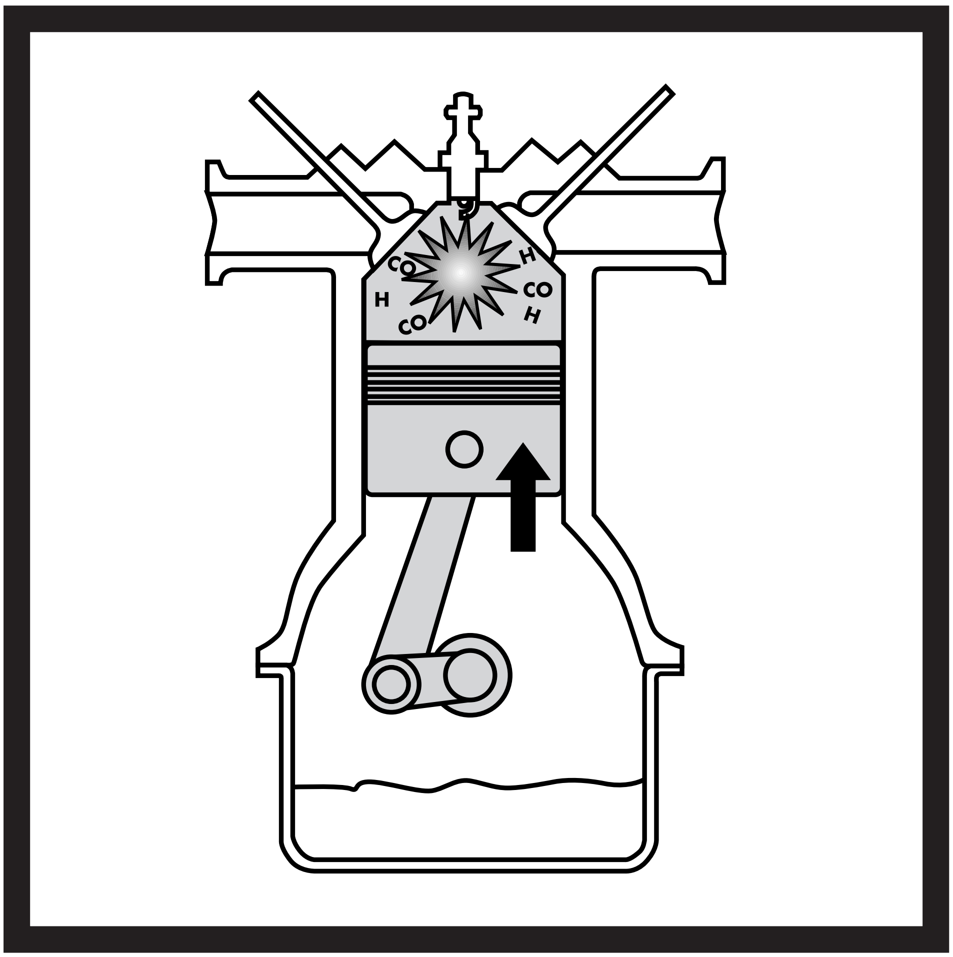
Technical Service Training

Global Fundamentals

Curriculum Training – TF1010008S

Engine Performance



Student Information

Ford Motor Company

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FCS-13194-REF

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Global fundamentals training overview

The goal of the Global Fundamentals Training is to provide students with a common knowledge base of the theory and operation of automotive systems and components. The Global Fundamentals Training Curriculum (FCS-13203-REF) consists of nine self-study books. A brief listing of the topics covered in each of the self-study books appears below.

- Shop Practices (FCS-13202-REF) explains how to prepare for work and describes procedures for lifting materials and vehicles, handling substances safely, and performing potentially hazardous activities (such as welding). Understanding hazard labels, using protective equipment, the importance of environmental policy, and using technical resources are also covered.
- Brake Systems (FCS-13201-REF) describes the function and operation of drum brakes, disc brakes, master cylinder and brake lines, power-assist brakes, and anti-lock braking systems.
- Steering and Suspension Systems (FCS-13196-REF) describes the function and operation of the power-assisted steering system, tires and wheels, the suspension system, and steering alignment.
- Climate Control (FCS-13198-REF) explains the theories behind climate control systems, such as heat transfer and the relationship of temperature to pressure. The self-study also describes the function and operation of the refrigeration systems, the air distribution system, the ventilation system, and the electrical control system.
- Electrical Systems (FCS-13197-REF) explains the theories related to electricity, including the characteristics of electricity and basic circuits. The self-study also describes the function and operation of common automotive electrical and electronic devices.
- Manual Transmission and Drivetrain (FCS-13199-REF) explains the theory and operation of gears. The self-study also describes the function and operation of the drivetrain, the clutch, manual transmissions and transaxles, the driveshaft, the rear axle and differential, the transfer case, and the 4x4 system.
- Automatic Transmissions (FCS-13200-REF) explains the function and operation of the transmission and transaxle, the mechanical system, the hydraulic control system, the electronic control system, and the transaxle final drive. The self-study also describes the theory behind automatic transmissions including mechanical powerflow and electro-hydraulic operation.
- Engine Operation (FCS-13195-REF) explains the four-stroke process and the function and operation of the engine block assembly and the valve train. Also described are the lubrication system, the intake air system, the exhaust system, and the cooling system. Diesel engine function and operation are covered also.
- Engine Performance (FCS-13194-REF) explains the combustion process and the resulting emissions. The self-study book also describes the function and operation of the powertrain control system, the fuel injection system, the ignition system, emissions control devices, the forced induction systems, and diesel engine fuel injection. Read Engine Operation before completing Engine Performance.

To order curriculum or individual self-study books, contact Helm Inc.

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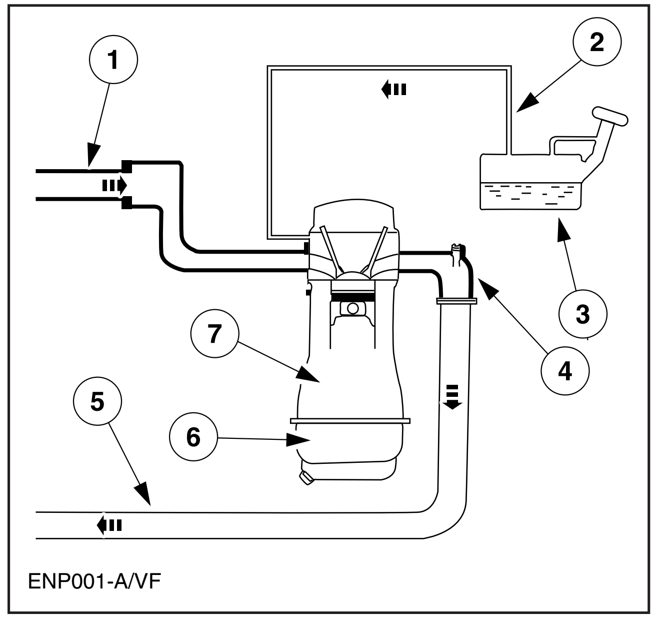
Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of the combustion process.
- Define combustion.
- Identify combustion elements.
- Explain the process of combustion.

Introduction

The internal combustion engine mixes a small amount of fuel with readily available air to create combustion. Unfortunately, the internal combustion engine cannot completely burn all the fuel it uses. Because of this, the engine sends out combustion by-products in the exhaust gases. Some of these by-products are harmful and pollute the air. In response to this problem, automobile manufacturers have developed emission control devices that limit or eliminate these harmful pollutants.



Engine operating system overview

1 Air intake
2 Fuel line
3 Fuel tank
4 Exhaust manifold
5 Exhaust pipe
6 Oil pan
7 Crankcase

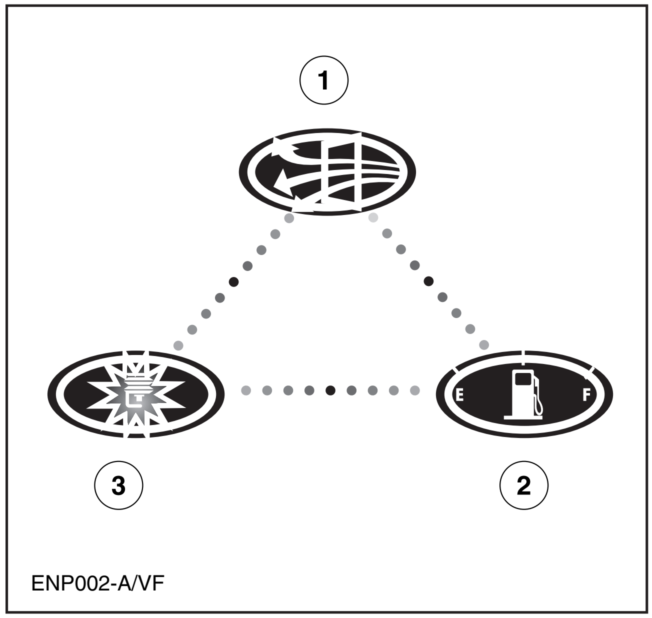
Combustion

During combustion, several chemical reactions take place. Some compounds break down, and new compounds form. Controlling the combustion process is key to controlling the overall performance and emissions of an internal combustion engine.

There are three elements required for combustion to occur:

1. Air
2. Fuel
3. Spark

These three elements are sometimes referred to as the "combustion triad". If one element is missing, combustion cannot take place. An internal combustion engine is designed to combine the three elements in a carefully controlled manner.



Combustion triad

1 Air
2 Fuel
3 Spark

Air

Air is composed of atoms of nitrogen (N), oxygen (O_2), and other gases. Air is mostly nitrogen, which is an inert, nonflammable gas. Air does not burn, but air does contain enough oxygen to support combustion.

Fuel

Gasoline is composed of hydrocarbons that have been refined from crude oil. Hydrocarbons are made up of hydrogen (H) and carbon (C) atoms. Various chemicals are added to gasoline, such as rust inhibitors, dyes, and detergents. These chemicals are referred to as additives.

The heat and pressure of an internal combustion engine can cause the gasoline to ignite in the combustion chamber before the spark occurs. This is called preignition and is described in greater detail later. A gasoline's octane rating indicates how well it resists preignition. Additional refining can increase the octane level.

Currently, a type of fuel called reformulated gasoline (RFG) is being used in regions with extremely high levels of air pollution. RFG has special additives called oxygenates, which improve combustion, increase octane, and reduce harmful emissions.

Spark

The internal combustion engine takes air and fuel into the combustion chamber and provides the spark to trigger combustion. Before igniting the air/fuel mixture, the engine heats and compresses the mixture. Heating helps the mixing process, and compression increases the energy created by the combustion.

Combustion (continued)

Combustion Process

In an internal combustion engine, combustion happens in a fraction of a second (approximately 2 milliseconds). In that instant, the bonds between the hydrogen and carbon atoms are broken. Breaking the bonds releases energy into the combustion chamber, forcing the piston downward and causing the crankshaft to rotate.

Once the hydrogen and carbon atoms are separated, they both combine with the oxygen atoms in the air. Hydrogen atoms combine with oxygen to form water. Carbon atoms combine with oxygen to form carbon dioxide.

Put into chemical terms, complete combustion in an internal combustion engine looks like this:

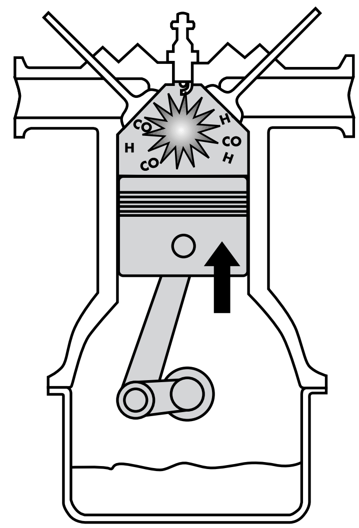
$HC + O_2 = H_2O + CO_2$

In other words:

fuel + oxygen = water and carbon dioxide

A perfectly efficient internal combustion engine would only emit water (H_2O) and carbon dioxide (CO_2), just as in the chemical formula above. That would mean that all the hydrocarbons were split apart during combustion. Unfortunately, this is not the case.

Inefficient combustion is the main cause of pollutants in automotive emissions. Efficient combustion produces the least amount of toxic emissions. Adjusting the air/fuel ratio increases combustion efficiency.



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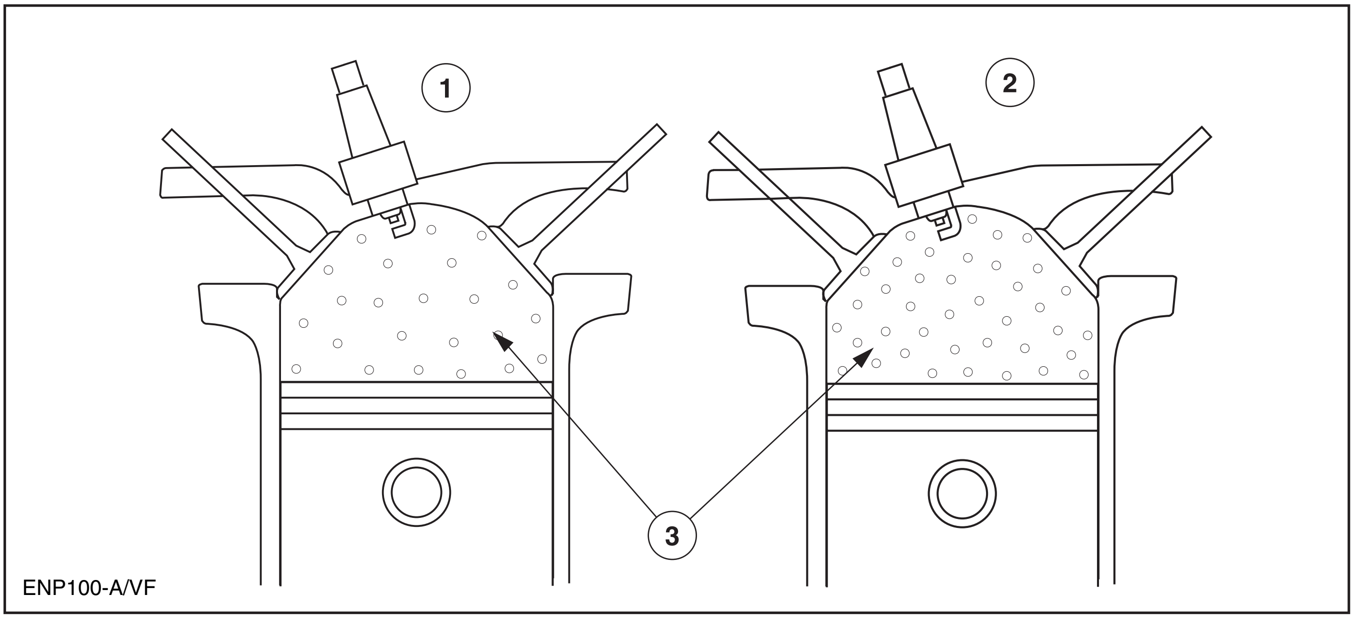
Combustion process

Air/fuel ratio



Comparison of lean and rich air/fuel ratio

1 Lean air/fuel ratio
2 Rich air/fuel ratio
3 Fuel molecules

Automotive engineers have determined that vehicle emissions can be reduced if a gasoline engine operates at an air-to-fuel ratio of 14.7:1. The technical term is known as “stoichiometric” ratio. Stoichiometric means a chemically correct mixture that produces the desired chemical reaction so that complete combustion of the fuel occurs with the desired gas emissions.

