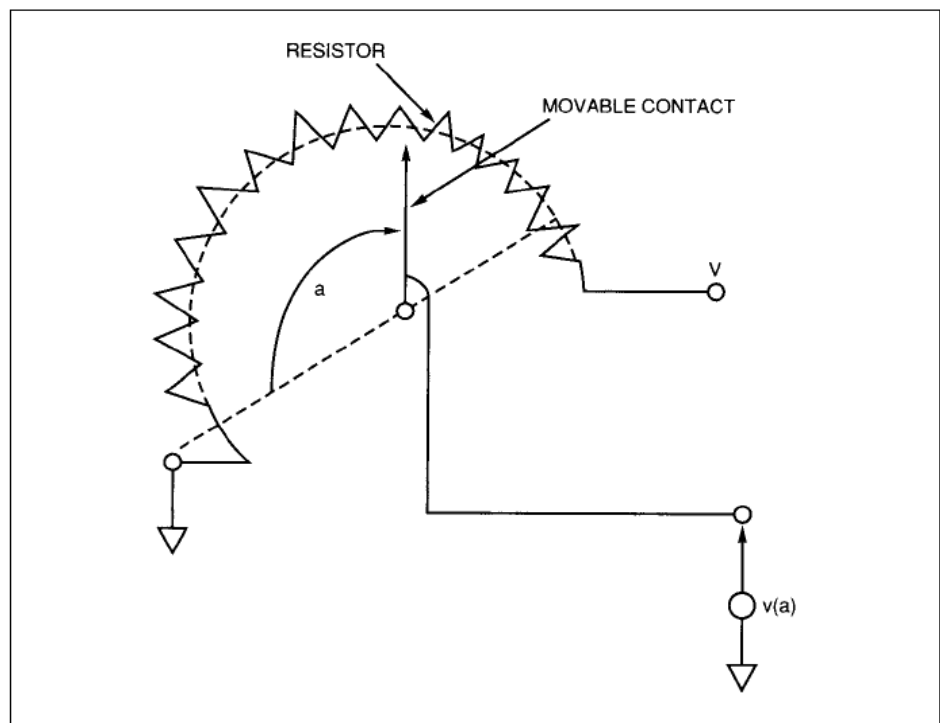
Figure 6.11
The Hall Effect



THROTTLE ANGLE SENSOR

Still 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. Measurement of the instantaneous throttle angle is important for control purposes, Most throttle angle sensors are essentially potentiometers. A potentiometer consists of a resistor with a movable contact, as illustrated in Figure 6.15.

Figure 6.15
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,

$$v(a) = ka$$

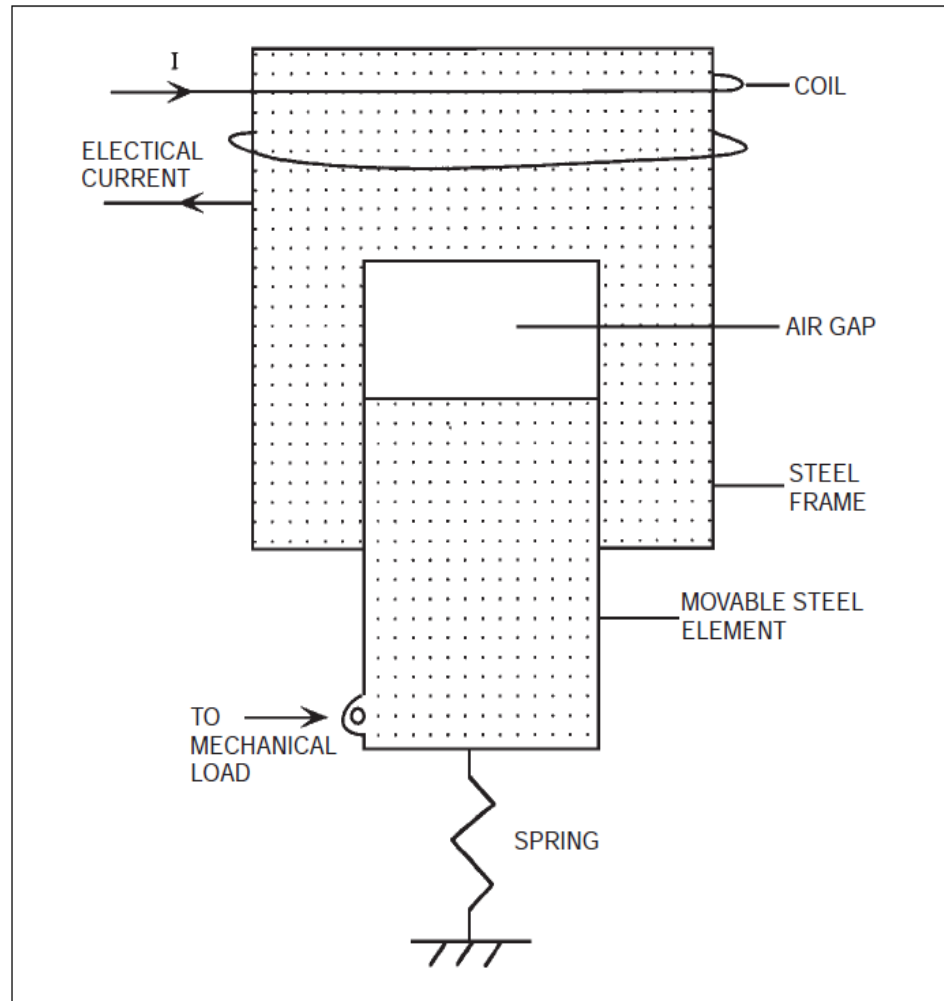
where $v(a)$ is the voltage at the contact point, k is a constant, and a is the angle of the contact point from the ground connection. This potentiometer can be used to measure any angular rotation. In

particular, it is well suited for measuring throttle angle. The only disadvantage to the potentiometer for automotive applications is its analog output. For digital engine control, the voltage $v(a)$ must be converted to digital format using an analog-to-digital converter.

AUTOMOTIVE ENGINE CONTROL ACTUATORS

In addition to 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. In general, 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. Examples of actuators include various types of electric motors, solenoids, and piezoelectric force generators. In automotive electronic systems the solenoid is the most commonly used device because it is relatively simple and inexpensive. The solenoid is used in applications ranging from precise fuel control to mundane applications such as electric door locks. A solenoid is in essence a powerful electromagnet having a configuration generally similar to that illustrated in Figure 6.25. The solenoid consists of a fixed steel (i.e., ferromagnetic) frame with a movable steel element. A spring holds the movable element in position such that there is a gap between the end of the movable element and the opening in the frame. A coil is wound around the steel frame, forming a powerful electromagnet. When a current passes through the coil, a magnetic field is created that tends to pull the movable element toward the steel frame. When the magnetic field, which is proportional to the current, is sufficient to overcome the force at the spring holding the movable element, then it begins to move toward the frame. As this element moves, the size of the gap is reduced, causing an increase in the strength of the magnetic field. This increase causes the movable element to accelerate toward the frame until it reaches the stop. This abrupt motion of the movable element is essentially in the form of a mechanical switching action such that the solenoid tends to be either in its rest position (as held by the spring) or against the mechanical stop. The movable element is typically connected to a mechanism that is correspondingly moved by the snap action of this element. Applications of solenoids in automotive electronics include fuel injectors and EGR valves.

Figure 6.25
Schematic Drawing of
a Solenoid



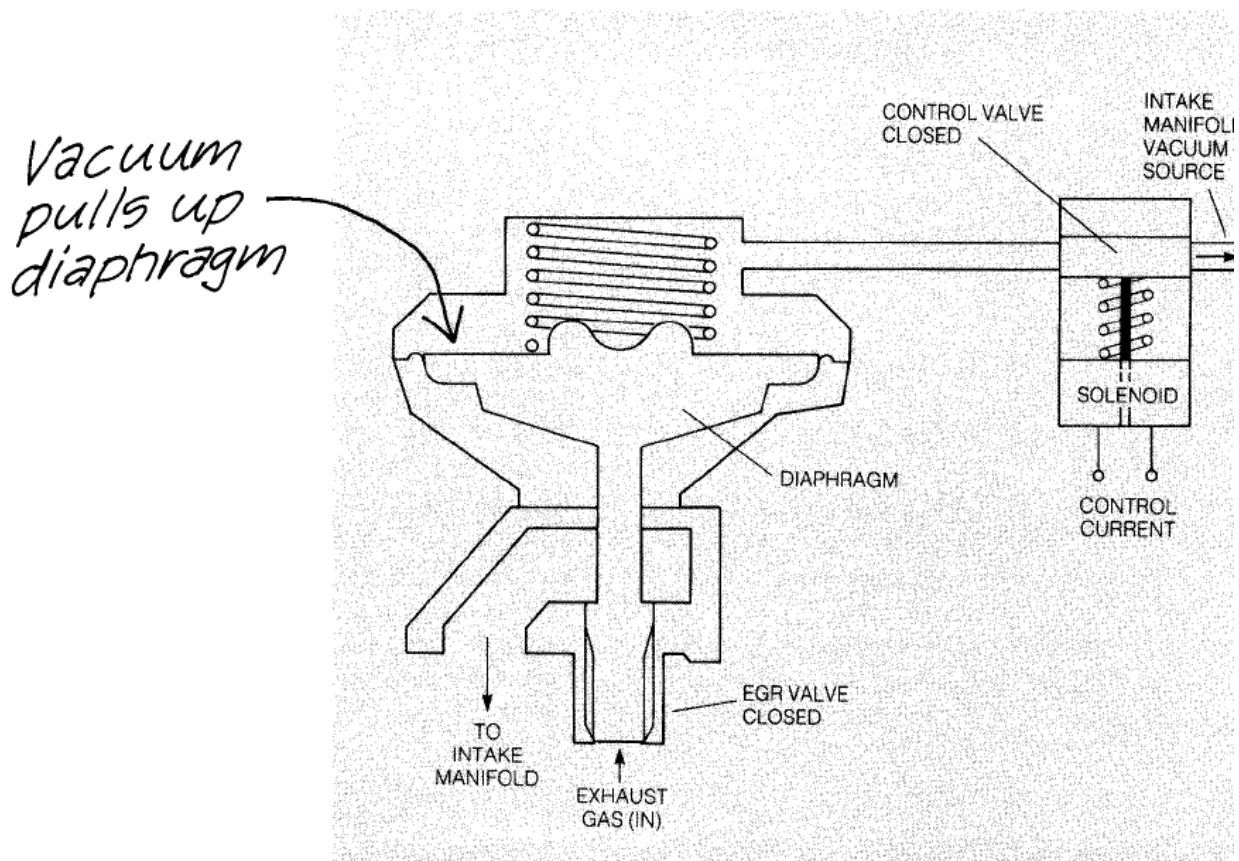
Exhaust Gas Recirculation Actuator

When the correct amount of EGR has been determined by the controller based on measurements from the various engine control sensors, the controller sends an electrical signal to the EGR actuator. Typically, this actuator is a variable-position valve that regulates the EGR as a function of intake manifold pressure and exhaust gas pressure. Although there are many EGR configurations, only one representative example will be discussed to explain the basic operation of this type of actuator. The example EGR actuator is shown schematically in Figure 6.28.

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. This solenoid operates essentially the same as that explained in the discussion on fuel injectors. 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. The duty cycle (see discussion on fuel injectors) of this pulsing current controls the average pressure in the chamber that affects the diaphragm deflection, thereby regulating the amount of EGR.

Figure 6.28
EGR Actuator Control



MODULE 3

Digital Engine Control Systems

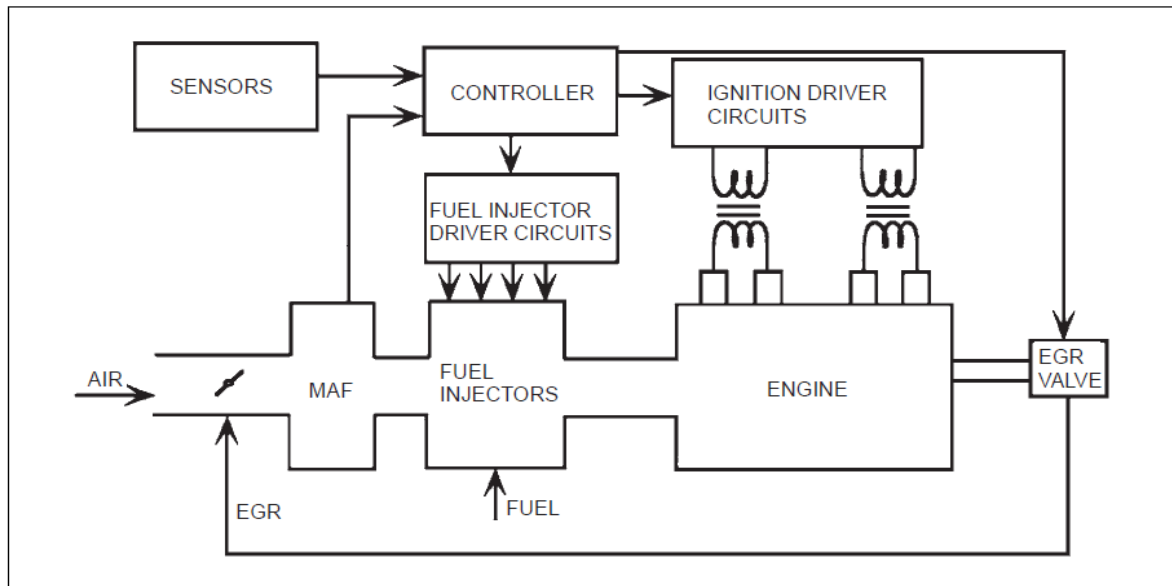
INTRODUCTION

Traditionally, the term power train has been thought to include the engine, transmission, differential, and drive axle/wheel assemblies. With the advent of electronic controls, the power train also includes the electronic control system (in whatever configuration it has). 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. Moreover, certain vehicles employ electronically controlled clutches in the differential (transaxle) for traction control.