The air/fuel ratio of 14.7:1 provides the best control for all three elements (hydrocarbons, carbon monoxide and oxides of nitrogen) in the exhaust under almost all conditions. The air/fuel ratio also increases the efficiency of the catalytic converter, which is part of the vehicle exhaust system.

Lean air/fuel mixture

A lean air/fuel mixture is usually caused by a faulty condition in the engine. Lean is when the engine is receiving too much air or oxygen. Vacuum leaks or a faulty fuel delivery system can cause the oxygen levels to be too high.

Rich air/fuel mixture

A rich air/fuel mixture is also an indication that there is a fault condition with the engine. Rich is when the engine is not able to burn all the fuel that went into the combustion chambers. A rich condition can occur as a result of high fuel pressure, a problem with ignition timing, or low compression.

Combustion (continued)

Abnormal combustion

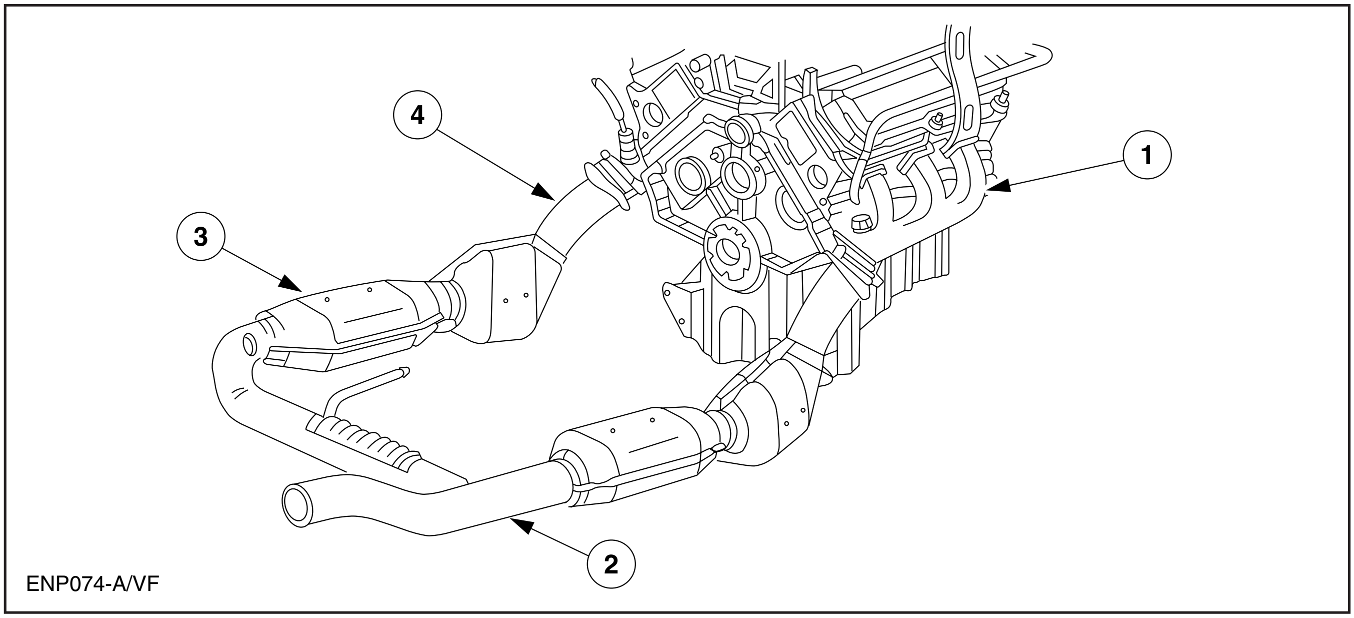
There are two types of abnormal combustion that can occur in an engine: detonation and pre-ignition.

Detonation (also called “spark knock”) is an erratic form of combustion that can cause head gasket failure as well as other engine damage. Detonation occurs when excessive heat and pressure in the combustion chamber develops. When this happens, an explosive force is created which produces a sudden rise in cylinder pressure accompanied by a sharp metallic pinging or knocking noise. The hammer-like shock waves created by detonation subjects the head gasket, piston, rings, spark plug and rod bearings to severe overloading.

Pre-ignition is another abnormal combustion condition that is sometimes confused with detonation. Pre-ignition occurs when a point within the combustion chamber becomes so hot that it becomes a source of ignition and causes the fuel to ignite before the spark plug fires which may contribute to or cause a detonation problem.

Instead of the fuel igniting at the right instant to give the crankshaft a smooth kick in the right direction, the fuel ignites prematurely, causing a momentary backlash as the piston tries to turn the crank in the wrong direction. This backlash can be very damaging because of the stresses it creates. Pre-ignition can also localize heat to such an extent that it can partially melt or burn a hole through the top of a piston.

Emissions



Typical exhaust system components

1 Exhaust manifold
2 Tail pipe
3 Catalytic converter
4 Exhaust pipe

A stoichiometric air/fuel mixture produces the best compromise between performance, economy, and emissions.

Rich air/fuel mixtures do not burn all the fuel, so hydrocarbon and carbon monoxide emissions increase. Lean air/fuel mixtures may burn extremely hot, so oxides of nitrogen increase. Extremely lean air/fuel mixtures result in misfire, so hydrocarbon emissions increase.

Catalytic converters, which chemically neutralize exhaust emissions, are most efficient in a very narrow range close to the stoichiometric ratio.

Emissions (continued)

Combustion By-Products

Because the internal combustion engine is not perfectly efficient, three unwanted by-products result from the combustion process:

1. Hydrocarbons (HC)
2. Carbon monoxide (CO)
3. Oxides of nitrogen (NO_X)

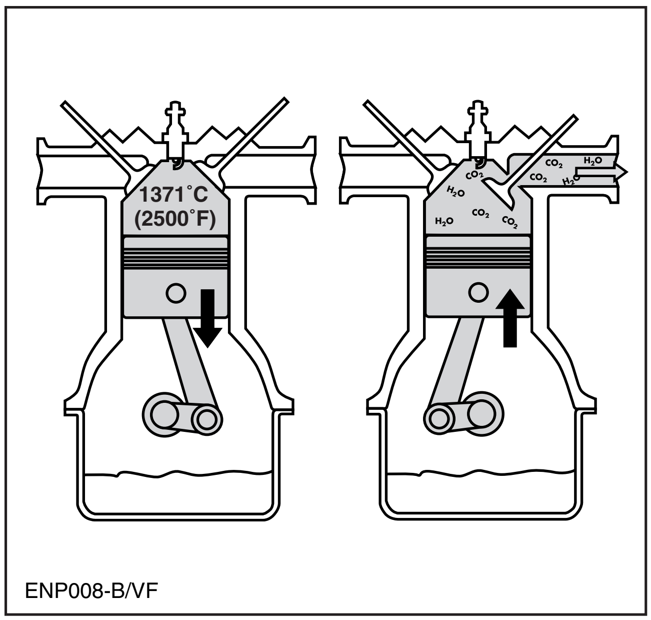
Incomplete combustion causes hydrocarbon and carbon monoxide emissions. Hydrocarbon emissions are the hydrocarbons that did not get broken down during combustion. Carbon monoxide is formed because there are not enough oxygen atoms to bond with.

Ideally, nitrogen would pass through the combustion chamber unchanged. But when the temperature of the combustion chamber reaches approximately 1,371º C (2,500º F), the nitrogen and oxygen atoms bond forming NO_X.

The chemical formula for combustion when oxides of nitrogen are formed looks like this:

$HC + O_2 + N_2 = H_2O + CO + NO_X$

The symbol "NO_X" is used for oxides of nitrogen because it represents the combination of a nitrogen atom and any number of oxygen atoms. For example, nitrogen oxide (NO) is made up of one nitrogen atom and one oxygen atom, while nitrogen dioxide (NO_2) is made up of one nitrogen atom and two oxygen atoms.



Nitrogen oxide produced by combustion

High HC

High HC can be caused by insufficient spark, incorrect ignition or valve timing, vacuum leaks, oil consumption, or low compression. Hydrocarbons are measured in parts per million.

High CO

High CO levels can be caused by:

- An overly rich fuel mixture
- A restricted air filter
- A failed PCV valve
- Oil contaminated by fuel
- A sticking or leaky fuel injector

On a properly operating vehicle with a catalytic converter, carbon monoxide is normally near zero. Carbon monoxide is measured as a percentage of total volume in air.

NO_x

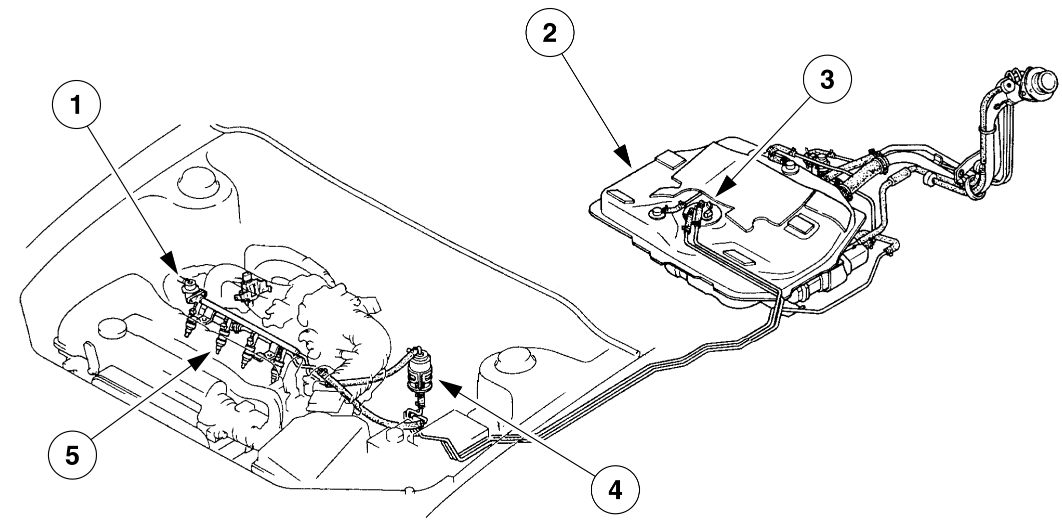
NO_x occur at high combustion temperatures above approximately 1,371º C (2,500° F) and occur normally unless the combustion temperature is controlled. Oxides of nitrogen are measured in parts per million (ppm).

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of the fuel delivery system.
- Describe the fuel delivery system.
- Identify the components of a fuel delivery system.
- Explain the theory and operation of the fuel delivery system.

Fuel delivery system



Fuel delivery system (typical)

1 Pressure regulator
2 Fuel tank
3 Fuel pump
4 Fuel filter
5 Fuel injector

Fuel delivery is a system for supplying the air and fuel mixture to an engine. The electronically controlled fuel delivery system replaced carburetor-based systems, which delivered fuel to the engine mechanically.

The fuel supply system provides fuel for combustion and maintains the fuel at a constant pressure relative to changes in intake manifold pressure. Two different fuel supply systems are used:

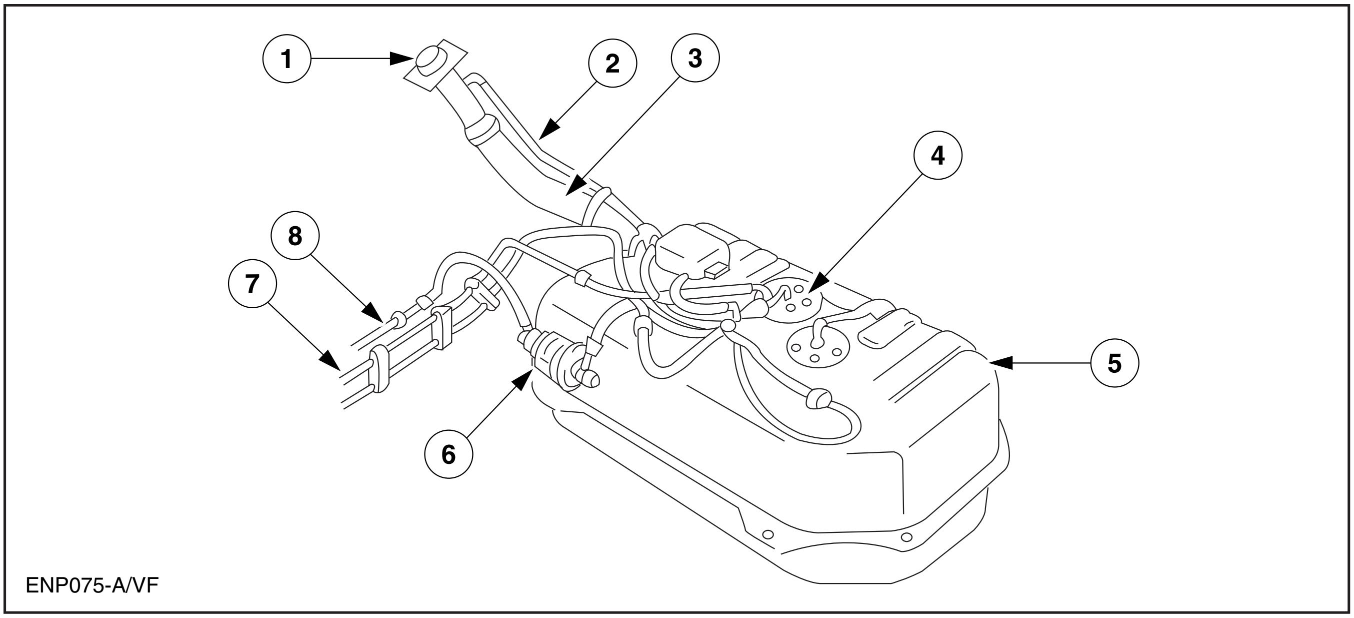
1. Loop, or return-type fuel system
2. Returnless fuel system

In the loop-type fuel system, pressurized fuel travels from the fuel tank to the injectors, and unused fuel circulates back to the fuel tank.