DIGITAL ENGINE CONTROL FEATURES

Virtually all major manufacturers of cars sold in the United States (both foreign and domestic) use the three-way catalyst for meeting exhaust emission constraints. For such cars, the air/fuel ratio is held as closely as possible to the stoichiometric value of about 14.7 for as much of the time as possible. Ignition timing and EGR are controlled separately to optimize performance and fuel economy. Figure 7.1 illustrates the primary components of an electronic engine control system. 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 (see Chapter 4). 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 earliest such systems incorporated 8-bit microprocessors, although the trend is toward implementation with 32-bit microprocessors. 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.

Figure 7.1
Components of an Electronically Controlled Engine



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. A diagram illustrating the lookup table selection of desired air/fuel ratios is shown in Figure 7.3. Essentially, the measured coolant temperature (CT) is converted to an address for the lookup table. This address is supplied to the ROM table via the system address bus (A/B). The data stored at this address in the ROM are the desired air/fuel ratio $(A/F)_d$ for that temperature. These data are sent to the controller via the system data bus (D/B). There is always the possibility of a coolant temperature failure. Such a failure could result in excessively rich or lean mixtures, which can seriously degrade the performance of both the engine and the three-way catalytic converter (3wcc). One scheme that can circumvent a temperature sensor failure involves having a time function to limit the duration of the engine warm-up mode. The nominal time to warm the engine from cold soak at various temperatures is known. The controller is configured to switch from engine warm-up mode to an open-loop (warmed-up engine) mode after a sufficient time by means of an internal timer. It is worthwhile at this point to explain how the quantity of fuel to be injected is determined. This method is implemented in essentially all operating modes and is described here as a generic method, even though each engine control scheme may vary somewhat from the following. The quantity of fuel to be injected during the intake stroke of any given cylinder (which we call F) is determined by the mass of air (A) drawn into that cylinder (i.e., the air charge) during that intake stroke. That quantity of fuel is given by the air charge divided by the desired air/fuel ratio:

$$F = \frac{A}{(A/F)_d}$$

The quantity of air drawn into the cylinder, A , is computed from the mass air flow rate and the RPM. The mass air flow rate (MAF) will be given in kg/sec. If the engine speed in revolutions/minute is RPM, then the number of revolutions/second (which we call r). The quantity of air drawn into the cylinder, A , is computed from the mass air flow rate and the RPM. The mass air flow rate (MAF) will be given in kg/sec. If the engine speed in revolutions/minute is RPM, then the number of revolutions/second (which we call r) is

$$r = \frac{\text{RPM}}{60}$$

Then, the mass air flow is distributed approximately uniformly to half the cylinders during each revolution. If the number of cylinders is N , then the air charge (mass) in each cylinder during one revolution is

$$A = \frac{\text{MAF}}{r(N/2)}$$

In this case, the mass of fuel delivered to each cylinder is

$$F = \frac{\text{MAF}}{r(N/2)(A/F)_d}$$

This computation is carried out by the controller continuously so that the fuel quantity can be varied quickly to accommodate rapid changes in engine operating condition. The fuel injector pulse duration T corresponding to this fuel quantity is computed using the known fuel injector delivery rate R_f :

$$T = \frac{F}{R_f}$$

This pulse width is known as the base pulse width.

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. 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):

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

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., an alternate method of computing mass air flow rate is the speed-density method. Although the speed-density method has essentially been replaced by direct mass air flow measurements, there will continue to be a number of cars employing this method for years to come,

so it is arguably worthwhile to include a brief discussion in this chapter. 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 ρ_a is computed from MAP and T_i , 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. The speed-density method can be implemented either by computation in the engine control computer or via lookup tables. Figure 7.5 is an illustration of the lookup table implementation. In this figure, three variables need to be determined: volumetric efficiency (η_v), intake density (ρ_a), and EGR volume flow rate (R_E). The volumetric efficiency is read from ROM with an address determined from RPM and MAP measurements. The intake air density is read from another section of ROM with an address determined from MAP and T_i measurements.

Figure 7.4
Engine Control System Using the Speed-Density Method

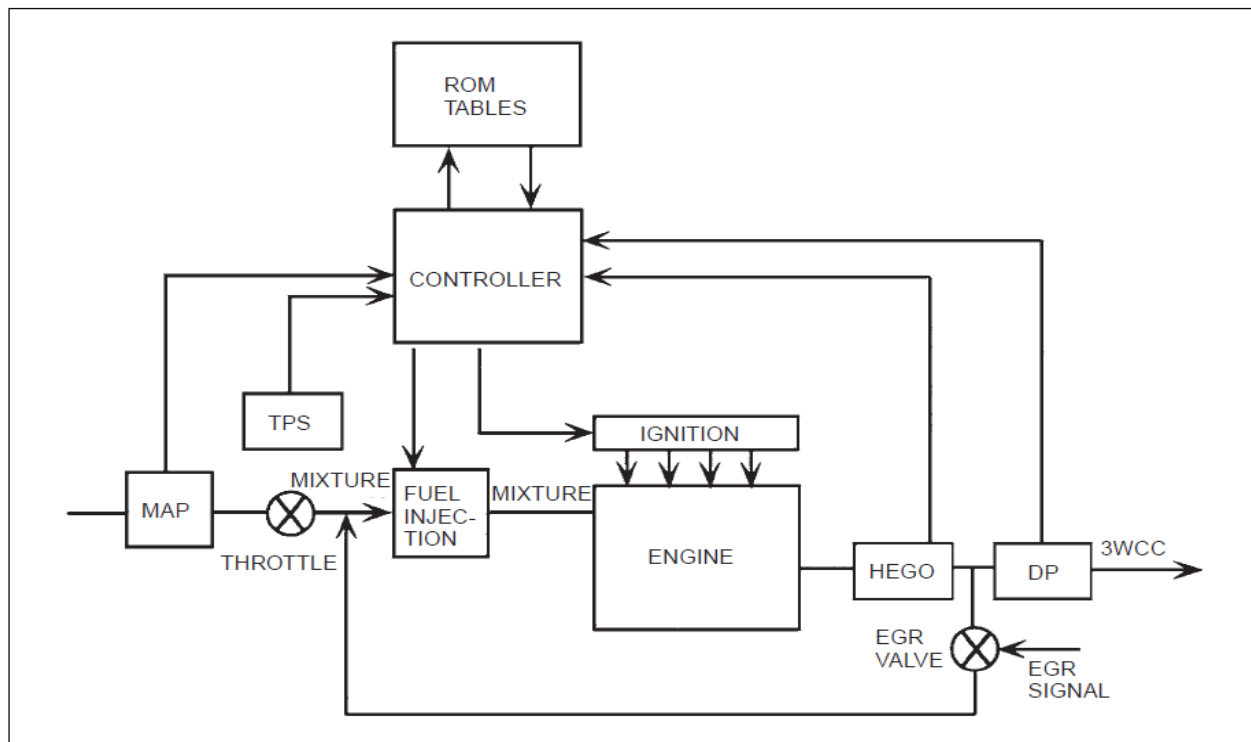
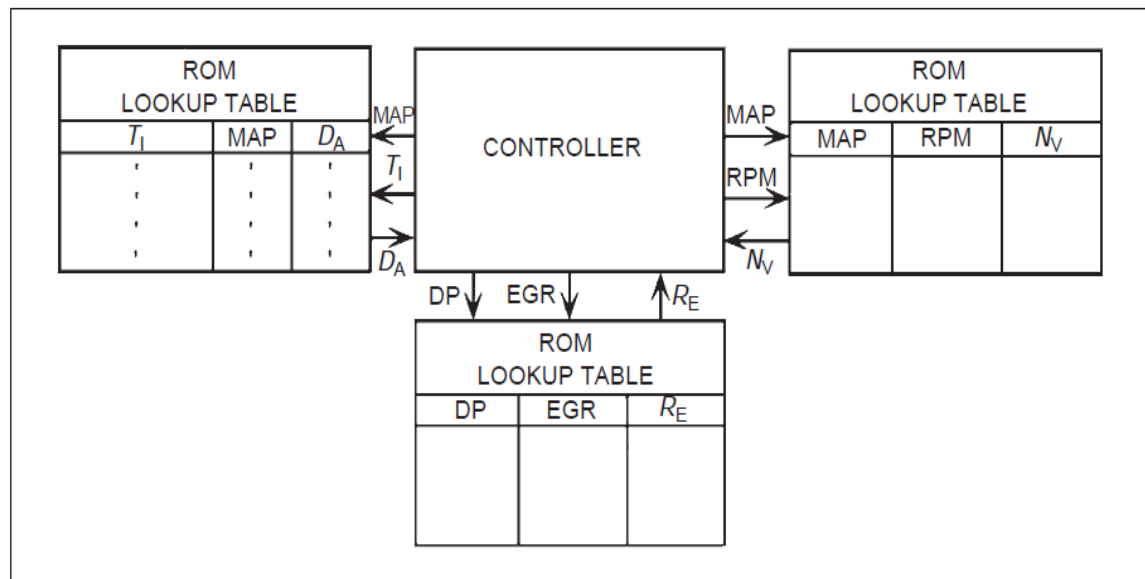


Figure 7.5
Lookup Table Determination of d_a , R_E , and n_v



Acceleration Enrichment

During periods of heavy engine load such as during hard acceleration, fuel control is adjusted to provide an enriched air/fuel ratio to maximize engine torque and neglect fuel economy and emissions. This condition of enrichment is permitted within the regulations of the EPA as it is only a temporary condition. It is well recognized that hard acceleration is occasionally required for maneuvering in certain situations and is, in fact, related at times to safety. The computer detects this condition by reading the throttle angle sensor voltage. High throttle angle corresponds to heavy engine load and is an indication that heavy acceleration is called for by the driver. In some vehicles a switch is provided to detect wide open throttle. The fuel system controller responds by increasing the pulse duration of the fuel injector signal for the duration of the heavy load. This enrichment enables the engine to operate with a torque greater than that allowed when emissions and fuel economy are controlled. Enrichment of the air/fuel ratio to about 12:1 is sometimes used.

Deceleration Leaning

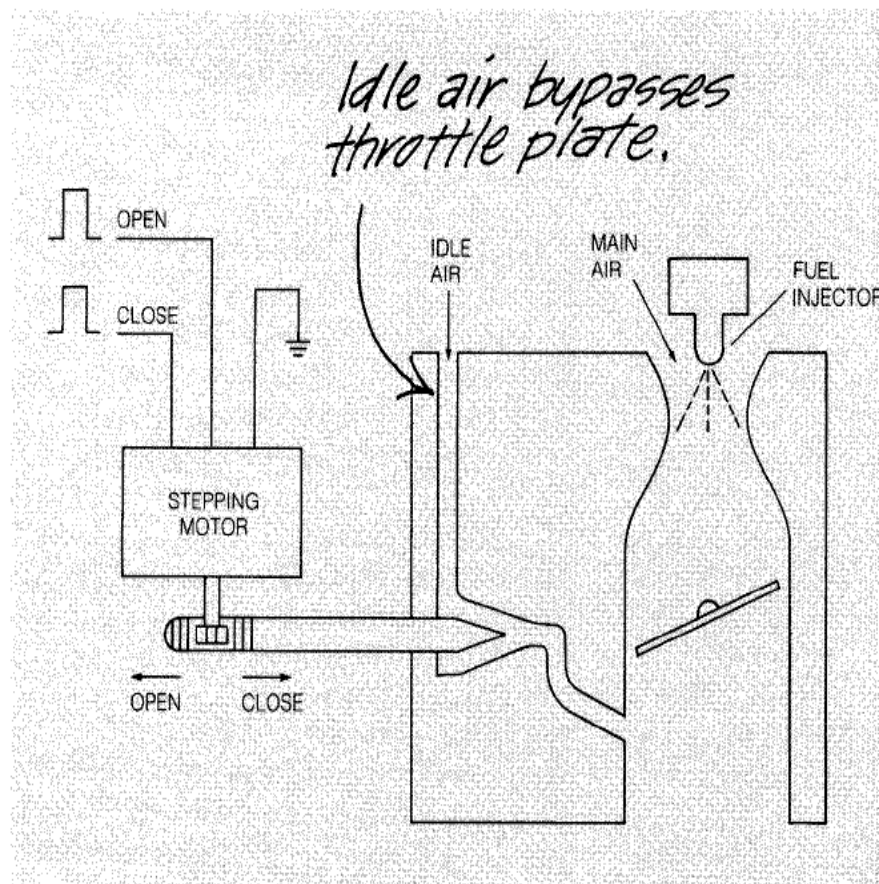
During periods of light engine load and high RPM such as during coasting or hard deceleration, the engine operates with a very lean air/fuel ratio to reduce excess emissions of HC and CO. Deceleration is indicated by a sudden decrease in throttle angle or by closure of a switch when the

throttle is closed (depending on the particular vehicle configuration). When these conditions are detected by the control computer, it computes a decrease in the pulse duration of the fuel injector signal. The fuel may even be turned off completely for very heavy deceleration.