In the returnless fuel system, a fuel return line is not necessary. Since no fuel return is required, fuel vapors in the fuel tank are reduced, thereby reducing evaporative emissions.

Fuel delivery system (continued)

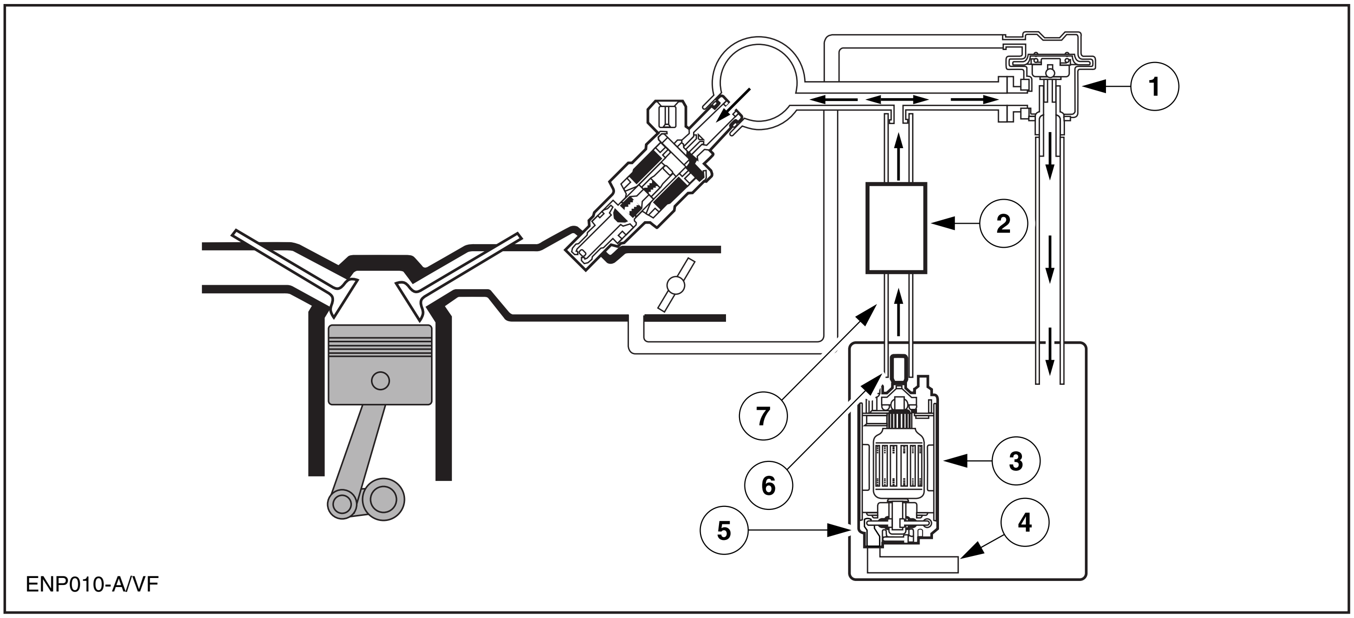
Fuel tank



Fuel tank components

1 Fuel filler cap
2 Breather hose
3 Filler tube
4 In-tank fuel pump
5 Fuel tank
6 Fuel filter
7 Fuel return pipe
8 Fuel feed pipe

The fuel tank is a reservoir that contains the fuel required for engine operation. The fuel tank generally is made of either metal or plastic. The fuel tank usually contains the fuel pump module, which includes an electric fuel pump. A fuel filler tube supplies fuel delivery into the tank. A removable, vented fuel filler cap threads into the fuel filler tube. The tank contains an anti-rollover valve that prevents fuel from escaping from the tank vent if a vehicle rollover occurs.



In-tank fuel pump (typical)

1 Fuel pressure regulator
2 Fuel filter
3 Fuel pump
4 Low-pressure filter/strainer
5 Pump inlet check valve
6 Pump outlet check valve
7 Fuel line to high-pressure fuel filter

Fuel pump

There are two types of fuel pumps, the in-tank type and the in-line type.

The in-tank type is a turbine pump mounted inside the fuel tank. The pump uses check valves to maintain line pressure when the pump is not running and prevent fuel from draining back into the tank while the engine is off, helping to prevent vapor lock (a condition where vapor fills the fuel lines instead of liquid).

The in-line type pump is outside the fuel tank. The pump consists of a motor, pump unit, check valve, relief valve, and silencer.

Fuel filter

The fuel filter removes dirt and other contaminants from the fuel to prevent sticking and damage to the injectors. There are two filters: low-pressure and high-pressure.

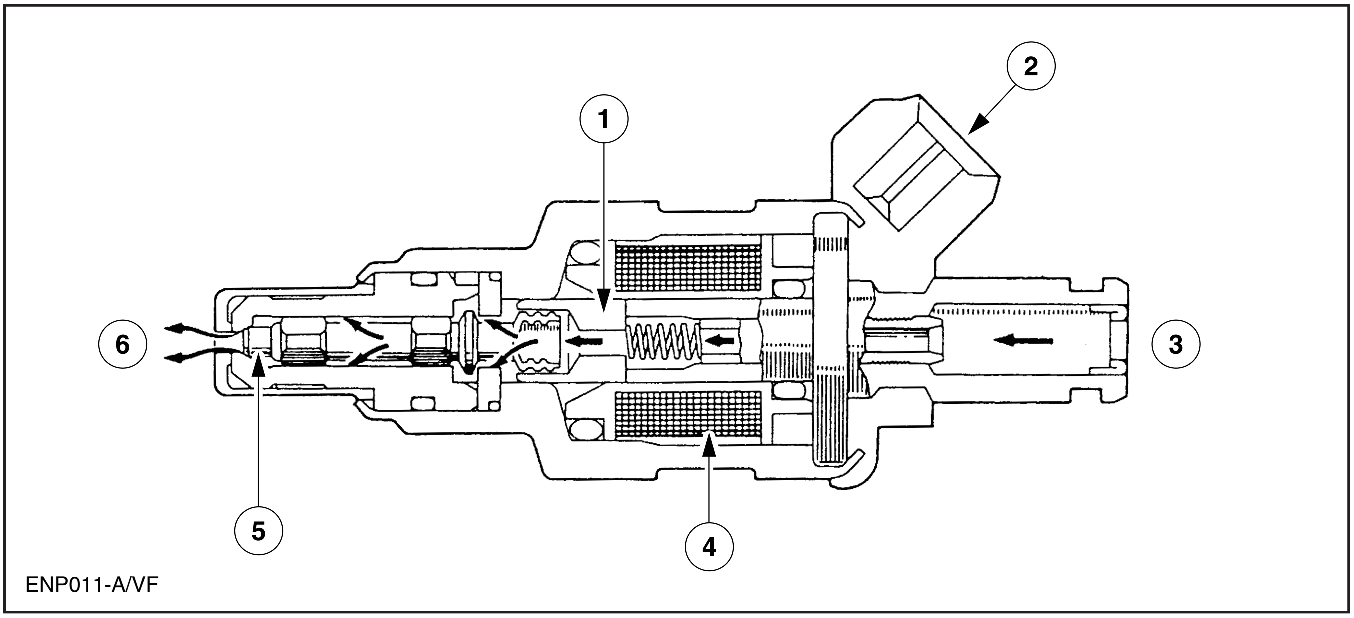
The low-pressure filter is usually in the fuel tank, upstream of the fuel pump, and filters out most of the dirt. The high pressure filter is between the fuel pump and the injectors. The high-pressure filter captures the very minute particles not filtered out by the low-pressure filter.

Fuel pressure regulator

Accurate fuel pressure regulation is essential because fuel pressure and the amount of time an injector is on (open) are the only two controls over the amount of fuel injected. The pressure regulator maintains fuel pressure at a constant level relative to pressure in the intake manifold.

Fuel delivery system (continued)

Fuel injector



Fuel injector

1 Plunger
2 Electrical connection
3 Fuel line inlet
4 Solenoid coil
5 Needle valve
6 Fuel outlet

A fuel injector is a fast-acting electrical solenoid valve which opens a fixed amount and has a fixed flow rate while it is open. An injector takes in fuel from either the top or the side, depending upon the model.

Fuel injectors receive fuel from the fuel rail, and each injector has an inlet filter to remove particles from the fuel that can clog or jam the injector valve.

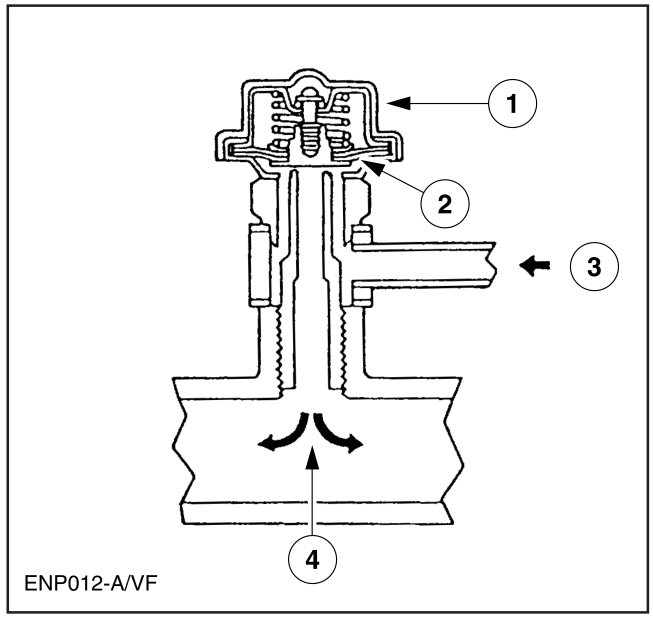
The injection pulse width (duration the injector is open) determines the fuel injection quantity. The fuel injectors are open for only milliseconds at a time.

An engine control computer determines the amount of fuel required and controls the fuel injection pulse width (injector ON time).

Fuel injectors spray fuel into the intake air manifold. The nozzle of the injector atomizes the fuel for optimum mixing with the air.

Pulsation damper

Although the pressure regulator maintains fuel pressure, there are slight variations in line pressure due to the opening and closing of the fuel injectors. For some engines, a pulsation damper absorbs these variations by means of a spring and diaphragm.



Pulsation damper

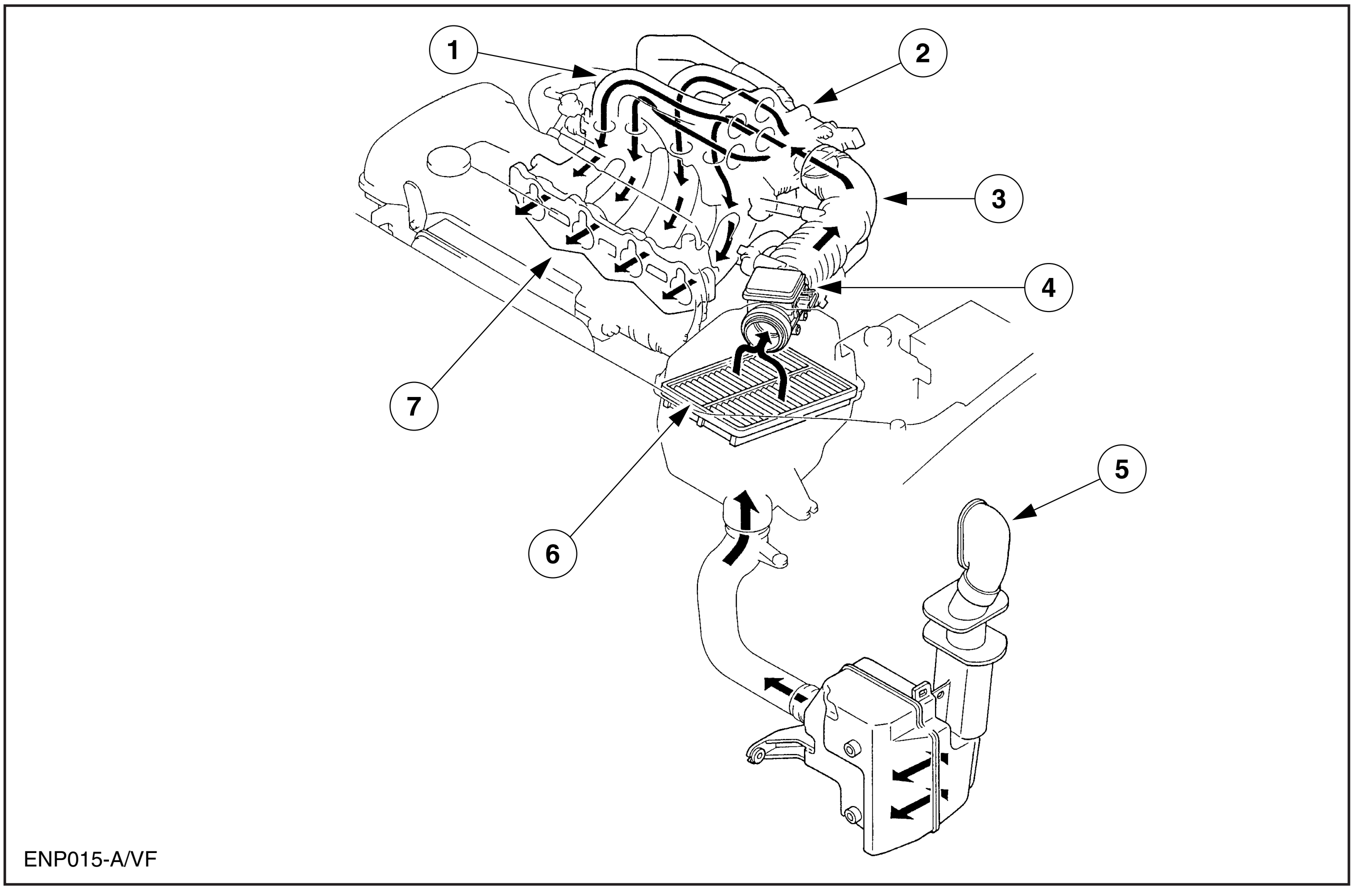
1 Pulsation damper cover
2 Diaphragm
3 Fuel flow from high-pressure filter
4 Fuel flow to injectors

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of the fuel injection system.
- Describe the fuel injection system and identify the types of fuel injection systems.
- Identify the components of the fuel injection system.
- Explain the theory and operation of the fuel injection system.