Idle Speed Control

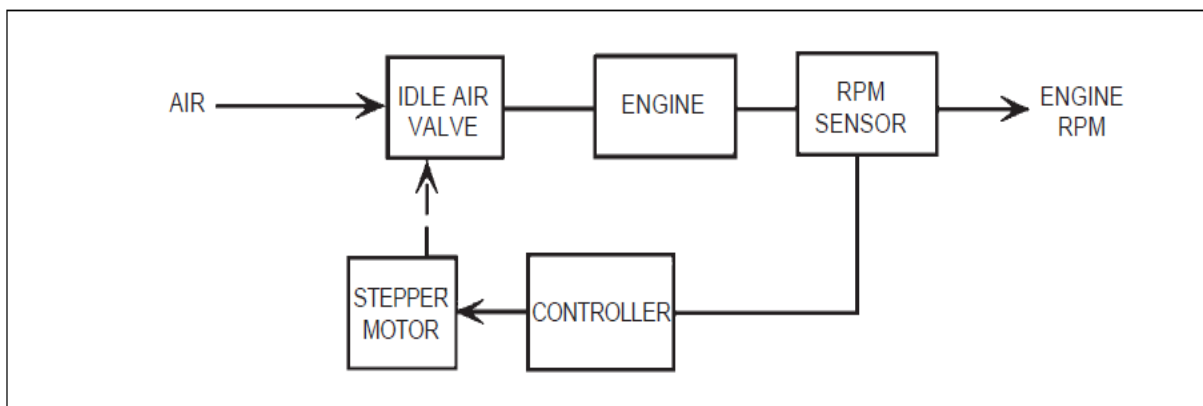
Idle speed control is used by some manufacturers to prevent engine stall during idle. The goal is to allow the engine to idle at as low an RPM as possible, yet keep the engine from running rough and stalling when power consuming accessories, such as air conditioning compressors and alternators, turn on. The control mode selection logic switches to idle speed control when the throttle angle reaches its zero (completely closed) position and engine RPM falls below a minimum value, and when the vehicle is stationary. Idle speed is controlled by using an electronically controlled throttle bypass valve (Figure 7.7a) that allows air to flow around the throttle plate and produces the same effect as if the throttle had been slightly opened.

Figure 7.7a
Idle Air Control



There are various schemes for operating a valve to introduce bypass air for idle control. One relatively common method for controlling the idle speed bypass air uses a special type of motor called a stepper motor. A stepper motor moves in fixed angular increments when activated by pulses on its two sets of windings (i.e., open or close). Such a motor can be operated in either direction by supplying pulses in the proper phase to the windings. This is advantageous for idle speed control since the controller can very precisely position the idle bypass valve by sending the proper number of pulses of the correct phasing. The engine control computer can know precisely the position of the valve in a number of ways. In one way the computer can send sufficient pulses to completely close the valve when the ignition is first switched on. Then it can send open pulses (phased to open the valve) to a specified (known) position. A block diagram of a simplified idle speed control system is shown in Figure 7.7b. Idle speed is detected by the RPM sensor, and the speed is adjusted to maintain a constant idle RPM. The computer receives digital on/off status inputs from several power-consuming devices attached to the engine, such as the air conditioner clutch switch, park-neutral switch, and the battery charge indicator. These inputs indicate the load that is applied to the engine during idle. When the engine is not idling, the idle speed control valve may be completely closed so that the throttle plate has total control of intake air. During periods of deceleration leaning, the idle speed valve may be opened to provide extra air to increase the air/fuel ratio in order to reduce HC emissions.

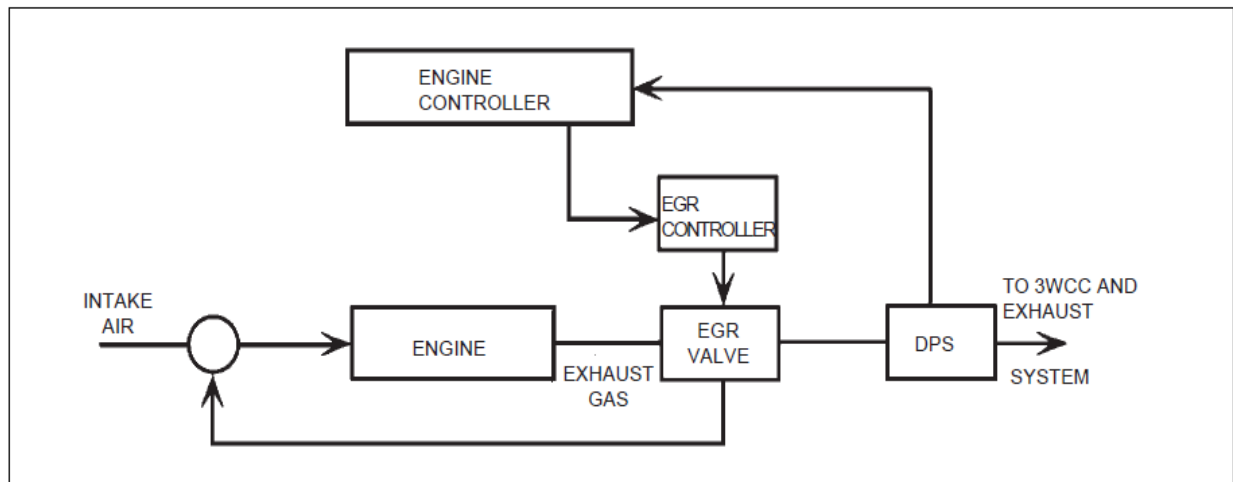
Figure 7.7b
Idle Air Control



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 NOx emissions. As explained in Chapter 5, a small amount of exhaust gas is introduced into the cylinder to replace normal intake air. This results in lower combustion temperatures, which reduces NOx 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 NOx exhaust emissions, its implementation has gone through considerable change.

Figure 7.8a
EGR Control



There are in fact many schemes and configurations for EGR realization. We discuss here one method of EGR implementation that incorporates enough features to be representative of all schemes in use today and in the near future. 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. 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). A simplified block diagram for an EGR control system is depicted in Figure 7.8a. In

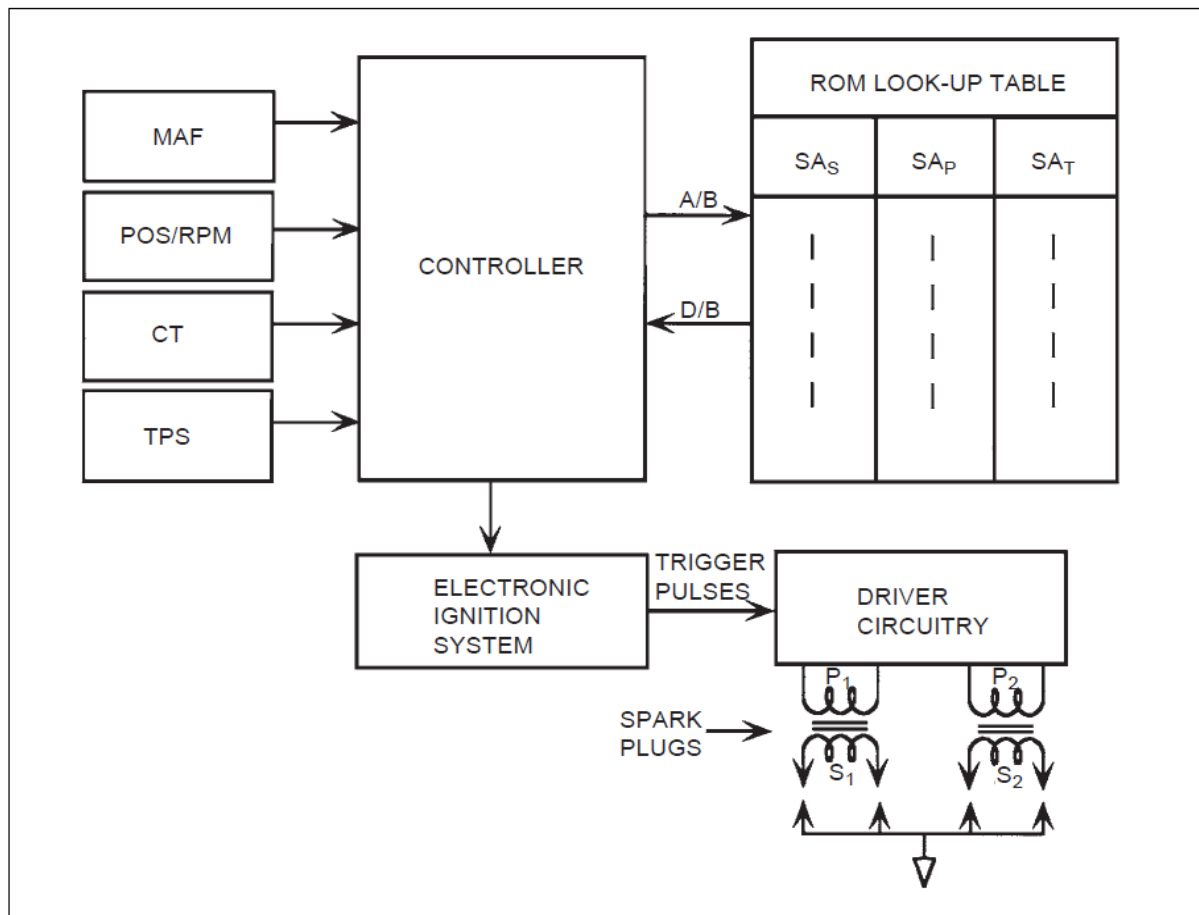
this figure the EGR valve is operated by a solenoid regulated vacuum actuator (coming from the intake). An explanation of this proportional actuator is given in Chapter 6. The engine controller determines the required amount of EGR based on the engine operating condition and the signal from the differential pressure sensor (DPS) between intake and exhaust manifolds. The controller then commands the correct EGR valve position to achieve the desired amount of EGR.

ELECTRONIC IGNITION CONTROL

An engine must be provided with fuel and air in correct proportions and the means to ignite this mixture in the form of an electric spark. Before the development of electronic ignition, the traditional ignition system included spark plugs, a distributor, and a high-voltage ignition coil (see Chapter 1). The distributor would sequentially connect the coil output high voltage to the correct spark plug. In addition, it would cause the coil to generate the spark by interrupting the primary current (ignition points) in the desired coil, thereby generating the required spark. The time of occurrence of this spark (i.e., the ignition timing) in relation of the piston to TDC influences the torque generated. In most present-day electronically controlled engines, the distributor has been replaced by multiple coils. Each coil supplies the spark to either one or two cylinders. In such a system the controller selects the appropriate coil and delivers a trigger pulse to ignition control circuitry at the correct time for each cylinder. (Note: In some cases, the coil is on the spark plug as an integral unit.) Figure 7.9a illustrates such a system for an example 4-cylinder engine. In this example a pair of coils provides the spark for firing two cylinders for each coil. Cylinder pairs are selected such that one cylinder is on its compression stroke while the other is on exhaust. The cylinder on compression is the cylinder to be fired (at a time somewhat before it reaches TDC). The other cylinder is on exhaust. The coil fires the spark plugs for these two cylinders simultaneously. For the former cylinder, the mixture is ignited and combustion begins for the power stroke that follows. For the other cylinder (on exhaust stroke), the combustion has already taken place and the spark has no effect. Although the mixture for modern emission-regulated engines is constrained by emissions regulations, the spark timing can be varied in order to achieve optimum performance within the mixture constraint. For example, the ignition timing can be chosen to produce the best possible engine torque for any given operating condition. This optimum ignition timing is known for any given engine configuration from studies of engine performance

as measured on an engine dynamometer. Figure 7.9a is a schematic of a representative electronic ignition system. In this example configuration the spark advance value is computed in the main engine control (i.e., the controller that regulates fuel). This system receives data from the various sensors (as described above with respect to fuel control) and determines the correct spark advance for the instantaneous operating condition.

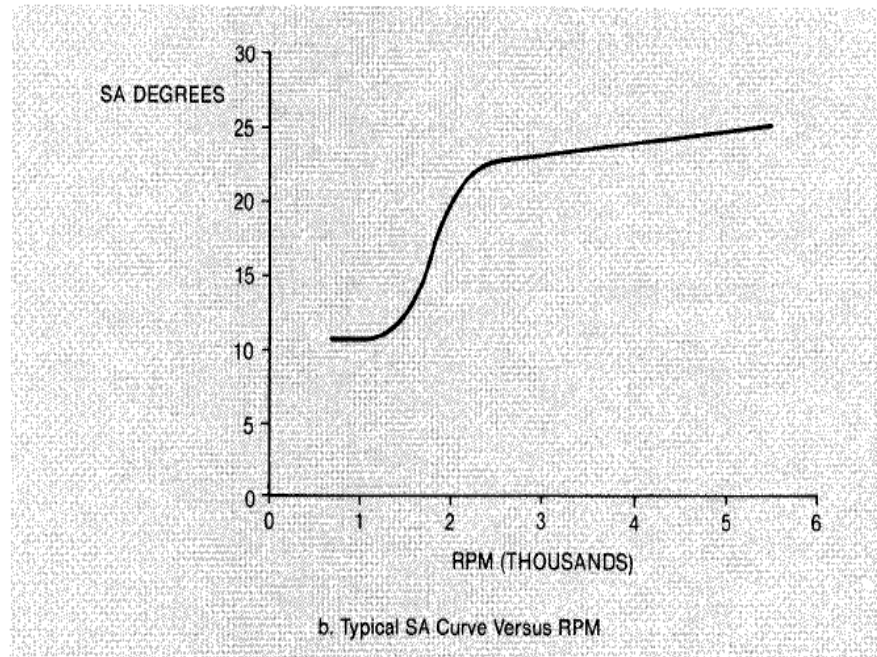
Figure 7.9a
Distributorless Ignition System



The variables that influence the optimum spark timing at any operating condition include RPM, manifold pressure (or mass air flow), barometric pressure, and coolant temperature. The correct ignition timing for each value of these variables is stored in a ROM lookup table. For example, the variation of spark advance (SA) with RPM for a representative engine is shown in Figure 7.9b. The engine control system obtains readings from the various sensors and generates an address to the lookup table (ROM). After reading the data from the lookup tables, the control system

computes the correct spark advance. An output signal is generated at the appropriate time to activate the spark.

Figure 7.9b
Spark Advance
versus RPM



MODULE 4

Automotive Networking & Vehicle Motion Control

INTRODUCTION

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. This chapter discusses motion control electronics beginning with control of motion along the longitudinal axis in the form of a cruise control system.

TYPICAL CRUISE CONTROL SYSTEM

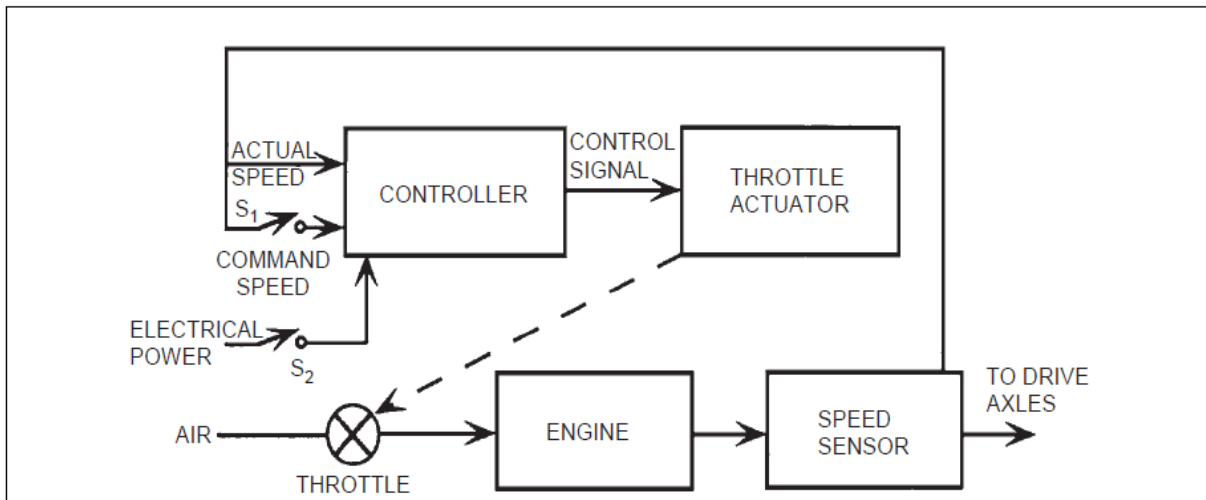
Automotive cruise control is an excellent example of the type of electronic feedback control system. Recall that the components of a control system include the plant, or system being controlled, and a sensor for measuring the plant variable being regulated. It also includes an electronic control system that receives inputs in the form of the desired value of the regulated variable and the measured value of that variable from the sensor. The control system generates an error signal constituting the difference between the desired and actual values of this variable. It then generates an output from this error signal that drives an electromechanical actuator. The actuator controls the input to the plant in such a way that the regulated plant variable is moved toward the desired value. 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.

Under normal driving circumstances, the total drag forces acting on the vehicle are such that a net positive traction force (from the power train) is required to maintain a constant vehicle speed. However, when the car is on a downward sloping road of sufficient grade, constant vehicle speed requires a negative tractive force that the power train can't deliver. In this case, the car will accelerate unless brakes are applied. For our initial discussion, we assume this latter condition does not occur and that no braking is required. The plant being controlled consists of the powertrain (i.e., engine and drivetrain), which drives the vehicle through the drive axles and wheels. As described above, the load on this plant includes friction and aerodynamic drag as well as a portion of the vehicle weight when the car is going up and down hills. 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 S1 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 S2 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. A block diagram of a cruise control system is shown in Figure 8.2. In the cruise control depicted in this figure, a proportional integral (PI) control strategy has been assumed. However, there are many cruise control systems still on the road today with proportional (P) controllers. Nevertheless, the PI controller is representative of good design for such a control system since it can reduce speed errors due to disturbances (such as hills) to zero. In this strategy an error e is formed by subtracting (electronically) the actual speed V_a from the desired speed V_d :

$$e = V_d - V_a$$

Figure 8.1
Cruise Control Configuration



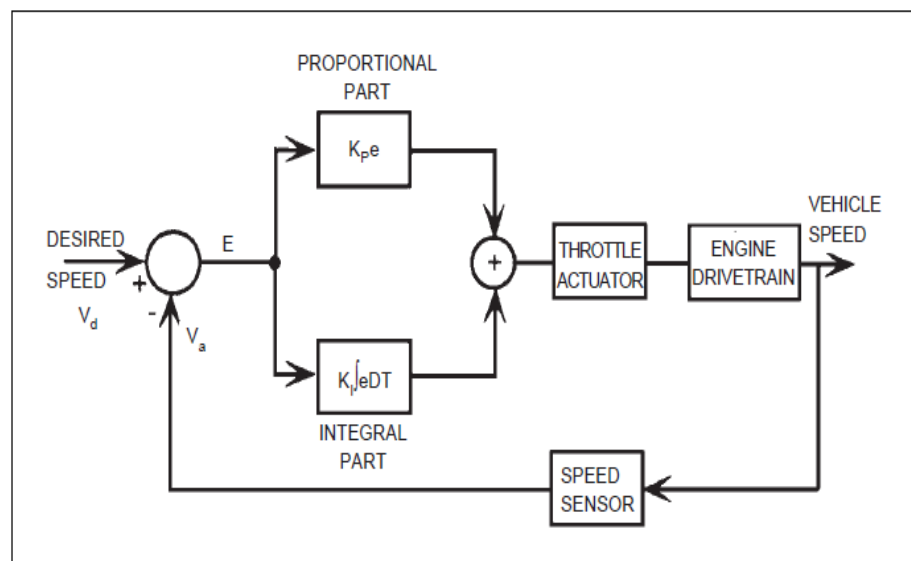
The controller then electronically generates the actuator signal by combining a term proportional to the error ($K_P e$) and a term proportional to the integral of the error:

$$K_I \int e dt$$

The actuator signal u is a combination of these two terms:

$$u = K_P e + K_I \int e dt$$

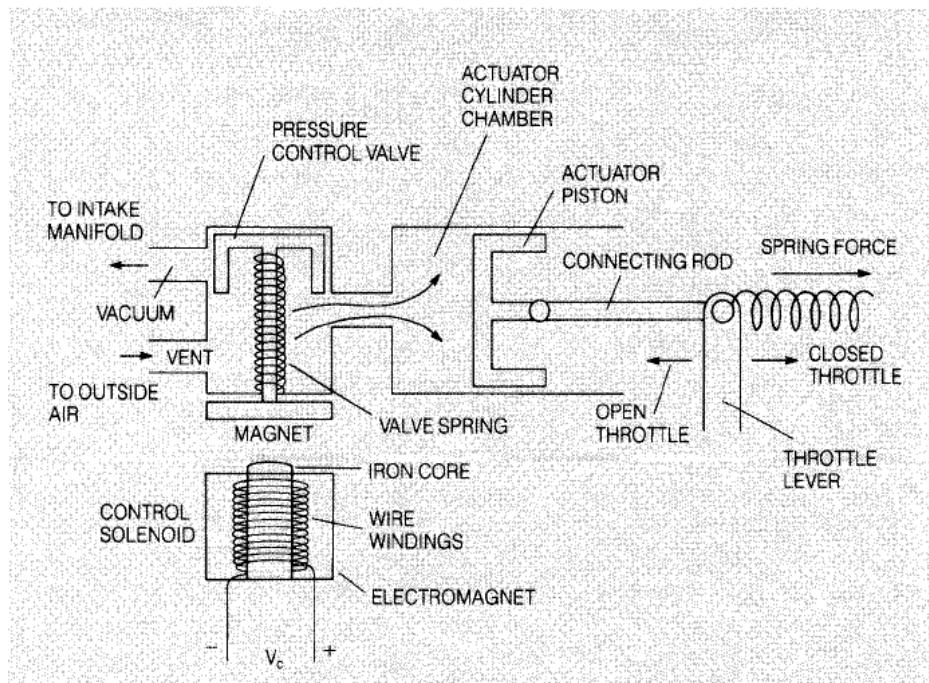
Figure 8.2
Cruise Control Block Diagram



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. The stepper motor implementation operates similarly to the idle speed control actuator described in Chapter 7. 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. The throttle actuator that is operated by manifold vacuum through a solenoid valve is similar to that used for the EGR valve and further explained later in this chapter. 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 8.7.

Figure 8.7
Vacuum-Operated
Throttle Actuator



A pneumatic piston arrangement is driven from the intake manifold vacuum. The piston-connecting rod assembly is attached to the throttle lever. There is also a spring attached to the lever. If there is no force applied by the piston, the spring pulls the throttle closed. When an actuator input signal energizes the electromagnet in the control solenoid, the pressure control valve

is pulled down and changes the actuator cylinder pressure by providing a path to manifold pressure. Manifold pressure is lower than atmospheric pressure, so the actuator cylinder pressure quickly drops, causing the piston to pull against the throttle lever to open the throttle.

The force exerted by the piston is varied by changing the average pressure in the cylinder chamber. This is done by rapidly switching the pressure control valve between the outside air-port, which provides atmospheric pressure, and the manifold pressure port, the pressure of which is lower than atmospheric pressure. In one implementation of a throttle actuator, the actuator control signal V_c is a variable-duty-cycle type of signal like that discussed for the fuel injector actuator. A high V_c signal energizes the electromagnet; a low V_c signal de-energizes the electromagnet. Switching back and forth between the two pressure sources causes the average pressure in the chamber to be somewhere between the low manifold pressure and outside atmospheric pressure. This average pressure and, consequently, the piston force are proportional to the duty cycle of the valve control signal V_c . The duty cycle is in turn proportional to the control signal d (explained above) that is computed from the sampled error signal e_n . This type of duty-cycle-controlled throttle actuator is ideally suited for use in digital control systems. If used in an analog control system, the analog control signal must first be converted to a duty-cycle control signal. The same frequency response considerations apply to the throttle actuator as to the speed sensor. In fact, with both in the closed-loop control system, each contributes to the total system phase shift and gain.