Air intake system



Air intake system (typical)

1 Dynamic chamber
2 Throttle body
3 Air intake hose
4 Mass air flow sensor
5 Fresh air duct
6 Air cleaner element
7 Intake manifold

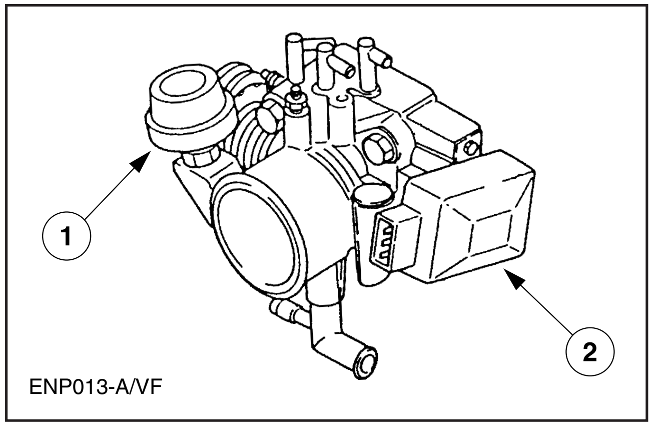
The fuel injection system combines fuel and air in the combustion chamber in a way that maximizes engine performance, fuel economy, and emission control. At the same time, the fuel injection system maintains the stoichiometric air/fuel ratio.

Air intake system (continued)

Throttle body

The throttle body regulates the flow of intake air. It consists of the throttle valve, which is linked to the accelerator, and the bypass system, which allows a small amount of air to bypass the throttle valve when it is closed. The bypass system is described in greater detail later. The throttle body also includes a throttle sensor, which detects the throttle valve opening, and in some cases a dashpot, which prevents a rich air/fuel mixture caused by a rapid closing of the throttle valve during deceleration.

Controlled directly by the accelerator pedal, the throttle valve modifies the volume of air entering the intake manifold. The throttle plate opens to allow more air to flow to the engine when the driver demands more power.



Throttle body assembly

1 Dashpot
2 Throttle position sensor

Types of fuel injection systems

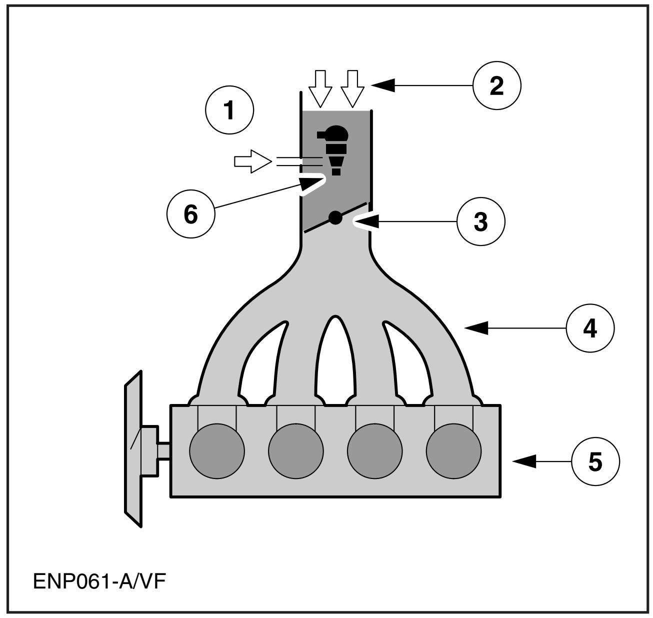
There are two basic types of fuel injection:

- Throttle body fuel injection
- Multiport fuel injection

Throttle body fuel injection system

In the throttle body fuel injection (TBI) system, all cylinders are supplied with fuel by one or two centrally mounted injectors. The following are characteristics of the TBI system:

- Electronically controlled
- An electric pump produces the pressure required to deliver the fuel to the injector.
- As the air flows into the intake manifold, it mixes with atomized fuel provided by one or two injectors that are located above the throttle plate.
- The air entering the engine is controlled by the throttle plate.



Throttle body fuel injection

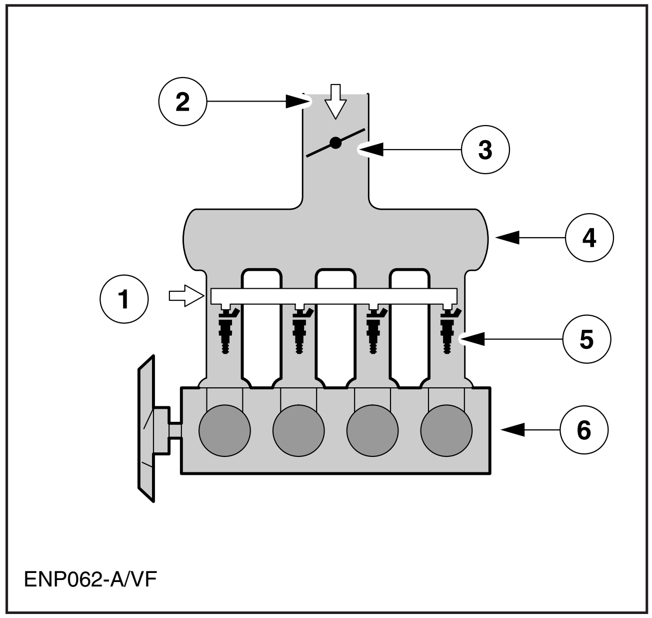
1 Fuel supply
2 Air
3 Throttle plate
4 Intake manifold
5 Cylinder head
6 Fuel injector

Types of fuel injection systems (continued)

Multiport

There are two types of multiport fuel injection systems:

- Multiport fuel injection (MFI): The fuel injectors are actuated in two groups. At any time one group of fuel injectors injects the fuel in two shots per engine revolution.
- Sequential multiport fuel injection (SFI): The fuel injectors operate individually in firing order. Fuel is delivered at the inlet valve just before the intake stroke begins.



Multiport fuel injection

1 Fuel supply
2 Air
3 Throttle plate
4 Intake manifold
5 Fuel injectors
6 Cylinder head

Types of fuel

There are basically two types of fuel for gasoline engines: leaded and unleaded. Leaded fuel contains lead compounds which increase knock resistance. Leaded fuel also provides lubrication for valve seats. However, lead is toxic, so it is being eliminated. Lead cannot be used with catalytic converters because it destroys the metal coating. Vehicles with a catalytic converter require unleaded fuel. For this reason, the lead content in so-called “lead-free gasoline” is reduced to a minimum (traces of lead cannot be avoided in practice). However, “lead-free gasoline” reduces knock resistance, which must be rectified by appropriate additives.

Gasoline

Gasoline is the fuel designed for spark-ignition internal combustion engines. Gasoline is derived from petroleum, and consists of over 200 different hydrocarbons. Gasoline is distilled and refined to create hydrocarbons that have the correct volatility and burning characteristics necessary for good engine performance.

Diesel fuel

There are two grades of diesel fuel for automotive use: One type is used in cold climates when a lower viscosity grade of fuel is needed. The other is formulated with sufficient viscosity and energy content to be applicable for most diesel engines, but is used in warmer climates.

Alternative fuels

Government and industry are working on a variety of alternative fuels to partially or even completely replace the use of gasoline fuels. Some of the types of alternative fuels include:

- Methanol
- Ethanol

Seasonal blends

Seasonal blends of gasoline are used to compensate for the seasonal changes in temperature. Winter fuels tend to be more volatile to provide better cold starts and warm-up performance. Summer fuels are less volatile to reduce hot driveability conditions such as vapor lock. Adjusting for seasonal conditions helps reduce problems, but does not completely eliminate problems. Temperatures are unpredictable, especially in the spring and fall, and may fall well below or rise above the fuel’s volatility limits.

Oxygenated fuels

Oxygenated fuels contain oxygen-bearing compounds (ethers or alcohol). Ethanol, methanol, and methyl tertiary butyl ether (MTBE) are oxygenating compounds. Since these compounds add oxygen to the air/fuel mixture, they artificially lean the air/fuel mixture, resulting in more complete combustion and lower hydrocarbons.

Types of fuel (continued)

Octane ratings

Octane is a measure of anti-knock quality. Anti-knock is a measure of a fuel's ability to resist engine knock. The octane index is stated as a number relating to anti-knock quality such as 87, 89 or 92, etc.

The method for calculating the octane number is (RON+MON)/2. The RON refers to the research octane number, and the MON to the motor octane number. The two numbers are derived from different test conditions. The RON method represents normal driving conditions, while the MON tests are done under severe conditions and high engine speeds.

BTUs

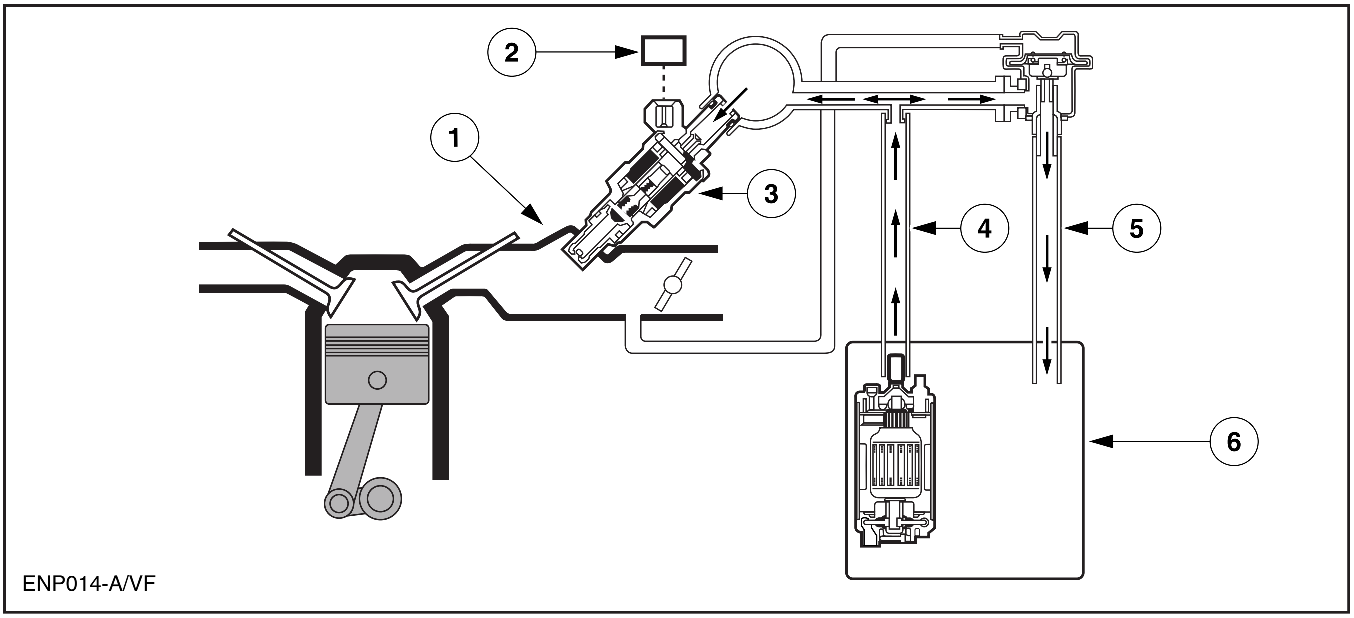
Fuel economy is determined by a number of variables, including the energy content of the fuel. Two fuels of identical octane could have different energy content due to different manufacturing processes. The energy content of a fuel is measured in British Thermal Units (BTU). The higher the BTU, the higher the energy content and the better the fuel economy.

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of the engine management system.
- Describe the engine management control system.
- Identify the components of the engine management control system.
- Explain the theory and operation of the engine management control system.

Fuel injection system



Fuel injection system

1 Intake manifold
2 Powertrain control module
3 Fuel injectors
4 Supply
5 Return
6 Fuel tank

The fuel injection system is made up of three sub-systems that work together to control the combustion process and provide feedback information on operating efficiency. The sub-systems are:

1. Air intake
2. Fuel supply
3. Fuel control (management)

The intake air system provides the air needed for combustion and measures the air entering the engine. Typical components include the air inlet, air filter, intake ducts, air flow (or air mass) meter (or sensor), and any specialized intake hardware.

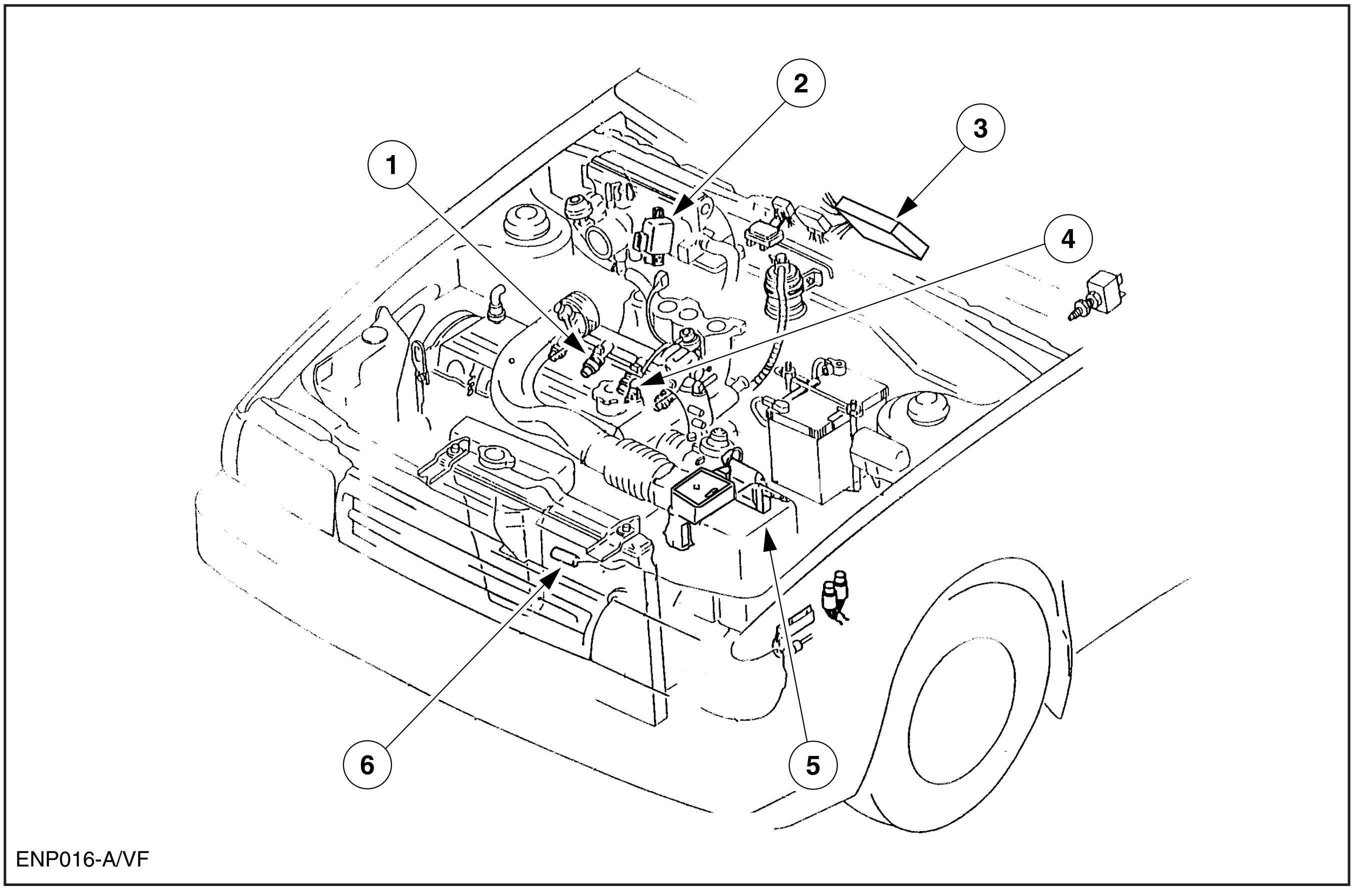
The fuel supply system pumps gasoline from the fuel tank, filters it, and provides it under high pressure to the engine. Components include the fuel pump, fuel filter, fuel rail, fuel injectors, pressure regulator, and pulsation damper. On loop system engines, the system also includes a fuel line that returns unused fuel to the tank.

In the fuel control, or management system, input sensors take continuous measurements and transmit the information to the engine control computer. The computer determines the amount of fuel to inject and uses output actuators to turn on the fuel injectors for a precise amount of time. Operation of the engine control computer is discussed in greater detail later.

The computer makes several thousand calculations each minute and adjusts the amount of fuel constantly as driving conditions change. These actions take place continuously from the moment the engine starts. Fuel injection relies on extremely accurate measuring of the intake air. Any malfunction that throws off this information results in the computer miscalculating the fuel injection rate.

The computer calculates the fuel injection amount based on input signals it receives about airflow amount, mass and intake air temperature.

Engine management system



Common engine management components

1 Fuel injector
2 Throttle sensor
3 Powertrain control module
4 Engine coolant temperature sensor
5 Mass airflow sensor
6 Oxygen sensor

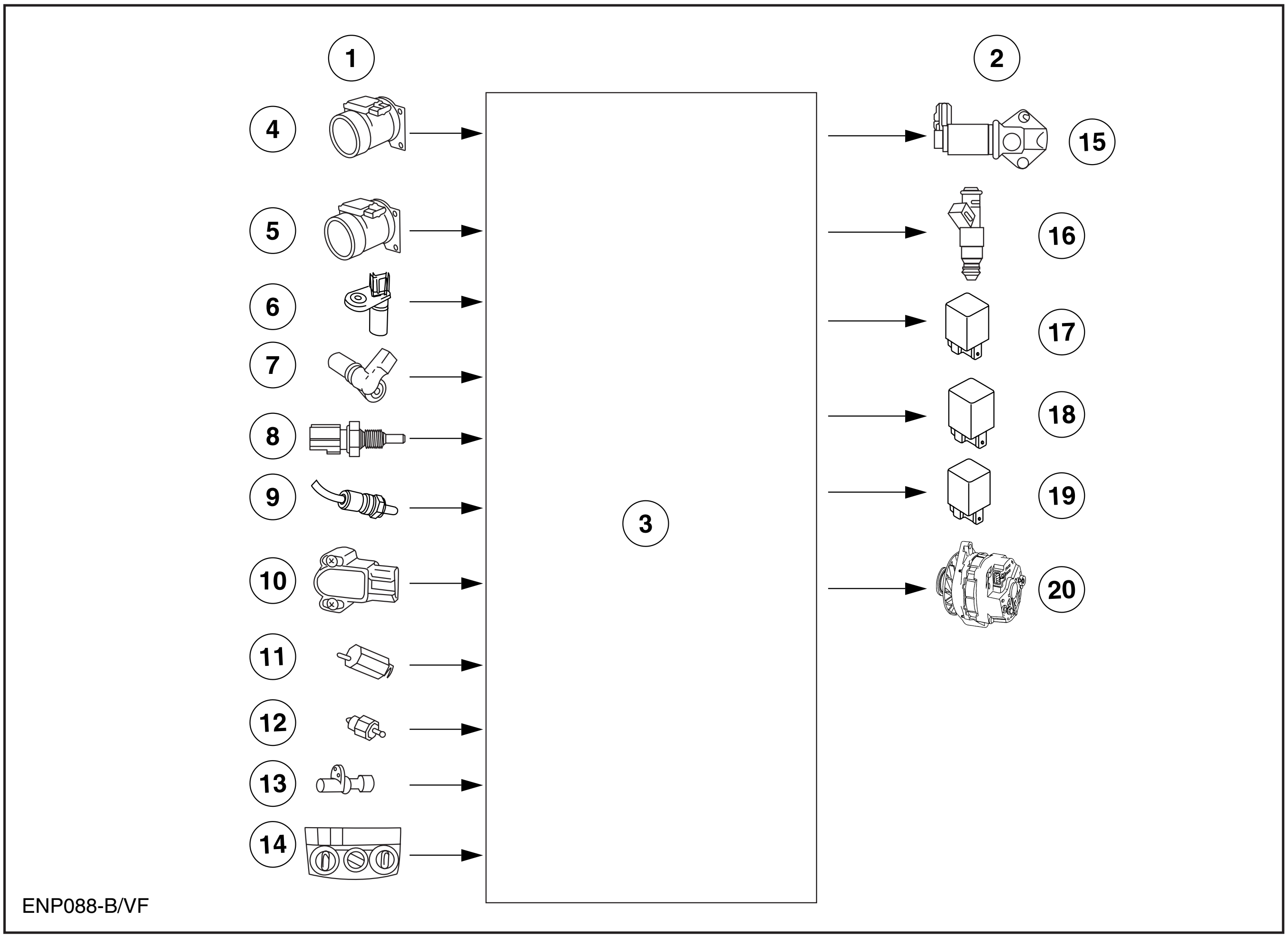
Engine management is controlled by an on-board computer which is called different names by different manufacturers. The following are two common names for the computer:

- Powertrain Control Module (PCM)
- Engine Control Module (ECM)

For this publication, the engine controller is referred to as the PCM.

The PCM is the heart of the modern engine management system. The PCM controls the ignition system, the fuel injection system and other components. The PCM is designed to increase engine efficiency and decrease exhaust emissions.

Engine management system (continued)



Typical PCM inputs and outputs

1 Typical inputs
2 Typical outputs
3 Powertrain control module
4 Mass airflow sensor
5 Intake air temperature sensor (in MAF sensor)
6 Crankshaft position sensor
7 Camshaft position sensor
8 Engine coolant temperature sensor
9 Oxygen sensor
10 Throttle
11 Knock sensor
12 Power steering pressure switch
13 Vehicle speed sensor
14 Air conditioning select switch
15 Idle air control valve
16 Fuel injector
17 Fuel pump relay
18 Cooling fan relay
19 Air conditioning relay
20 Generator

The PCM maintains a stoichiometric air/fuel ratio during cruising conditions. However, driving conditions change and a stoichiometric air/fuel mixture is not ideal for all conditions. The PCM makes the air/fuel mixture richer or leaner depending upon conditions.

The PCM takes the information from the input sensors and sends control signals to the outputs, such as the fuel injectors. The location of the PCM and sensors varies by model and manufacturer. Always check the workshop manual for component location.

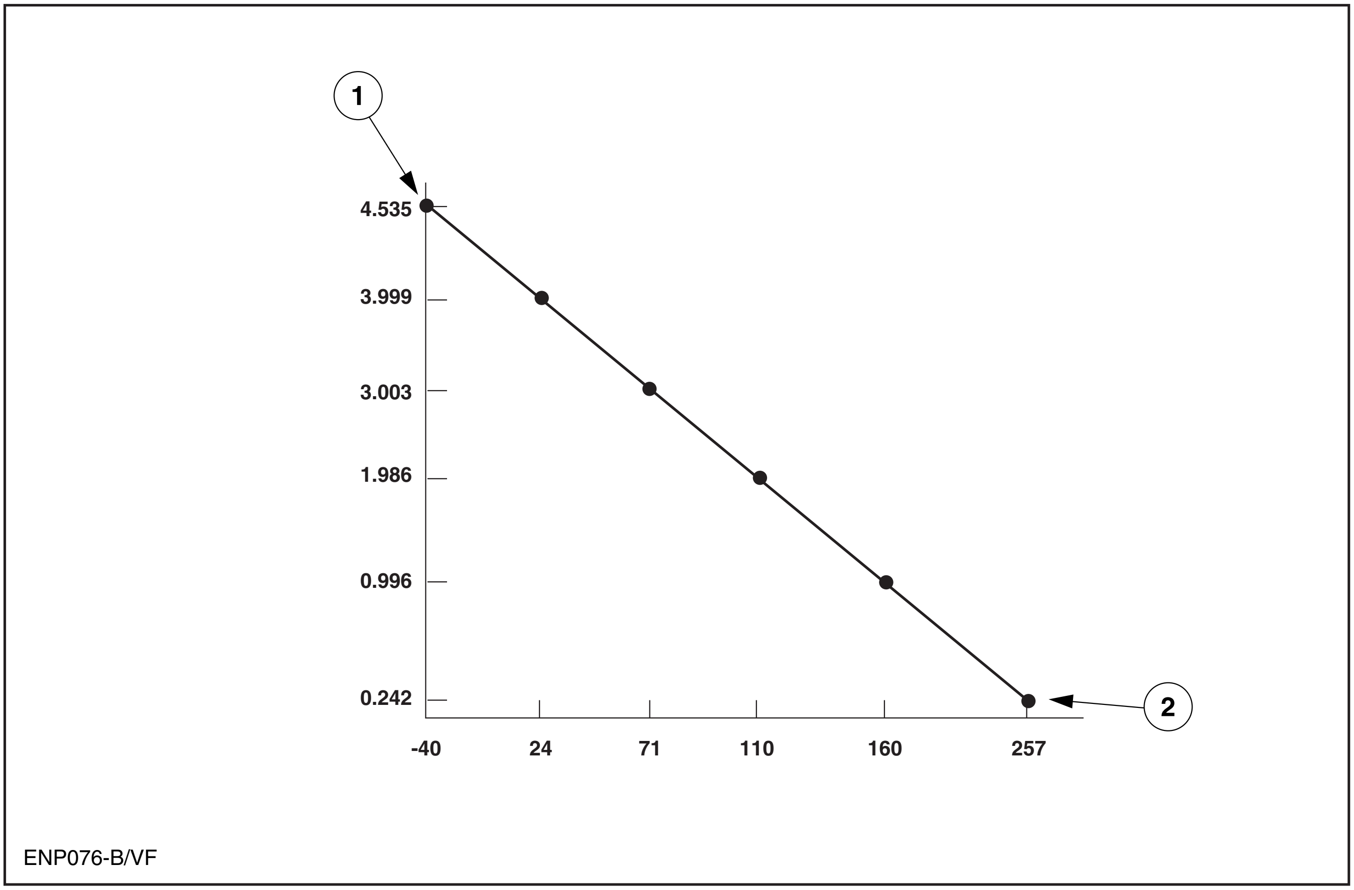
PCM inputs

Input sensors provide continuous, detailed information related to various aspects of vehicle operation. The following section describes the sensors typically found in modern powertrain control systems.

Ignition pulse signal

The PCM receives an ignition pulse signal from the ignition coil and sets fuel injection amount and timing by the signal.

PCM Inputs (continued)



Volts versus temperature graph

1 High voltage

2 High temperature

Engine coolant temperature sensor

Richer air/fuel mixtures compensate for poor fuel vaporization in low temperatures. The PCM monitors coolant temperature and increases fuel injection volume to improve driveability while the engine is cold.

The engine coolant temperature (ECT) sensor measures coolant temperature by electrical resistance; the thermosensor changes its electrical resistance with changes in temperature.

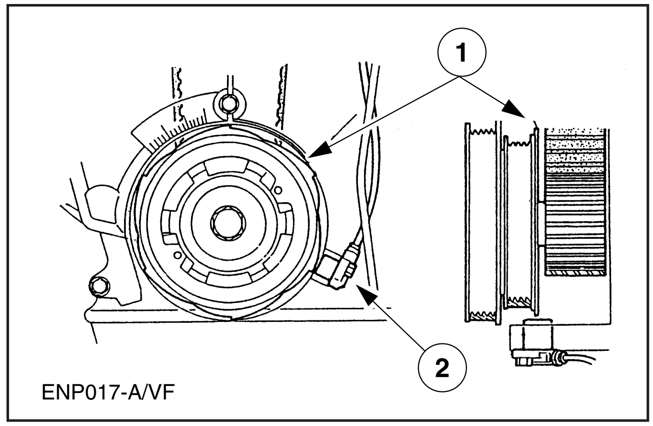
Intake air temperature sensor

The intake air temperature (IAT) sensor is a thermistor device and is positioned in the engine air intake to register the temperature of incoming air. The IAT sensor provides a varying voltage signal depending on resistance. Sensor resistance and the resulting sensor voltage are high when the sensor is cold. As temperature rises, resistance and sensor voltage go down.

Crankshaft position (CKP) sensor

The PCM uses engine speed to help set the base injection amount. The crankshaft position (CKP) sensor can be on the crankshaft or inside the distributor.