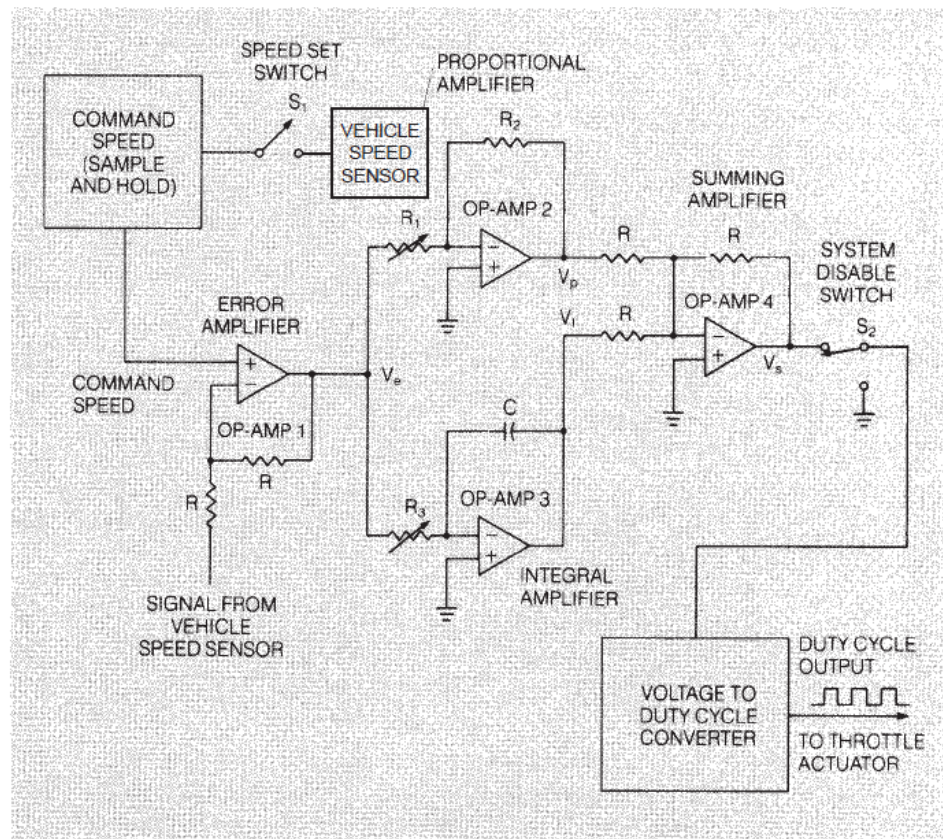
Vacuum-Operated Actuator

The driver electronics for a cruise control based on a vacuum-operated system generates a variable-duty-cycle signal. In this type of system, the duty cycle at any time is proportional to the control signal. For example, if at any given instant a large positive error exists between the command and actual signal then a relatively large control signal will be generated. This control signal will cause the driver electronics to produce a large duty-cycle signal to operate the solenoid so that most of the time the actuator cylinder chamber is nearly at manifold vacuum level. Consequently, the piston will move against the restoring spring and cause the throttle opening to increase. As a result, the engine will produce more power and will accelerate the vehicle until its speed matches the command speed. It should be emphasized that, regardless of the actuator type used, a microprocessor-based cruise control system will:

1. Read the command speed.
2. Measure actual vehicle speed.
3. Compute an error (error = command - actual).
4. Compute a control signal using P, PI, or PID control law.
5. Send the control signal to the driver electronics.
6. Cause driver electronics to send a signal to the throttle actuator such that the error will be reduced.

An example of electronics for a cruise control system that is basically analog is shown in Figure 8.10.

Figure 8.10a
Cruise Control
Electronics (Analog)



Notice that the system uses four operational amplifiers (op amps) as described in Chapter 3 and that each op amp is used for a specific purpose. Op amp 1 is used as an error amplifier. The output of op amp 1 is proportional to the difference between the command speed and the actual speed. The error signal is then used as an input to op amps 2 and 3. Op amp 2 is a proportional amplifier with a gain of $K_P = -R_2/R_1$. Notice that R_1 is variable so that the proportional amplifier gain can

be adjusted. Op amp 3 is an integrator with a gain of $KI = -1/R_3C$. Resistor R_3 is variable to permit adjustment of the gain. The op amp causes a current to flow into capacitor C that is equal to the current flowing into R_3 . The voltage across R_3 is the error amplifier output voltage, V_e . The current in R_3 is found from Ohm's law to be

$$I = \frac{V_e}{R_3}$$

ANTILOCK BRAKING SYSTEM

One of the most readily accepted applications of electronics in automobiles has been the antilock brake system (ABS). ABS is a safety-related feature that assists the driver in deceleration of the vehicle in poor or marginal braking conditions (e.g., wet or icy roads). In such conditions, panic braking by the driver (in non-ABS-equipped cars) results in reduced braking effectiveness and, typically, loss of directional control due to the tendency of the wheels to lock. 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). In order to understand the ABS operation, it is first necessary to understand the physical mechanism of wheel lock and vehicle skid that can occur during braking. Figure 8.13 illustrates the forces applied to the wheel by the road during braking.

The car is traveling at a speed U and the wheels are rotating at an angular speed w , given

$$w = \frac{\pi \text{RPM}}{30}$$

and where RPM is the wheel revolutions per minute. When the wheel is rolling (no applied brakes),

$$U = R w$$

where R is the tire radius. When the brake pedal is depressed, the calipers are forced by Hydraulic pressure against the disk, as explained in Chapter 1.

Figure 8.12
Antilock Braking
System

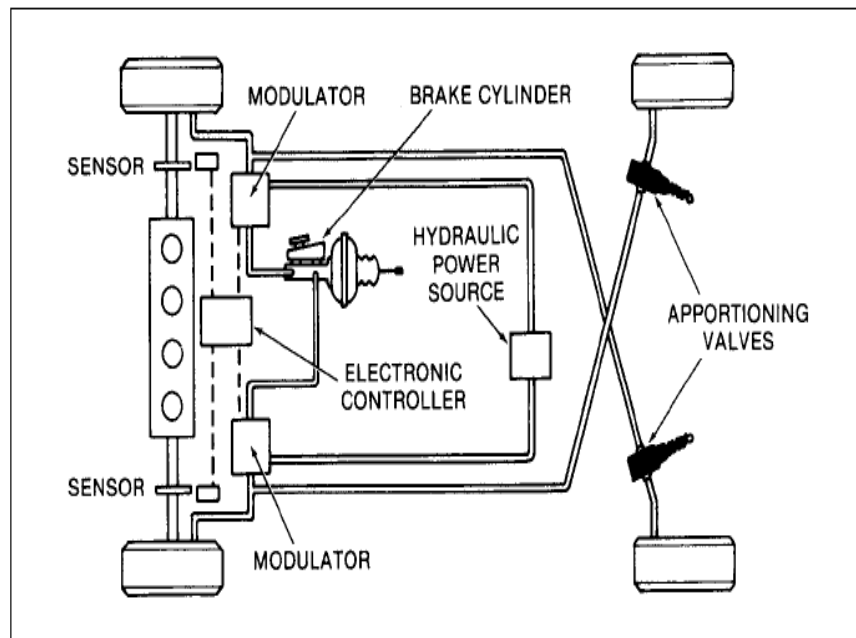
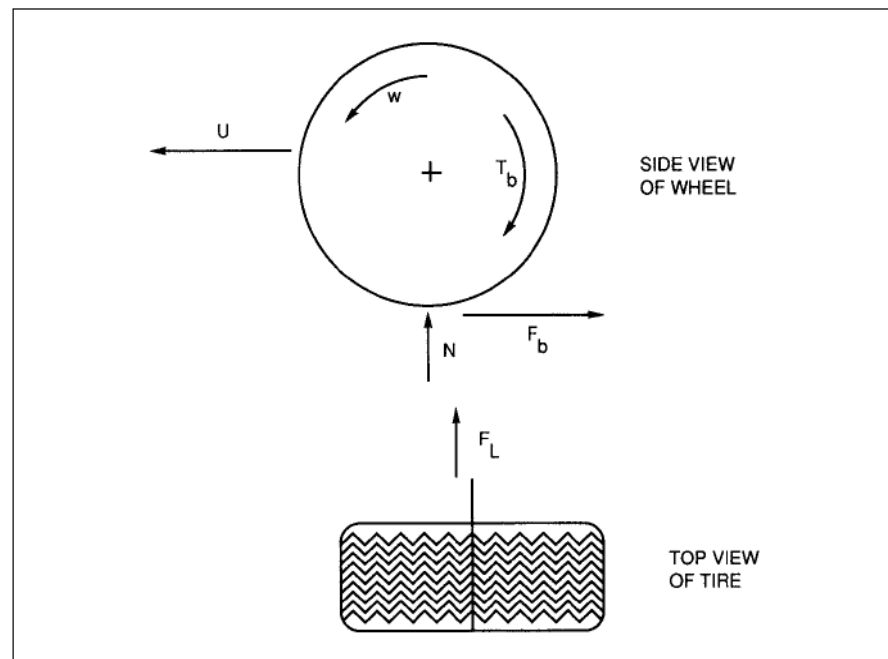


Figure 8.13
Forces During
Braking

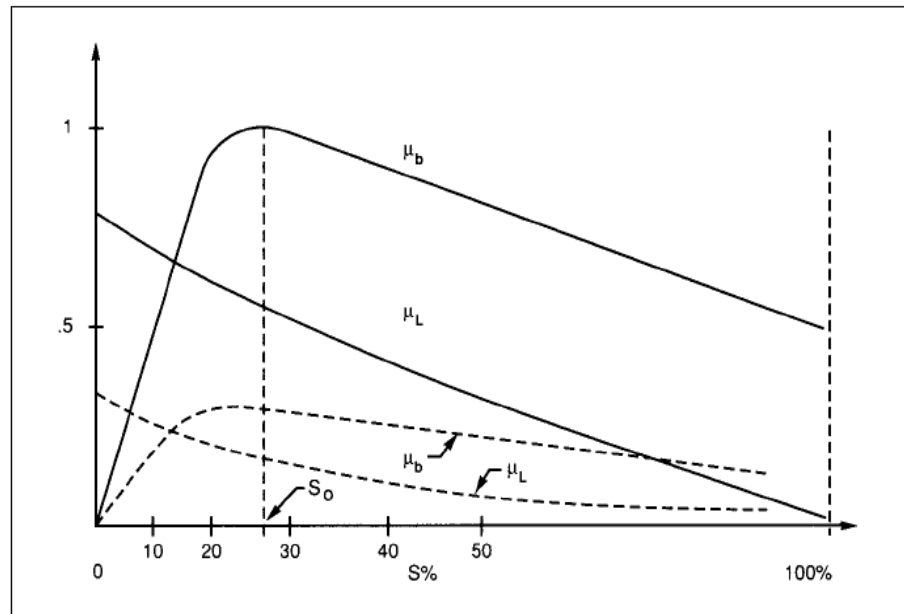


This force acts as a torque T_b in opposition to the wheel rotation. The actual force that decelerates the car is shown as F_b in Figure 8.13. The lateral force that maintains directional control of the car is shown as F_L in Figure 8.13. The wheel angular speed begins to decrease, causing a difference between the vehicle speed U and the tire speed over the road (i.e., wR). In effect, the tire slips

relative to the road surface. The amount of slip (S) determines the braking force and lateral force. The slip, as a percentage of car speed, is given by

$$S = \frac{U - wR}{U} \times 100\%$$

Figure 8.14
Braking Coefficients
versus Tire Slip (Solid
curves for dry road,
dashed curves for wet
or icy road)



MODULE 5

Automotive Diagnostics & Future Automotive Electronic Systems

TIMING LIGHT

The timing light (Figure 10.1) is used to measure and set ignition timing. It is a special stroboscopic light source that generates very short duration light pulses, the timing of which coincides with ignition pulses. The timing of these pulses is obtained from a special probe connected to a spark-plug wire. Figure 10.2 is a block diagram of a typical timing light. The probe generates a very short duration voltage pulse each time the spark plug fires. The pulse is amplified and then operates a trigger electrode on a flash lamp that is a gas discharge tube. When triggered, a current pulse flows through the flash lamp, generating a short burst of light. In timing the ignition, the light from the flash lamp is directed at the pulley on the front end of the crankshaft. Adjacent to the pulley is a pointer, such as seen in Figure 10.3. On the pulley are several marks. The relationship between the pointer and these marks corresponds to specific crankshaft angular positions relative to top dead center (TDC). The relationship of the pointer and crankshaft pulley marks at the time of ignition can be seen by viewing the pulley using the light from the flash lamp. When the ignition timing is correct, the pointer will align with the correct pulley mark.