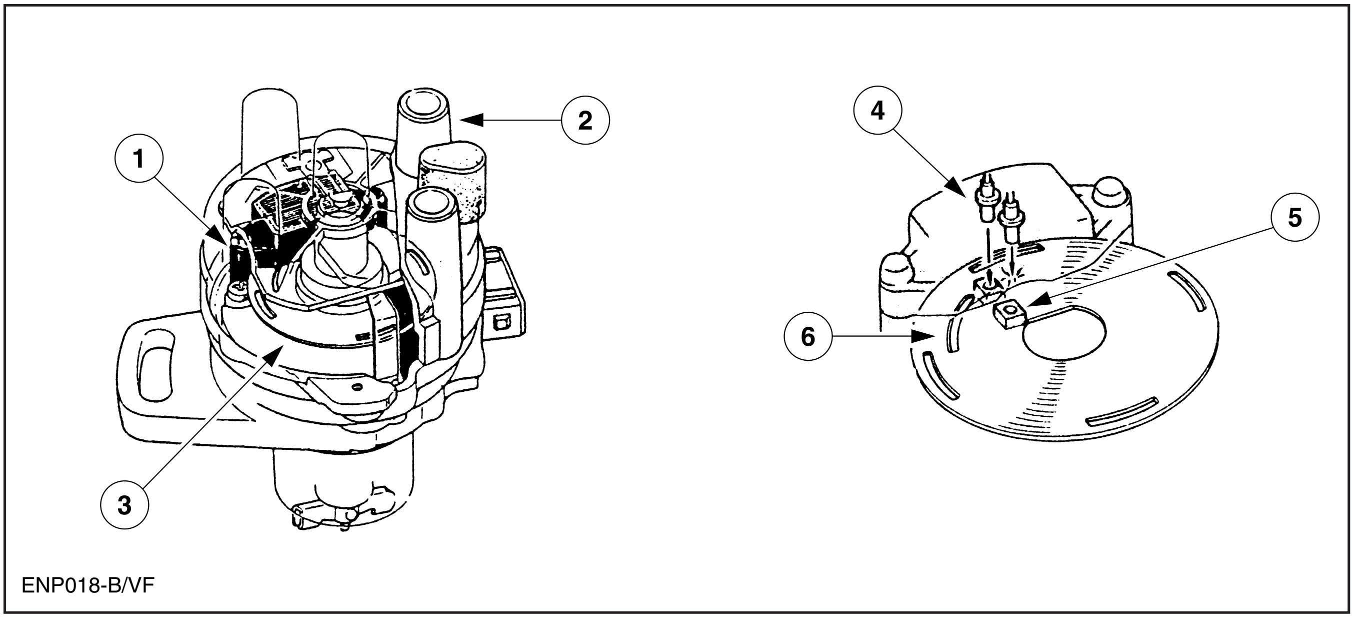
A special rotor with projections, or teeth, on the crankshaft spins near a sensor. The sensor detects changes in magnetic force as each projection passes by it.



Crankshaft position sensor

1 Signal rotor (front and side views)
2 Crankshaft position sensor (front and side views)

PCM Inputs (continued)



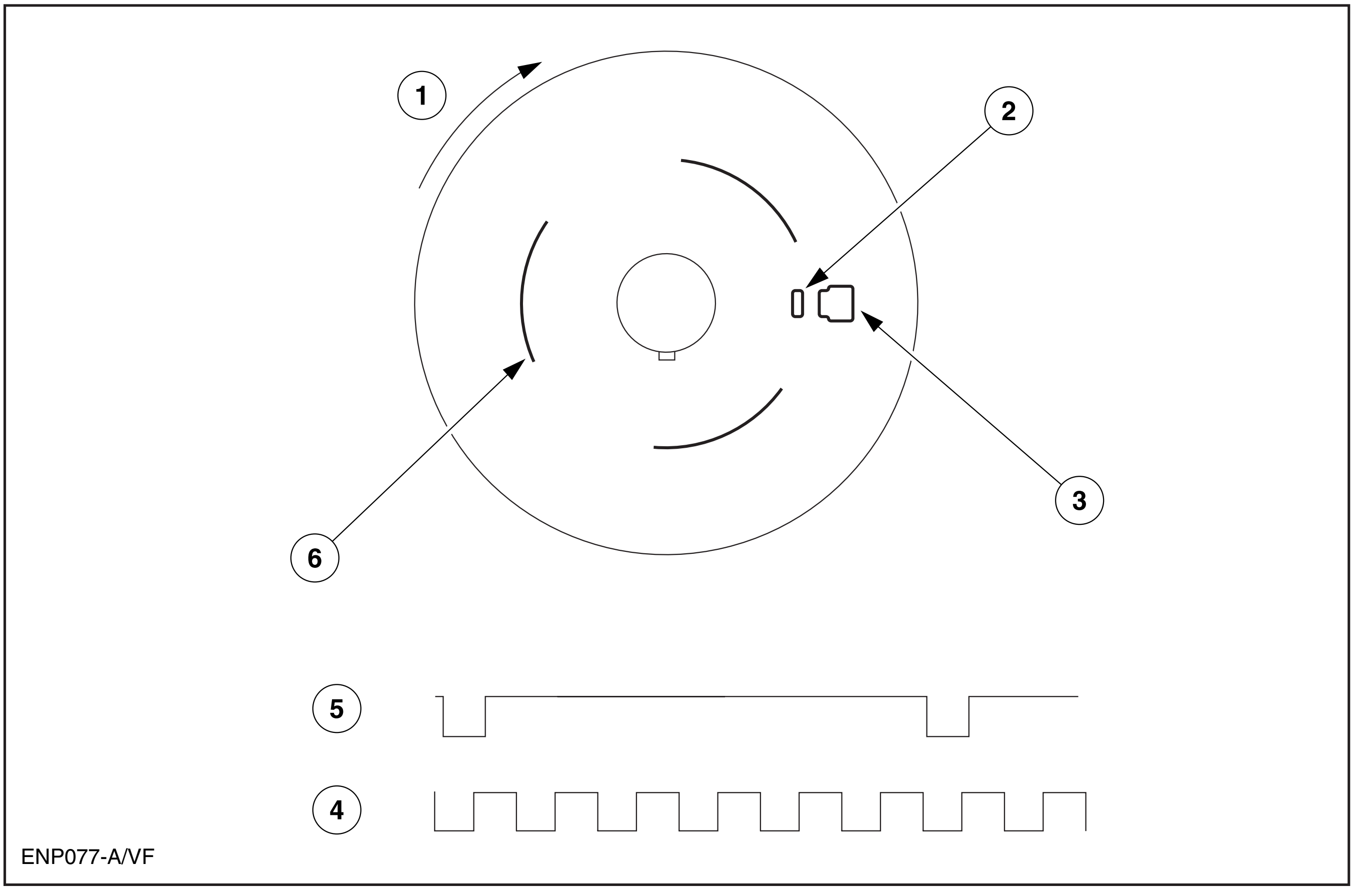
Distributor-mounted engine speed sensor

1 Sensor
2 Distributor cap
3 Disc
4 Light emitting diodes (LED)
5 Photodiodes
6 Disc

The distributor-mounted engine speed sensor, or crank angle sensor, can be a disc-type or a Hall-effect device.

The disc type sensor uses a slotted disk mounted on the distributor shaft, two light emitting diodes (LEDs), and two photodiodes. One LED indicates crank angle, while the second LED indicates Cylinder No. 1 position.

Camshaft position (CMP) sensor



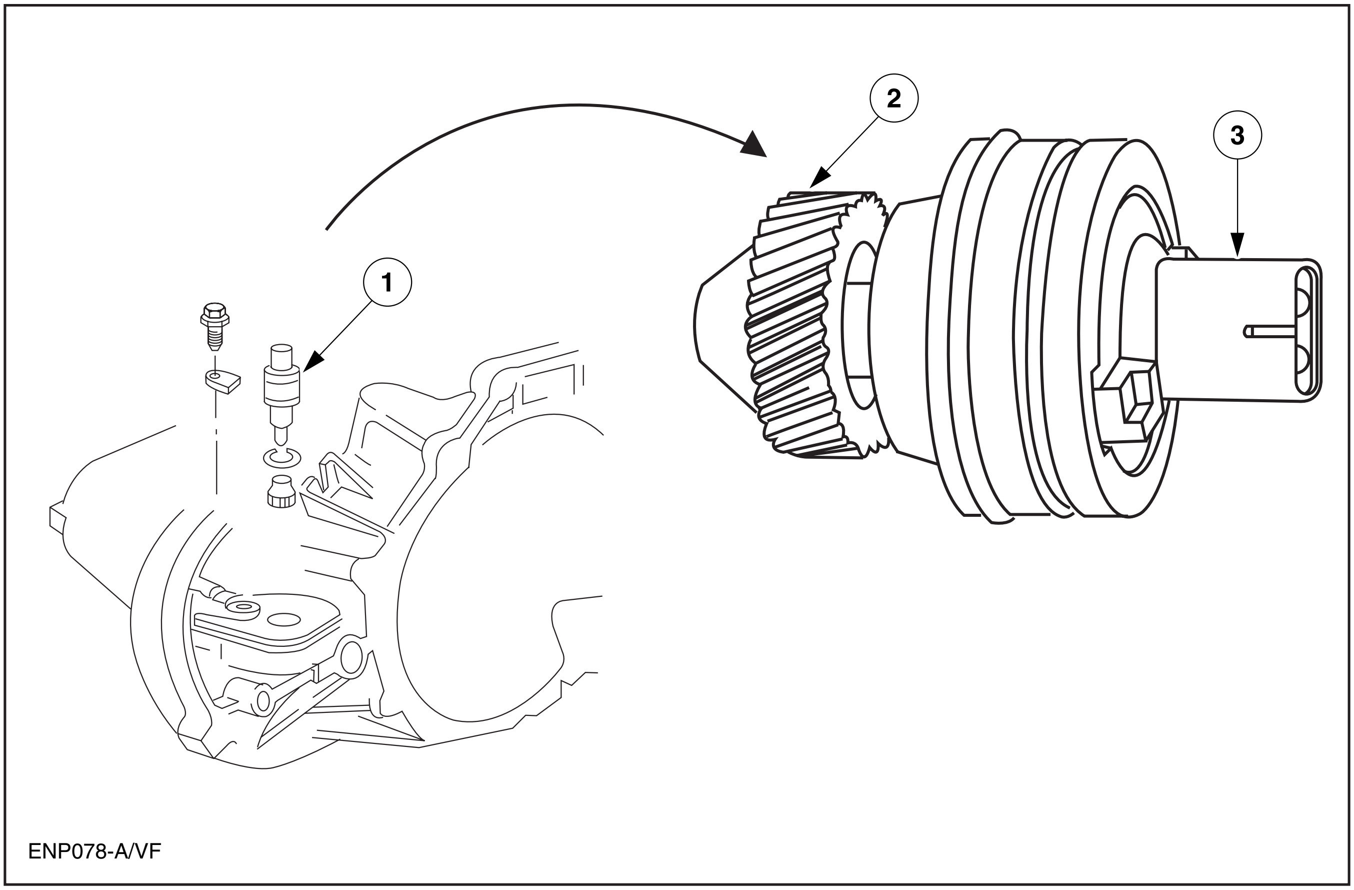
Camshaft position sensor operation

1 Rotation
2 Magnet
3 Hall-effect switch
4 Crankshaft signal
5 Camshaft signal
6 Interrupter blade (1 of 3)

The PCM uses a camshaft position (CMP) sensor to track the position of all cylinders and control the fuel and ignition systems. The sensor detects the TDC compression of Cylinder No. 1 and can be located in the distributor or near the camshaft. The CMP sensor detects changes in magnetic force caused by projections on the camshaft pulley.

PCM Inputs (continued)

Vehicle speed sensor



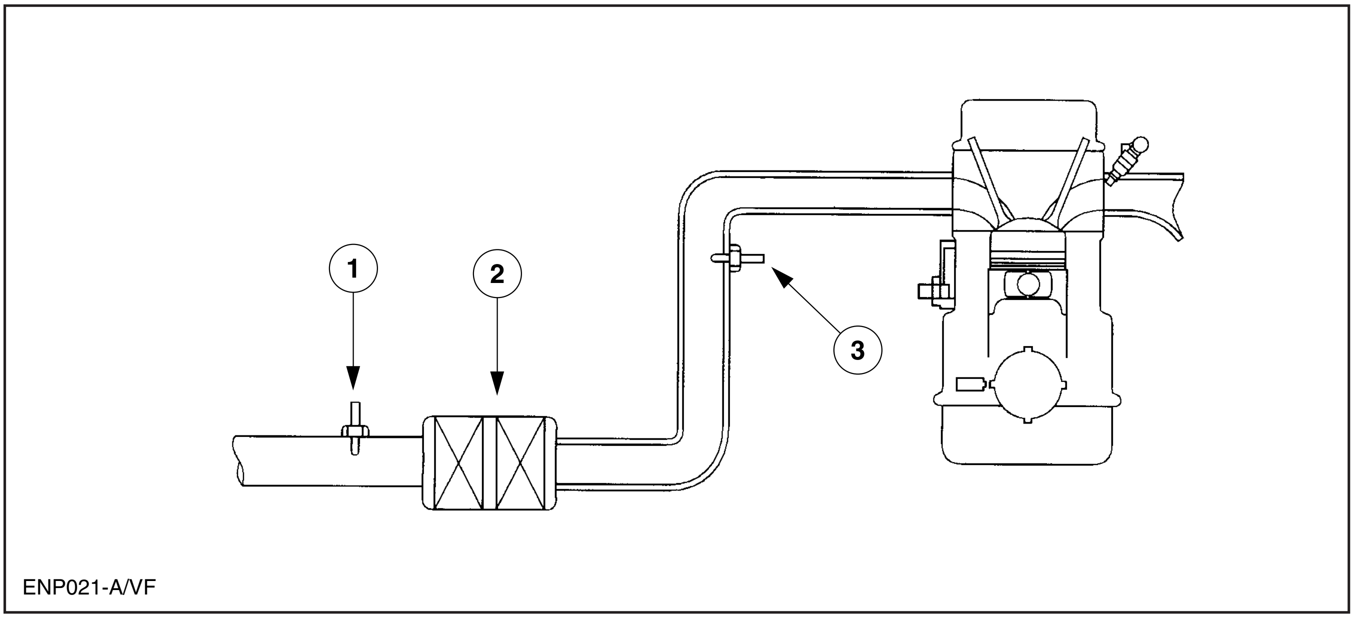
Electromagnetic pickup vehicle speed sensor

1 Vehicle speed sensor
2 Gear
3 Output connector

A vehicle speed sensor (VSS) indicates the speed at which the vehicle is traveling. There are three common types of VSS – the reed switch type and photocoupler type are in the speedometer, and the electromagnetic pickup type is on the transmission output shaft.

Some vehicle manufacturers also use a wheel speed sensor, which is part of an anti-lock braking system, to obtain vehicle speed information.

Oxygen sensors



Oxygen sensor locations

1 Rear oxygen sensor
2 Catalytic converter
3 Front oxygen sensor

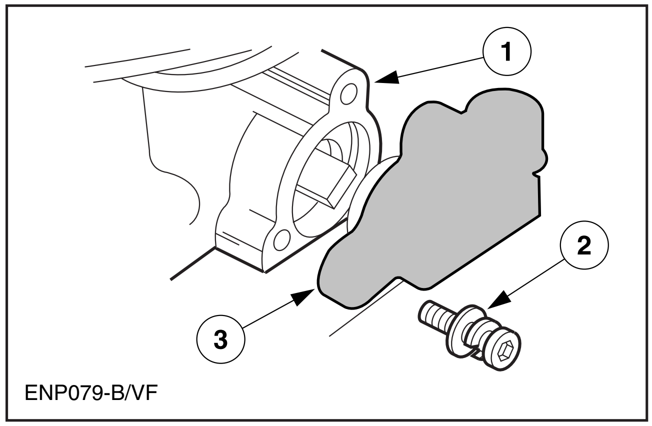
The front oxygen sensor measures the density of oxygen in the exhaust gas and signals this information to the PCM. The front oxygen sensor is located forward of the catalytic converter. The PCM uses this input from the front oxygen sensor to calculate changes in the air/fuel ratio.

There is also a rear oxygen sensor downstream of the catalytic converter. The PCM compares signals from the two oxygen sensors to monitor the operating efficiency of the catalytic converter and determine if the catalytic converter is operating properly.

PCM inputs (continued)

Throttle position sensor (TPS)

The throttle position sensor (TPS) is a variable resistor (potentiometer) mounted to the throttle. The throttle body is opened and closed by way of a cable that is connected to the gas pedal. When the throttle is closed, the computer reads a low voltage signal. When the throttle is wide open, the computer reads a high voltage signal.

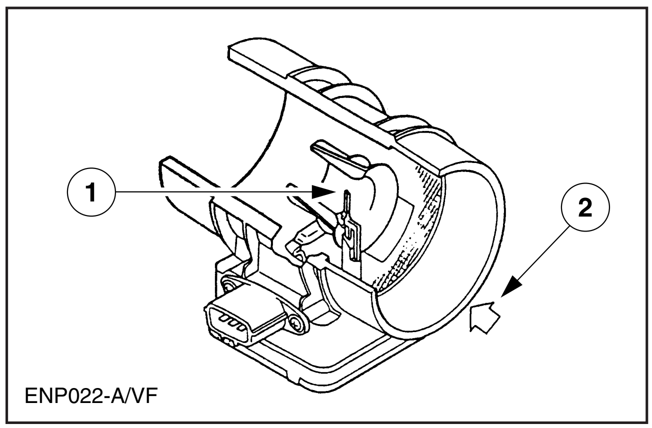


Throttle position sensor

1 Throttle body assembly
2 Screw assembly
3 Throttle position sensor

Mass air flow/air flow sensor

The mass airflow (MAF) sensor measures the volume and density of the incoming air. Because of the way the MAF sensor makes a measurement, the sensor is able to take temperature, density and humidity of the air into account. All these variables together determine the “mass” of the incoming air. The computer reads actual mass airflow to help calculate air/fuel ratio.



Mass air flow sensor

1 Heated resistor
2 Airflow direction

Other inputs

There are several other input devices, depending on manufacturer. Other inputs may include the following:

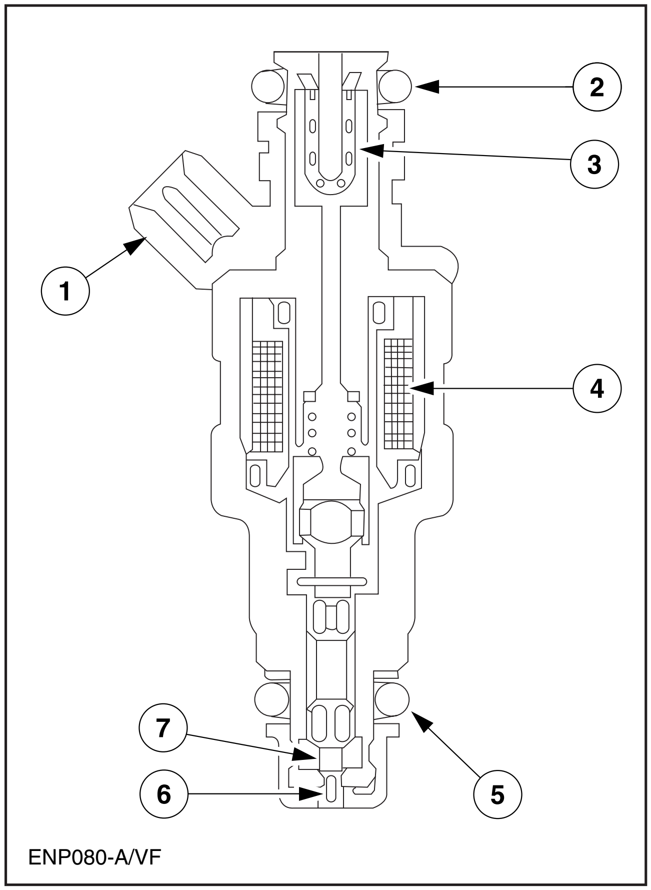
- Manifold absolute pressure (MAP) sensor – measures changes in intake manifold air pressure.
- Knock sensor – sends a signal to the PCM to retard ignition timing in case of extreme detonation.
- Park/neutral (P/N) position switch – indicates to the PCM whether the transmission is in PARK or NEUTRAL, or in one of the normal drive gears.
- Power steering pressure switch (idle speed) – used to detect high power steering system fluid pressure.
- A/C high pressure switch – sends an A/C “request” to the PCM so the PCM can turn on the A/C compressor.
- Cruise control switch – when the PCM receives a cruise control signal, it stores the desired speed in memory in order to maintain the desired speed.

PCM outputs

Output actuators open and close valves, inject fuel, and perform other tasks in response to control signals from the PCM. Some actuators are controlled in a variable manner, while others are simply ON or OFF. The length of time that an actuator operates is its duty cycle. The PCM controls duty cycles and can lengthen or shorten them as needed.

Fuel injectors

Fuel is delivered to the engine by way of the fuel injectors. The PCM controls the fuel injectors. The fuel injector is provided a continuous supply of pressurized fuel by a fuel pump. The fuel injector is a solenoid that, when grounded by the computer, becomes energized and the pressurized fuel is "injected" into the intake manifold. The computer controls fuel flow by pulse width modulation of the injector ON time. The ON time of the injector is determined by a combination of the PCM inputs previously described.

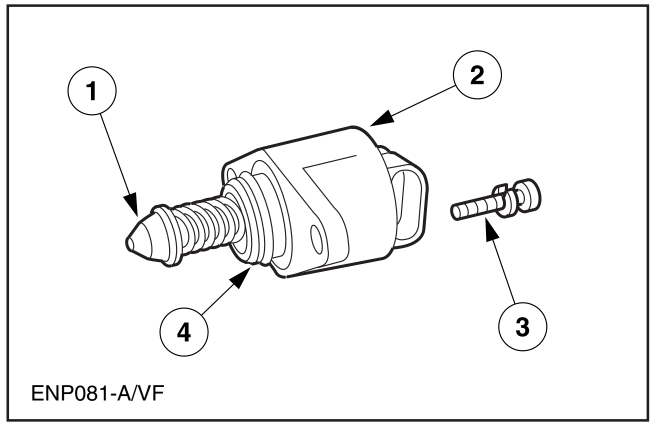


Fuel injector components

1 Electrical connection
2 Upper O-ring
3 Fuel inlet filter
4 Solenoid windings
5 Lower O-ring
6 Nozzle
7 Pintle valve

Idle air control valve

The idle air control (IAC) valve is located in the throttle body. The IAC valve consists of a moveable pintle, which is driven by a small electric motor called a stepper motor. The stepper motor is capable of moving in very exact, measured amounts called "steps". The computer uses the IAC valve to control idle rpm. The IAC valve changes the pintle position in the idle air passage of the throttle body. The incoming air is then varied around the throttle plate when the throttle is closed.



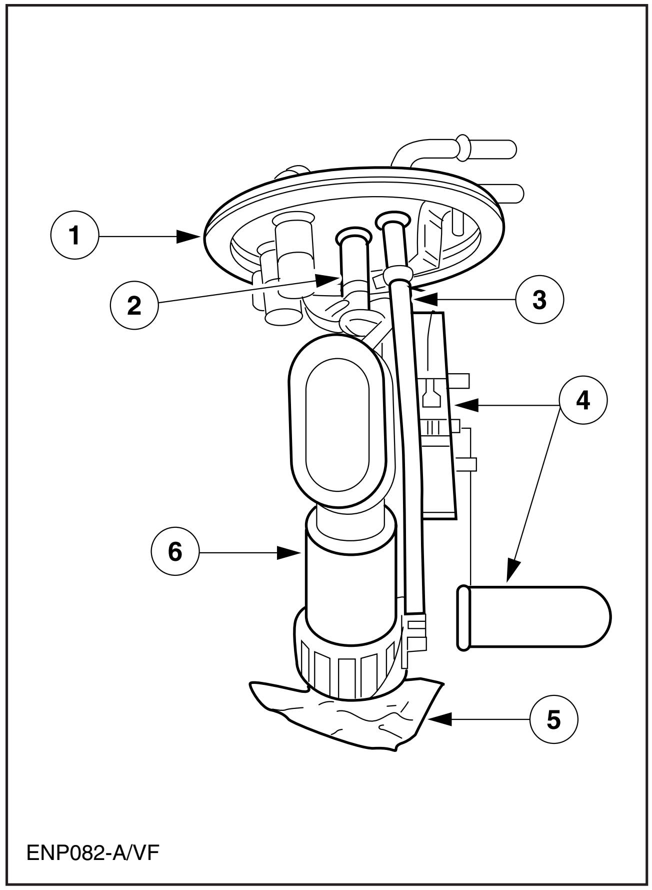
Idle air control valve

1 IAC valve pintle
2 Idle air control valve
3 IAC valve attaching screw assembly
4 IAC valve O-ring

PCM outputs (continued)

Electric fuel pump

Most fuel injection systems use an in-tank electric fuel pump controlled by a relay. When the ignition switch is turned ON, the computer energizes the relay that controls the fuel pump by applying battery voltage. The relay remains on as long as the engine is cranking or running, and the computer is receiving reference pulses. If there are no reference pulses, the computer shuts off the relay.



Typical fuel pump components

1 Fuel pump seal
2 Fuel pump outlet
3 Fuel return line
4 Fuel level sending unit
5 Fuel inlet strainer
6 Pump

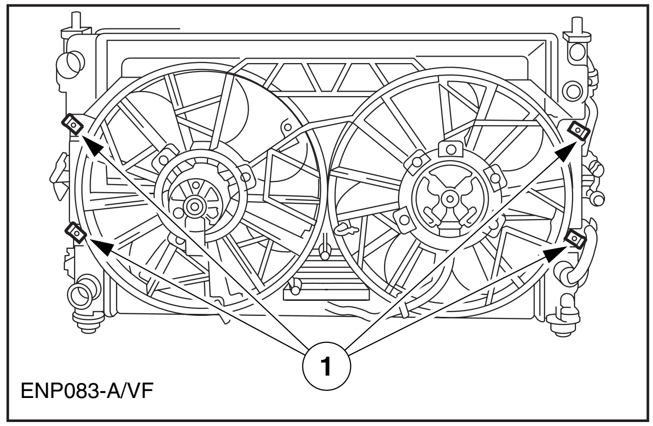
Electric cooling fan

Single or dual electric cooling fans are used to help cool the radiator and/or the A/C condenser under certain conditions. On most applications, the PCM controls the cooling fans. The computer-controlled applications use a cooling fan relay. The computer grounds the cooling fan relay, providing system voltage to the cooling fan motor under some or all of the following conditions:

- Coolant temperature sensor indicates hot coolant
- A/C system is requested
- A/C is ON and vehicle speed is below a specified mph
- A/C high side pressure is above specified value, possibly opening the high-pressure switch

Malfunction indicator lamp

The service engine soon or malfunction indicator lamp (MIL) illuminates when the ignition key is turned to the ON position, with the engine not running. Don't worry if this happens because that's just a quick bulb check. When the engine is running, the MIL is normally OFF. If a trouble code stores, or the computer goes into backup mode, the MIL illuminates, meaning that the computer is grounding the MIL circuit. If the condition changes and the trouble code or codes no longer exist, the lamp may turn off, but a code remains stored in the computer’s memory.



Electric cooling fans

1 Fan module to radiator fasteners

On-board diagnostics

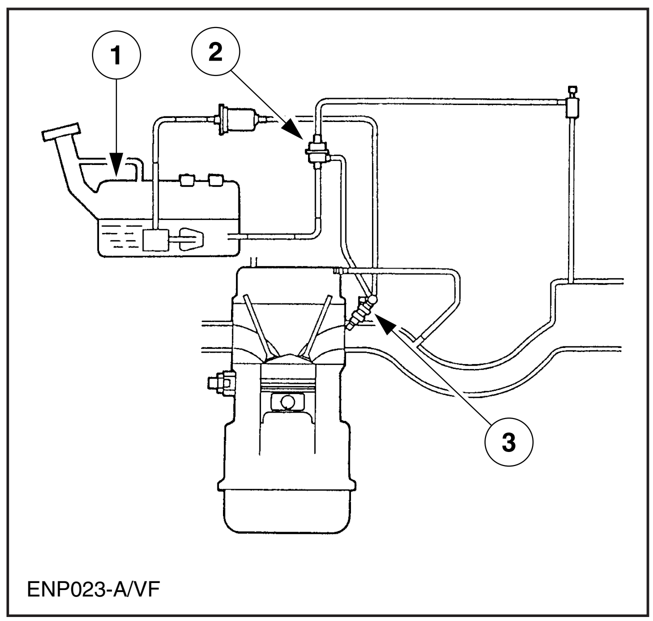
The PCM contains diagnostic software, which monitors vehicle operation and logs malfunctions that occur. This software is referred to as on-board diagnostics (OBD).