Figure 10.1
Typical Engine Timing
Light

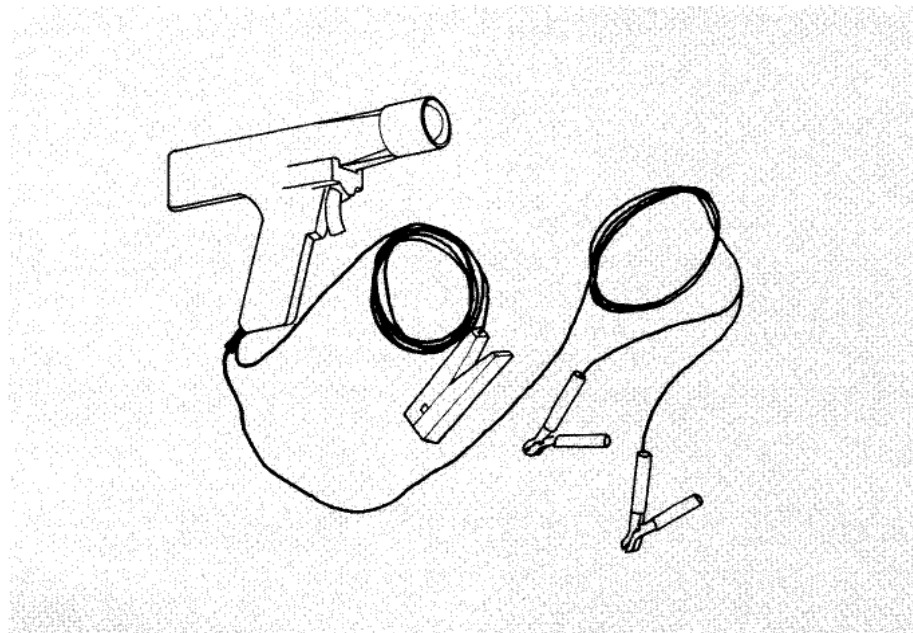


Figure 10.2
Timing Light Block
Diagram

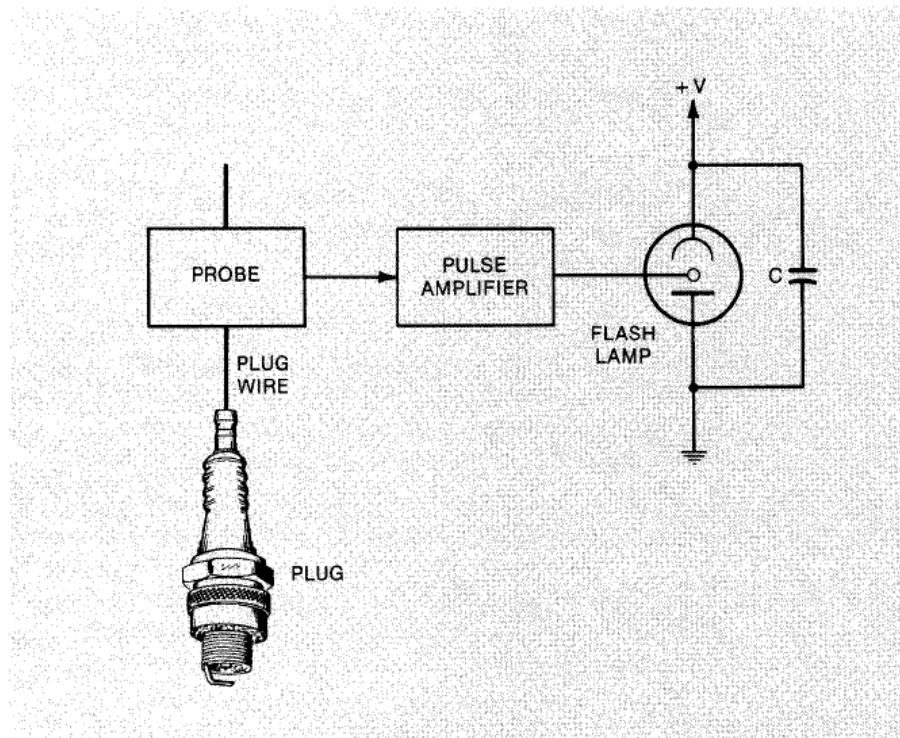
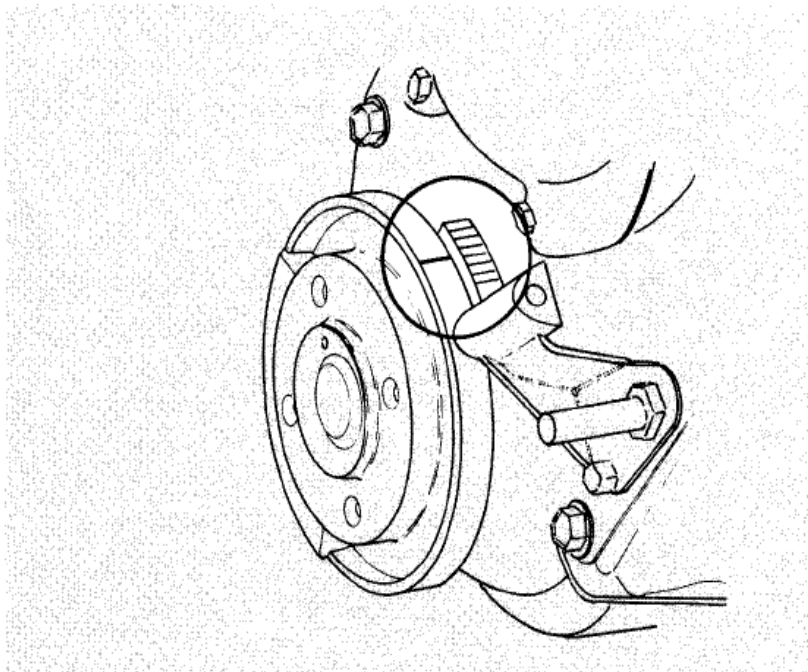


Figure 10.3
Timing Marks



ENGINE ANALYZER

The engine analyzer is an instrument that has existed for many years and continues to be used in garages for several tune up tasks. It provides, for example, a means for optimally setting the gap for ignition points (in cars that still have them, of course) by measuring the so-called dwell. Dwell is essentially the fractional duration that the ignition points are closed. However, an engine analyzer's role in diagnosing cars that have digital engine control systems is markedly different than its role in the diagnosis of cars that have analog or mechanical control systems. For example, ignition points have virtually been eliminated in digitally controlled cars. Nevertheless, the concept of dwell is still applicable, only today it represents the amount of time current flows through the coil primary circuit before this circuit is interrupted. In addition, in certain cases ignition timing can be measured by measuring the relative strength (peak voltage) of ignition pulses. Although the engine analyzer continues to be a useful instrument, it is not adequate for diagnosing problems in electronically controlled systems.

While it is true that both the timing light and the engine analyzer will continue to be used because there are many cars still on the roads whose engines are controlled either by analog or mechanical systems, it is probable that the use of these two diagnostic instruments will be phased out within a few years.

On-Board Diagnostics

Limited diagnostic capability is provided in any modern microprocessor based electronic control system. These diagnostic functions are performed by the microprocessor under the control of stored programs, and are performed only when the microprocessor is not fully committed to performing normal control calculations. While it is beyond the scope of this book to review the actual software involved in such diagnostic operations, the diagnostic procedures that are followed and explanations of on-board diagnostic functions can be reviewed. During the normal operation of the car, there are intermittent periods during which various electrical and electronic components are tested. Whenever a fault is detected, the data are stored in memory using a specific fault code. At the same time, the controller generates or activates a warning lamp (or similar display) on the instrument panel, indicating that service is required. The on-board diagnostic functions have one

major limitation—they cannot detect intermittent failures reliably. For the system to detect and isolate a failure, the failure must be nonreversible. In most on-board diagnostics, the electronic control module stores trouble codes that are automatically cleared by the microprocessor after a set number of engine cycles have occurred without a fault reappearing. The on-board diagnostic capabilities can be manually activated by causing the engine controller to enter a diagnostic mode. The method for accomplishing this task varies from car to car. For example, in certain older-model fuel-injected Cadillac cars, the diagnostic mode is entered by first switching on the ignition, then simultaneously depressing the Off and Warmer buttons on the climate control system. The use of on-board diagnostics can easily be illustrated by outlining typical procedures and using the Cadillac system as an example system. Although display of the fault codes varies from car to car, in each case the codes must be readable as a numeric code. A typical method involves flashing the “Check Engine” light. The mechanic enters the display mode and then counts the number of times that this light is flashed, in two-digit groups. For example, a fault code 24 would be given by 2 flashes then 4 flashes. After a short time interval, the next code would similarly be flashed in two-digit sequence. At one time Cadillac used the environment controller to display a two-digit code. Figure 10.4 is a drawing of a Cadillac environmental system displaying code 88. This particular code is used to check that all display segments are working correctly and is the first display shown when the diagnostic mode is entered. After verifying that all display segments are working, the fault codes for all component failures are displayed in sequence, beginning with the lowest and proceeding to the highest. The mechanic notes the fault codes that are displayed and, using a reference manual, identifies the failed components. Table 10.1 is a summary of the Cadillac fault codes, which we present here simply as an example of two-digit fault code assignment. After all fault codes have been displayed, the number 70 appears on the climate control head, and the engine control system awaits further action by the mechanic. Typically, the “Check Engine” light on the instrument panel is illuminated whenever any fault occurs. For codes 12 through 38 and 51 in Table 10.1, this warning light goes out automatically if the malfunction clears. However, the control module stores the code associated with the detected failure until the diagnostic system is manually cleared, or until 20 engine cycles occur with no malfunction. For codes 44 and 45, the “Check Engine” light will not go out until cleared from memory by the mechanic. For codes 60 through 68, there is no activation of the “Check Engine” light. Whenever a defect occurs (as

indicated by a fault code), the mechanic must follow a specific procedure to isolate the particular problem. These procedures are outlined for the mechanic as a sequence of steps to be followed. An example procedure will be illustrated here by following the steps necessary to respond to the specific fault code 13, which indicates that the oxygen (O₂ or EGO) sensor is not ready. Recall from the discussion in Chapter 6 that the O₂ sensor switches between approximately 0 and 1 volt as the mixture switches between the extreme conditions of lean and rich. Recall also that this voltage swing requires that the O₂ sensor must be at a temperature above 200°C. Fault code 13 means that the O₂ sensor will not swing above or below its cold voltage of approximately 0.5 volt

Figure 10.4
Fault Code Display

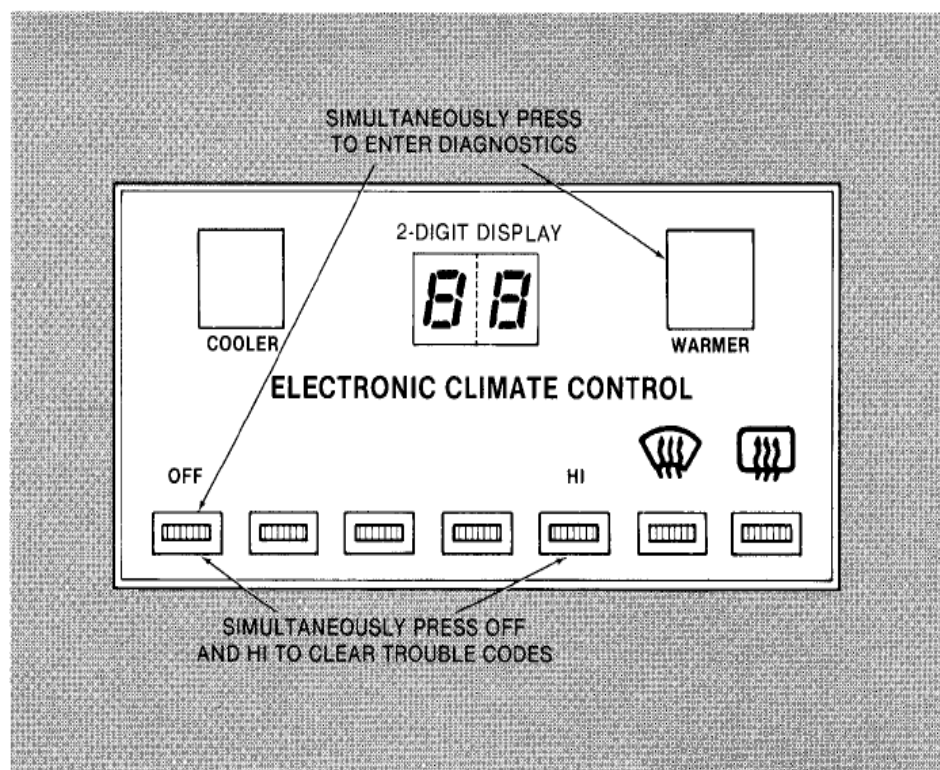


Table 10.1
Summary of
Fault Codes

Circuit Affected	Two-Digit Fault Code
No distributor signal	12
EGO sensor not ready	13
Coolant sensor circuit (short)	14
Coolant sensor (open)	15
Generator voltage out of range	16
Crank signal (short)	17
Crank signal (open)	18
Fuel pump circuit (short)	19
Fuel pump circuit (open)	20
Throttle position sensor circuit (short)	21
Throttle position sensor (open)	22
Ignition/Bypass	23
Engine speed sensor	24
Throttle switch (short)	26
Throttle switch (open)	27
Idle speed control	30
MAP sensor circuit (short)	31
MAP sensor circuit (open)	32
MAP/Baro sensor correlation	33
MAP signal too high	34
Baro sensor circuit (short)	35
Baro sensor circuit (open)	36
Manifold air temp (short)	37
Manifold air temp (open)	38
Lean exhaust signal	44
Rich exhaust signal	45
PROM error indicator	51
Transmission not in drive	60
"Set" and "resume" circuits engaged simultaneously	61
Car speed exceeds maximum limit	62

Table 10.1
(Continued)

Circuit Affected	Two-Digit Fault Code
Car and set speed tolerance exceeded	63
Car acceleration exceeds maximum limit	64
System ready for further tests	70
Cruise control brake circuit test	71
Throttle switch circuit test	72
Drive (ADL) circuit test	73
Reverse circuit test	74
Cruise on/off circuit test	75
"Set/Coast" circuit test	76
"Resume/Acceleration" circuit test	77
"Instant/Average" circuit test	78
"Reset" circuit test	79
Air conditioner clutch circuit test	80
Display check	88
System ready to display engine data	90
All diagnostics complete	00

Off-Board Diagnosis

An alternative to the on-board diagnostics is available in the form of a service bay diagnostic system. This system uses a computer that has a greater diagnostic capability than the vehicle-based system because its computer is typically much larger and has only a single task to perform—that of diagnosing problems in engine control systems. An example of an early service bay diagnostic system is General Motors' CAMS (Computerized Automotive Maintenance System). Although the system discussed here is essentially obsolete, it is at least representative of this level of diagnosis. The GM-CAMS used an IBM PC/AT computer that had considerable computational capability for its time. Its memory included 640K of RAM, 1.2 million bytes on a 5.75-inch diskette drive and 20 million bytes on a fixed disk drive. This system was capable of detecting,

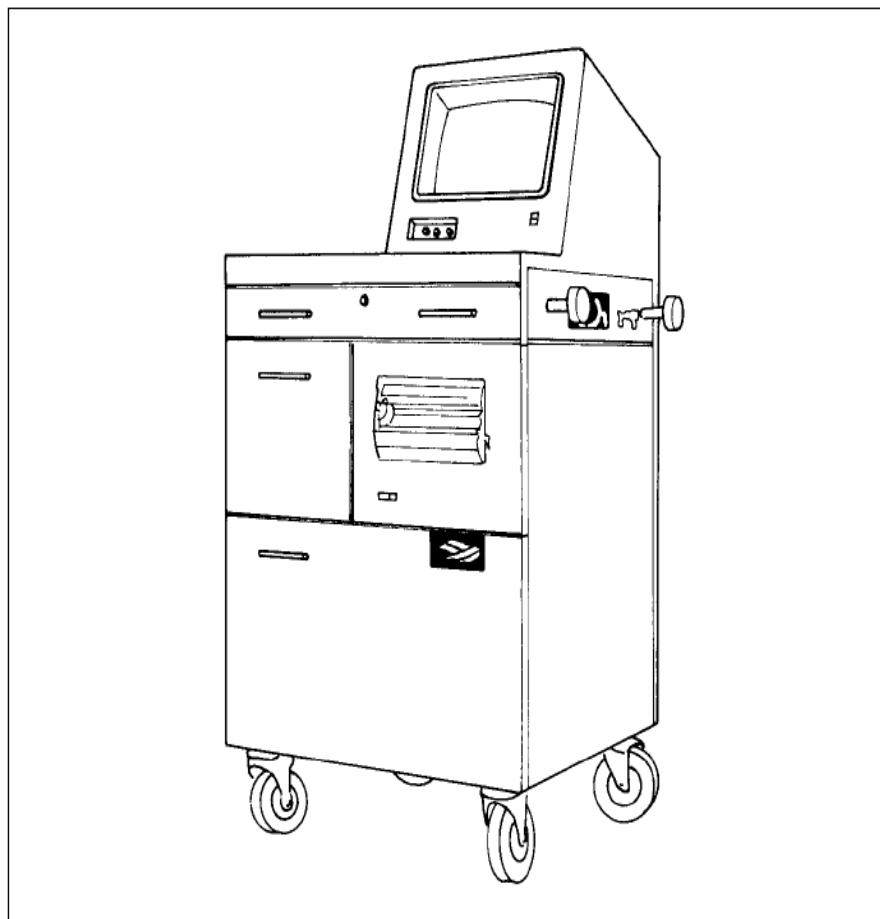
analyzing, and isolating faults in late-model GM vehicles that are equipped with a digital engine control system. This system, commonly called the technicians' terminal, has a modem equivalent that operates in essentially the same way as the CAMS. The technicians' terminal is mounted on a rugged portable cart (Figure 10.12) suitable for use in the garage. It connects to the vehicle through the assembly line data link (ALDL). The data required to perform diagnostics are obtained by the terminal through this link. The terminal has a color CRT monitor (similar to that of a typical home computer) that displays the data and procedures. It has a touch-sensitive screen for technician input to the system. The terminal features a keyboard for data entry, printer for hard copy output and modem for a telephone link to a network that collects and routes GMCAMS information.

The GM system also features a mainframe computer system at the General Motors Information Center (GMIC) that contains a master database that includes the most recent information relating to repair of applicable GM cars. This information, as well as computer software updates, is relayed throughout the network. Mechanics can also obtain diagnostic assistance by calling the GM-CAMS Customer Support Center. When using the GM-CAMS, the mechanic enters the vehicle identification number (VIN) via the terminal. The computer responds by displaying a menu in which several choices are presented. To select a particular choice the technician touches the portion of the display associated with that choice. Next, the computer displays an additional menu of further choices; this continues until the mechanic has located the desired choice. Among the many capabilities of the technicians' terminal is its ability to store and display the diagnostic charts that appear in the shop manual. Whenever a fault is located, the appropriate chart(s) are automatically displayed for the mechanic.

This capability greatly increases the efficiency of the diagnostic process. In addition, the GM-CAMS computer can store all of the data that are associated with the diagnostic procedures for several vehicles and then locate and display, virtually instantaneously, each specific procedure as required. Furthermore, updates and the most recent service bulletins are brought into the mechanics' terminal over the phone network so that mechanics lose no time trying to find the most recent data and procedures for diagnosing vehicular electronic systems. The technology for the technicians' terminal has continued to evolve from the GM-CAMS system to the present-day system by incorporating all new digital technology. Of course, the computational capability and memory capacity of evolving systems have taken advantage of the latest improvements in

computer and digital communication technology. Newer and faster microprocessors are incorporated as they become available. Memory capacity is many orders of magnitude greater than that available in GM-CAMS or similar systems. Repair procedures and illustrated parts lists are downloaded via a dedicated satellite link to the technicians' terminal as needed for any given repair, completely replacing the printed versions that were used in the past. This electronic version of the shop manual has greatly simplified the task of updating repair procedures and other maintenance/diagnostic data and information with respect to any model changes or any other changes that occur during the production run of a given car model. In addition to storing and displaying shop manual data and procedures, a computer-based garage diagnostic system can automate the diagnostic process itself. In achieving this objective, the technicians' terminal has the capability to incorporate what is commonly called an expert system.

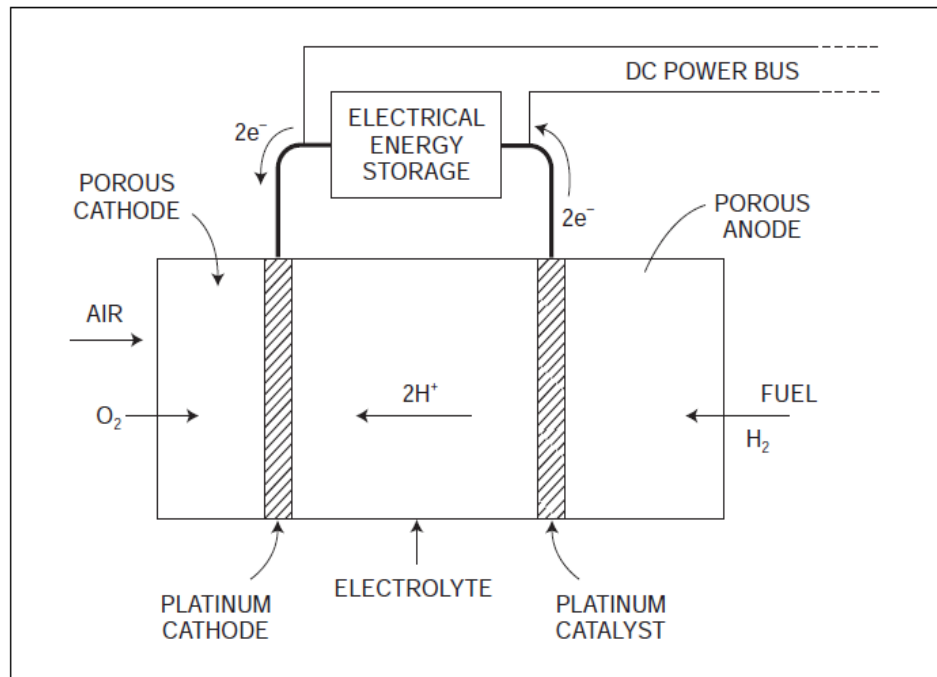
Figure 10.12
Engine Data Display



Fuel Cell-Powered Cars

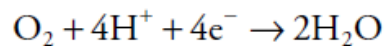
There is a form of electrically powered car that may mitigate the energy density problem. The energy is stored in a chemical fuel that has the capability of great energy density, and electric power is created in a device known as a fuel cell. In its simplest form, a fuel cell converts energy stored in hydrogen (H_2).

Figure 11.9
FFV System
Fuel Cell
Configuration



Directly into electric power. Its only exhaust product is water (H_2O). hydrogen-fueled fuel cell can theoretically produce electricity in amounts suitable to power a car (via an electric motor), with performance comparable to that of gasoline-fueled cars and with zero harmful exhaust emissions (i.e., only water). The great potential for fuel-cell-powered cars has motivated and will continue to motivate research and development aimed at solving a myriad of practical problems that pose obstacles to the practical fuel-cell-powered car. For an understanding of some of those problems, it is instructive to briefly review the theory of the fuel cell. A fuel cell configuration is shown in Figure 11.9. The fuel cell structure depicted here is known as a proton exchange membrane (PEM) cell. It consists of a pair of porous electrodes: an anode and a cathode separated by an electrolyte. Each electrode is coated on the electrolyte side with a platinum catalyst. The porous anode is supplied with hydrogen (H_2) which diffuses through the anode to the platinum-coated junction between the anode and the electrolyte. The platinum catalyst causes each hydrogen

atom to separate into a free electron and a positively charged hydrogen ion (H⁺) which is, in fact, a proton. At the same time, the porous cathode is exposed to oxygen (O₂), which passes through the cathode to the corresponding platinum catalyst. The free electrons migrate from the anode to the cathode passing through an external circuit (including an energy storage device or battery). Owing to the catalytic action, the cathode chemical reaction is:



That is, the oxygen combines with free electrons and hydrogen ions to form water. There is no other exhaust product for this ideal reaction. Unfortunately, a number of tough technical problems must be overcome before the fuel-cell-powered electric car can become a practical reality. Not the least of these problems is the storage of hydrogen, which can be achieved either directly as gaseous or liquid hydrogen or indirectly in a liquid hydrogen-rich fuel. These storage methods have numerous advantages and disadvantages. The direct storage technique has the advantage that the hydrogen is available to be supplied from the storage means directly to the fuel cell. The disadvantage of direct storage is that the hydrogen must be stored at very high pressure or at very low temperatures. Another disadvantage of direct storage is the lack of an existing infrastructure to supply gaseous or liquid hydrogen to the customer. However, should the direct storage method prove to be practical, this infrastructure will develop rapidly. The advantages of indirect storage include high-energy density for liquid fuel and a wide range of liquid fuels from gasoline through vegetable oil. Even methanol has great potential as a liquid fuel for fuel-cell-powered cars. The major disadvantage of indirect storage is the requirement to create hydrogen from the hydrogen-rich fuel. Creation of hydrogen from liquid fuel requires a catalytic device known as a reformer. The reformer chemically breaks down the liquid fuel into hydrogen and various compounds of carbon and other chemical elements, all of which must be separated from the hydrogen before it is supplied to the fuel cell. Even small amounts of impurities in the hydrogen can eventually degrade the fuel cell performance. Moreover, these other chemical compounds are released in the system exhaust and are potentially harmful. Another practical problem limiting the application of fuel cells in electric cars is their relatively slow dynamic response. Performance of a fuel cell is enhanced by nearly steady-state operation. A practical fuel cell-powered car will most likely require electrical storage cells, that can supply current as required at the widely varying power

levels associated with driving an electric car. The fuel cell will mostly be used to replace electric energy taken from the storage cells, with the goal of maintaining a target state-of-charge.

Collision Avoidance Radar Warning System

An interesting safety-related electronic system with potential for future automotive application is the anticollision warning system. An on-board low-power radar system can be used as a sensor for an electronic collision avoidance system to provide warning of a potential collision with an object lying in the path of the vehicle. As early as 1976, at least one experimental system was developed that could accurately detect objects up to distances of about 100 yards. This system gave very few false alarms in actual highway tests. For an anti-collision warning application, the radar antenna should be mounted on the front of the car and should project a relatively narrow beam forward. Ideally, the antenna for such a system should be in as flat a package as possible, and should project a beam that has a width of about 2° to 3° horizontally and about 4° to 5° vertically. Large objects such as signs can reflect the radar beam, particularly on curves, and trigger a false alarm. If the beam is scanned horizontally for a few degrees, say 2.5° either side of center, false alarms from roadside objects can be reduced. In order to test whether a detected object is in the same lane as the radar equipped car traveling around a curve, the radius of the curve must be measured. This can be estimated closely from the front wheel steering angle for an unbanked curve. Given the scanning angle of the radar beam and the curve radius, a computer can quickly perform the calculations to determine whether or not a reflecting object is in the same lane as the protected car. For the collision warning system, better results can be obtained if the radar transmitter is operated in a pulsed mode rather than in a continuous wave mode. In this mode, the transmitter is switched on for a very short time, then it is switched off. During the off time, the receiver is set to receive a reflected signal. If a reflecting object is in the path of the transmitted microwave pulse, a corresponding pulse will be reflected to the receiver. The round-trip time, t , from transmitter to object and back to receiver is proportional to the range, R , to the object, as illustrated in Figure 11.11 and expressed in the following equation.

$$t = \frac{2R}{c}$$

Figure 11.11
Range to Object for
Anticollision Warning
System

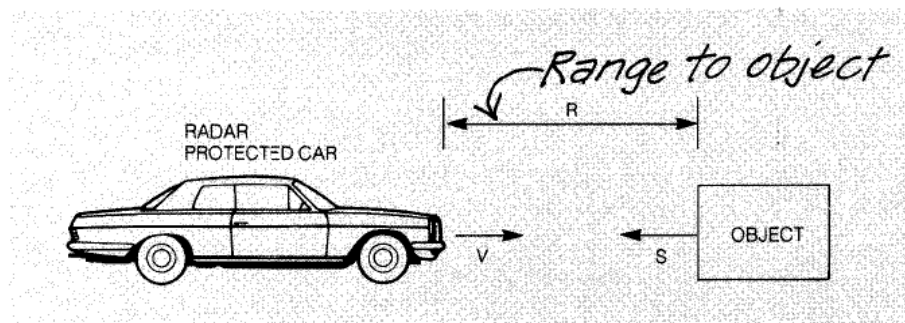
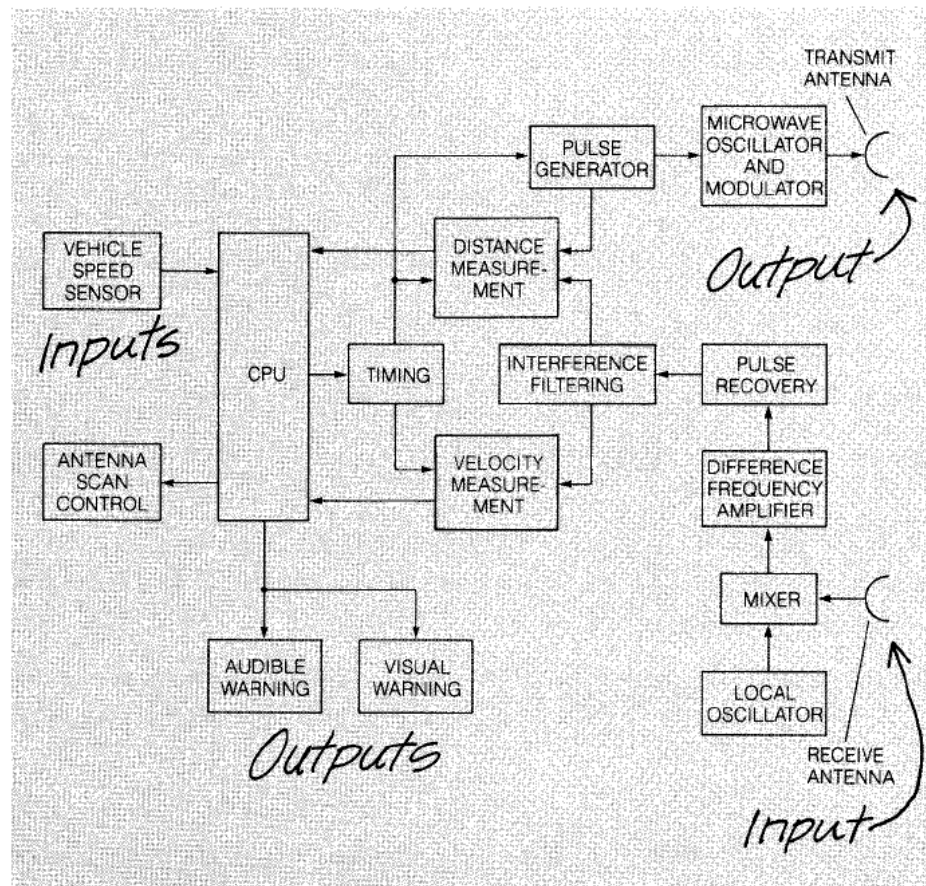


Figure 11.12
Collision Avoidance
Warning System

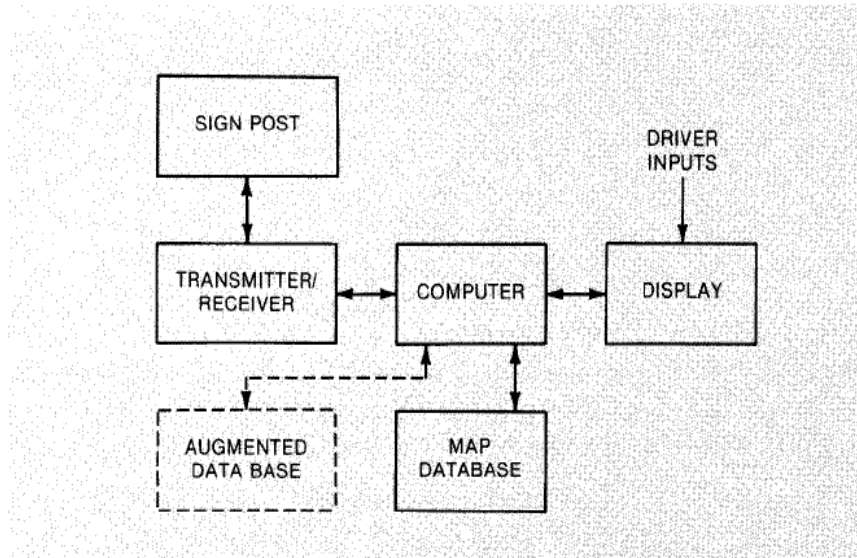


Signpost Navigation

In signpost navigation, a number of information stations (signposts) are located throughout the road network. In one scheme, the signpost continuously transmits data concerning its geographic location. The on-board navigation system converts these data to map coordinates, which are displayed. Figure 11.21 is a block diagram of a typical signpost navigation system. This system requires an augmented database to convert the transmitted data to map coordinates. This system

has the capability to provide position to an accuracy of a few meters. There are drawbacks to the signpost system, however, including an inability to determine position between signposts, inability to show a turn until the next signpost is reached, the need for signposts at every intersection, and the requirement for a large number of codes. Thus, in spite of the high accuracy of this system, it inherently requires a huge investment in infrastructure.

Figure 11.21
Signpost Navigation
System



Dead Reckoning Navigation

Dead reckoning navigation is a method of determining present position from a known earlier position and information about vehicle motion. Figure 11.22 is a block diagram for such a system. The sensor components of this system include a heading sensor and a wheel speed sensor. Navigation systems of this type have been commercially available for some time. However, integration of this dead reckoning navigation system into a multi sensor navigation system has not been available (the combined system being potentially a future electronic feature). The use of heading and speed information is illustrated in Figure 11.23. Experimental systems have used a form of magnetic compass sensor, known as a flux gate, to measure heading. Although this system is conceptually simple, it suffers from poor accuracy. It is estimated that a position error of about half a block would accrue for trips of less than six miles. Typically, an electronic dead reckoning system employs a solid-state CRT-type screen (see Chapter 9) as a display device for presenting a map of the relevant geographic region. In at least one commercial system, there are eight different

levels of resolution. The maps are generated from digital data that are stored on a compact disk (CD-ROM). Using the stored data, the electronic map is displayed on the screen, identifying the present position of the car as well as its destination. Using the present position (Po of Figure 11.23), the new position (P1) is calculated.

Errors occur in any dead reckoning navigation system after a time. However, in automotive navigation systems, such errors can be readily bounded. It is presumed that the car is on a road (or in a driveway or parking lot) at all times. The coordinates of the road are known as part of the navigation database. Wherever the estimated position (P1) is off the road, the computer adjusts the car position to the nearest point on the road. This correction procedure is known as map matching and results in extremely accurate navigation.

QUESTION BANK**MODULE-1**

1. Discuss the operation of 4-stroke cycle of an engine.
2. What is stoichiometric mixture? Discuss the effect of air-fuel ratio on engine's performance.
3. Define the general terms i) Parameter i) Variable
4. Explain the working principle spark plug with a neat sketch
5. What are the potential applications of electronics in automobile?
6. What is meant by distributor less ignition system (DIS)? How it is different from Distributor based ignition system.
7. Define fuel economy. Why the mileage (fuel economy) of vehicles is not unique?
8. What is suspension? Explain its working operation.
9. Discuss the working of disk brake system.
10. What is steering angle? Discuss the steering mechanism with neat sketch.
11. Define bottom dead center.
12. Define top dead center.
13. What is Three-Way Catalyst? Discuss its importance.
14. What are the different control strategies available in automobiles to avoid exhaust emission?
15. Discuss the Effect of Exhaust Gas Recirculation on Performance.
16. Discuss the Effect of Effect of Spark Timing on Performance.
17. Discuss the Effect of Effect of Air/Fuel Ratio on Performance.
18. Define Volumetric Efficiency.
19. Define Thermal Efficiency.
20. Define Calibration.

MODULE 2

1. What are the variables to be measured with respect to engine control?
2. Explain the working of air flow sensor.
3. What is need of strain guage sensor? Mention its advantages.
4. Write a brief note on Magnetic Reluctance Position Sensor.
5. What is Hall Effect? Discuss the working of Hall effect Position Sensor.
6. Write a note on Throttle Angle Sensor.
7. Discuss the working of Exhaust Gas Oxygen (O₂/EGO) Lambda Sensors.
8. Discuss the need of Fuel Injector in automobiles.
9. Define actuator. Discuss the working of EGR Actuator.
10. Explain the ignition system in detail.
11. Discuss the working of Engine Coolant Temperature (ECT) Sensor.
12. Mention the importance of Knock Sensor.
13. Give the working principle of Solenoid.
14. Discuss the working of Optical Crankshaft Position Sensor.
15. What is piezoelectric sensor?
16. Sketch the Waveform of Hall Element Output Voltage for Position Sensor.
17. Sketch the Output Voltage Waveform from the Magnetic Reluctance Crankshaft Position Sensor Coil.
18. Discuss the working of magnetic reluctance sensor.
19. Define variable valve timing.
20. Sketch Ideal EGO Switching Characteristics.

MODULE 3

1. Discuss the seven Control modes for fuel Control.
2. List out the Spark Advance Correction Schemes.
3. Explain the Closed loop Ignition timing.
4. Briefly discuss the secondary air management system.
5. What is fuel economy? List the parameters which affect the fuel economy.
6. Define parameter & variables.
7. Define brake specific force.
8. Discuss the function of Evaporative Emissions Canister Purge.
9. Mention the Operating conditions of automobile.
10. Write a short note on i) Data processing ii) Programming.
11. List out the Digital modules in the Control unit.
12. Write a note on Control unit software.
13. Explain about System Diagnostics.
14. What is EGR Control? Discuss its importance.
15. Discuss variable valve timing control.
16. What is knock level detector?
17. Discuss fast correction spark advance scheme.
18. Discuss slow correction spark advance scheme.
19. What is need of Automatic System Adjustment in automobiles.
20. Mention the Digital Engine control features.

MODULE 4

1. Classify the bus system. Discuss each class in brief.
2. List out Applications in the vehicle.
3. Write a note on networked vehicles.
4. Discuss CAN Bus technology.
5. Discuss MOST Bus technology.
6. Discuss LIN Bus technology.
7. Explain Bluetooth technology in automobile.
8. Explain FlexRay technology in automobile.
9. What is Digital Cruise Control System? Explain its operation with block diagram.
10. What is Antilock Brake System (ABS)? Discuss its operation.
11. Write a note on coupling networks.
12. Discuss Diagnostic Interfaces in automobiles.
13. Discuss each block of Typical Cruise Control System.
14. Explain the working of Digital Speed Sensor.
15. What is throttle actuator? Discuss its operation.
16. Explain the working of Vacuum-Operated Actuator.
17. Write the circuit of Typical Sample-and-Hold process.
18. Sketch Wheel Torque versus Slip curve.
19. Sketch ABS Braking Action curve.
20. What is Tire-Slip Controller.

MODULE 5

1. Write a short note on Timing Light.
2. Write a short note on Engine Analyzer.
3. Discuss On-board diagnostics.
4. Discuss Off -board diagnostics.
5. What are expert systems? Discuss in detail.
6. Explain the operations of Accelerometer based Air Bag systems.
7. Differentiate between Alternative Fuel Engines, Electric and Hybrid vehicles.
8. Discuss about Fuel cell powered cars.
9. Explain Collision Avoidance Radar warning Systems.
10. Write a note on Radio Navigation.
11. What is Signpost navigation.
12. What is dead reckoning navigation.
13. Discuss the advantages of Voice Recognition Cell Phone dialing.
14. Discuss Advanced Cruise Control.
15. What is Stability Augmentation?
16. Explain Automatic driving Control.
17. What are Occupant Protection Systems?
18. Write a short note on Low tire pressure warning system.
19. How to do Speech Synthesis in automobiles.
20. Discuss about Heads Up display with respect to automobiles.