In 1994, manufacturers began equipping vehicles with PCMs containing On-Board Diagnostics Second Generation (OBD II) or EOBD for Europe. The programming monitors anything in the fuel injection and emission control systems that would cause emissions to rise. In addition to checking for component failure, OBD II checks and tests operation of complete subsystems for proper operation as well as monitors sensors and actuators for degrading operation.

Fuel pressure regulator control

In some engines, the PCM increases fuel pressure to prevent fuel vapor lock (boiling) when the engine temperature is high during re-start. For example, if coolant temperature is 212° F (100° C) or higher during starting, the PCM activates the pressure regulator control solenoid valve.

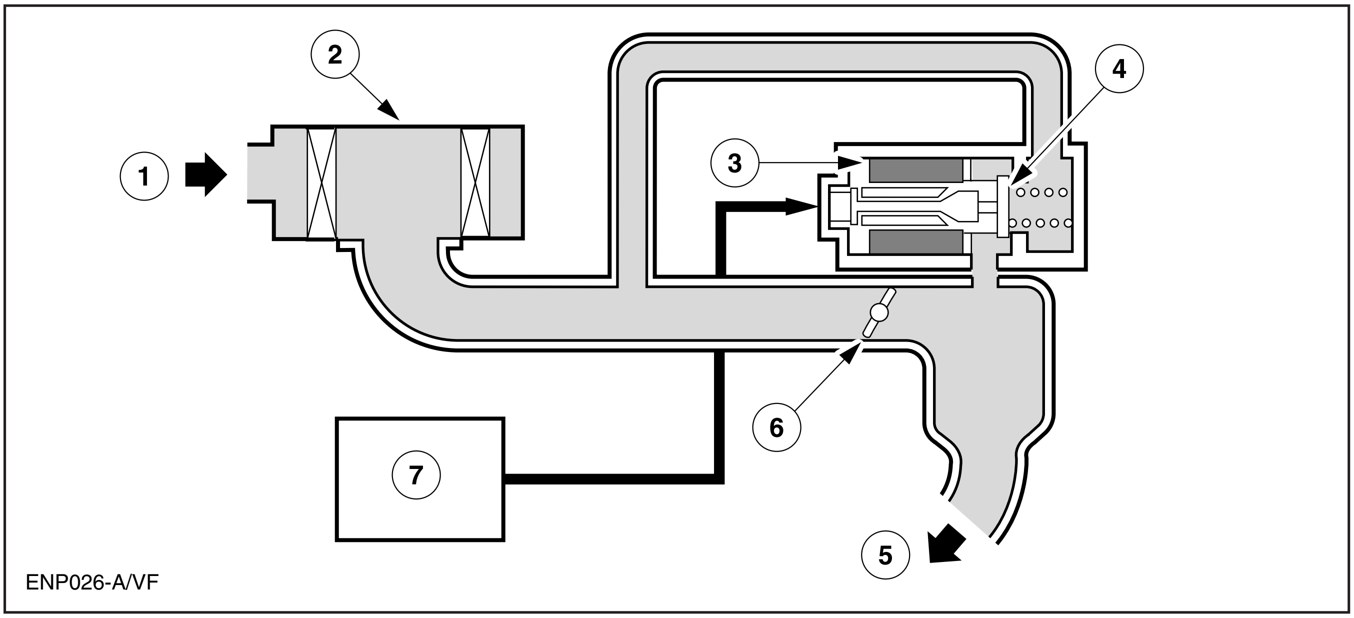
When the solenoid valve operates, vacuum is cut to the pressure regulator, causing fuel pressure to be higher than for normal engine conditions. The solenoid valve remains on for a short time after the engine starts.



Fuel pressure regulation components

1 Fuel tank
2 Pressure regulator
3 Fuel injector

Base idle system



Base idle system

1 Intake airflow
2 Air cleaner
3 Solenoid coil
4 Idle air control/idle speed control valve
5 Airflow to intake manifold
6 Throttle plate
7 PCM

A bypass allows some intake air to pass into the intake manifold during idle because the throttle valve is almost completely closed. The IAC valve controls bypass air needed to stabilize idle speed under various loads (A/C, electrical load, power steering, etc.). The PCM operates the IAC valve, which is a solenoid-type actuator. This valve provides accurate control of the amount of air that bypasses the throttle valve.

Some vehicles use a mechanical and solenoid two-valve combination for base idle control. Both valves are open during cold start, allowing extra air to flow during starting and warm-up. As the coolant temperature increases to normal, the mechanical valve gradually closes, and air flows through the solenoid valve only.

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of the ignition control system.
- Describe the ignition system and identify the types of ignition control systems.
- Identify the components of the ignition control system.
- Describe the theory and operation of the ignition control system.

Ignition control systems

Distributor-type ignition system

In a distributor-type ignition system, the PCM uses the distributor to send high-voltage secondary ignition voltage pulses to the spark plugs. The PCM uses low-voltage primary signals from the distributor to determine the proper time to generate an ignition spark.

The PCM also uses other sensor inputs to precisely control ignition timing, such as:

- Barometric pressure sensor
- Closed throttle position switch
- Engine coolant temperature sensor
- Intake air temperature sensor
- Knock sensor
- Throttle position sensor

To generate a spark, the PCM energizes a power transistor, which begins current flow through the ignition coil. A magnetic field builds up in the coil and creates a high voltage.

To trigger the spark, the PCM de-energizes the power transistor to interrupt current flow. The magnetic field in the ignition coil collapses and releases the high voltage. The distributor routes the high voltage from the ignition coil to the appropriate spark plug through the distributor rotor, cap and secondary ignition wires.

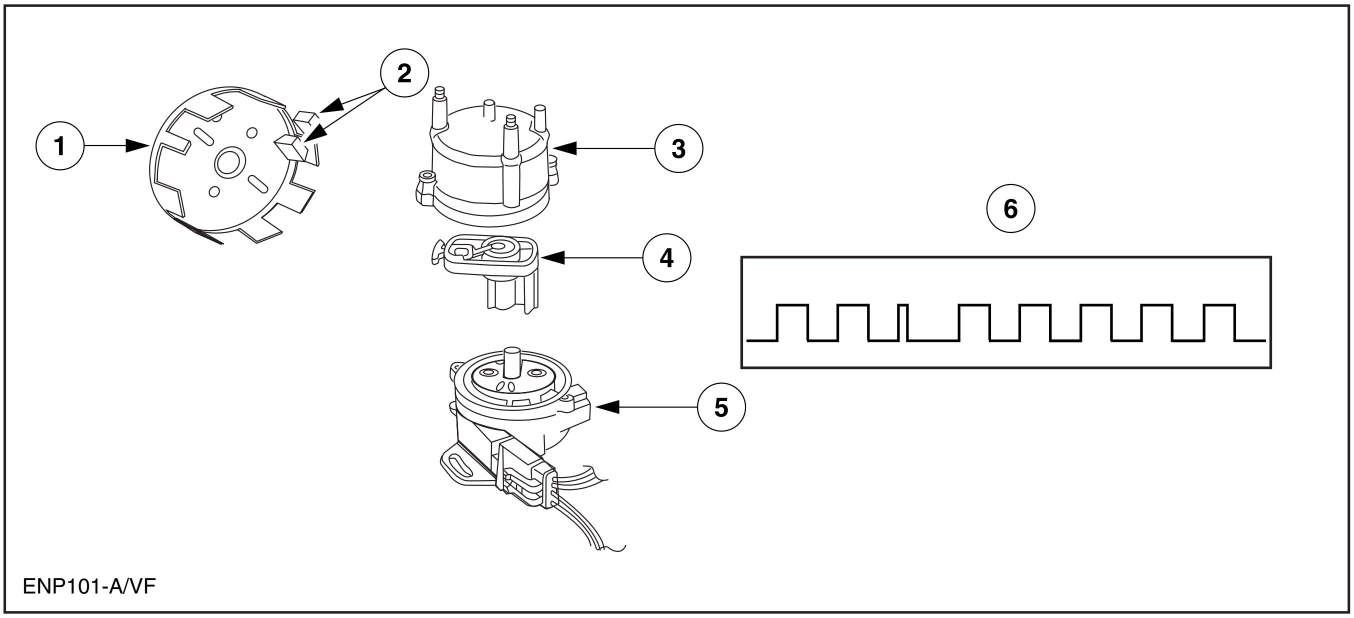
Modern ignition controls eliminate conventional centrifugal and vacuum advance mechanisms from the distributor. The PCM controls spark advance electronically by reading information transmitted by sensors inside the distributor and other engine sensors.

These distributor-type sensors provide the PCM with electrical signals which indicate crankshaft position, and Cylinder No. 1 position. The sensors may be one of three types:

1. Pickup coil
2. LED disk
3. Hall effect device

Ignition control systems (continued)

Pickup coil sensors

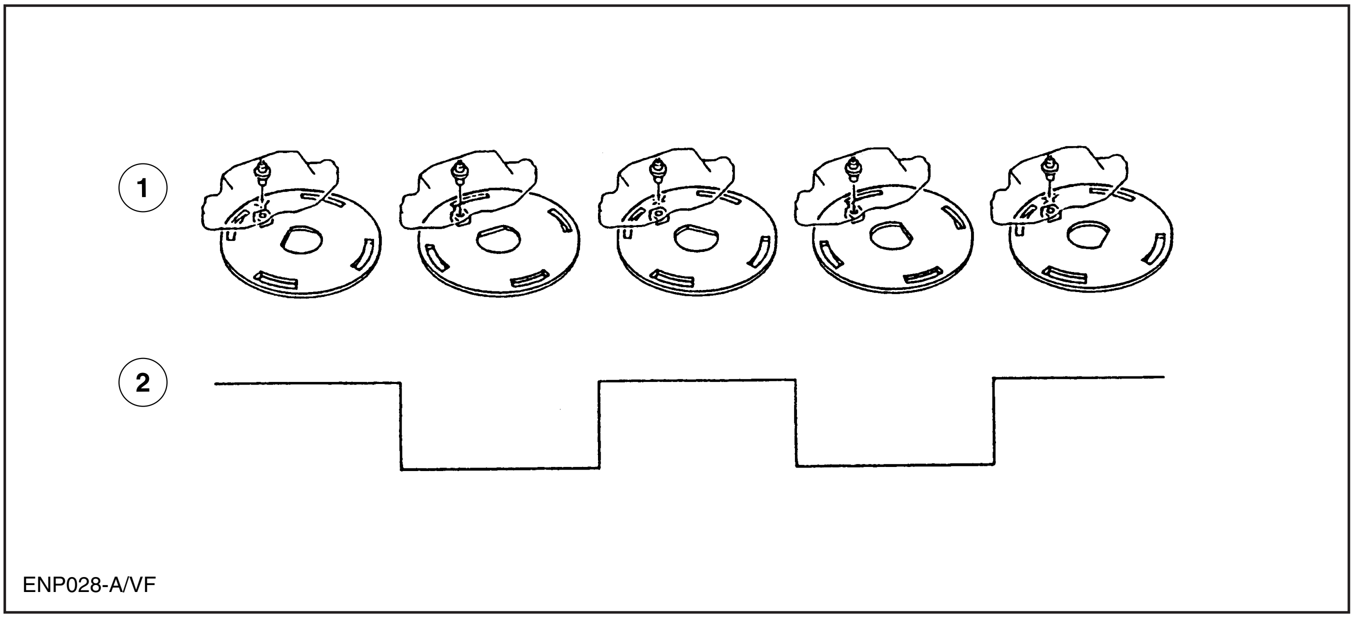


Pickup coil sensor

1 Timing rotor
2 Pickup coils
3 Distributor cap
4 Distributor rotor
5 Distributor
6 Electrical signal

Pickup coil sensors use timing rotors and pickup coils for the signals. The number of teeth on the rotor and the number of pickup coils vary depending on the number of engine cylinders. As a tooth on the rotor passes by a pickup coil, it creates an electrical signal.

Disc sensors



Disc sensor

1 Disc spinning between LEDs and photodiodes
2 Electrical signal to PCM

Disc type sensors consist of a slotted disc mounted on the distributor shaft, a sensor unit assembly, and a high-voltage distribution section.

There are 4 slots 90 degrees apart (in a 4-cylinder engine) on the edges of the disk to allow the distributor to signal top dead center (TDC) of each piston (NE signal). One inboard slot identifies the No. 1 cylinder (G signal).

The sensor unit assembly consists of two LEDs, and two light receptors (photodiodes) that produce the NE signal and the G signal. The sensor unit assembly outputs low-level voltage (0-0.5V) when light from the LED hits the base of the photodiode. The sensor unit assembly outputs high-level voltage (4.5-5V) if the light is blocked.

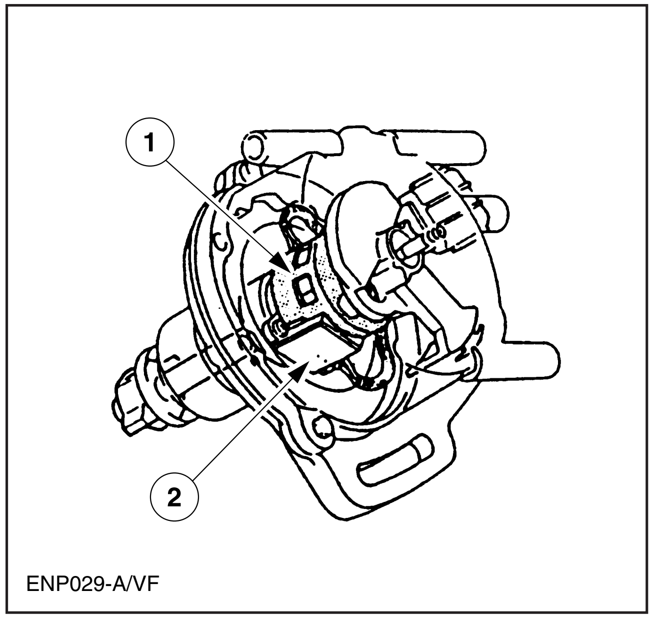
The disc-type sensors are non-contact devices. Both sensors are in a single unit assembly to detect movement of the slots in the disc. Non-contact sensors are free of malfunctions associated with contact-type sensors.

Ignition control systems (continued)

Hall-effect sensors

In a Hall-effect sensor a single NE/G rotor shares a common axis with the driven shaft. The combination NE/G rotor is a cylinder with six windows (in a 6-cylinder engine) for the NE signal, and an extended finger for the G signal.

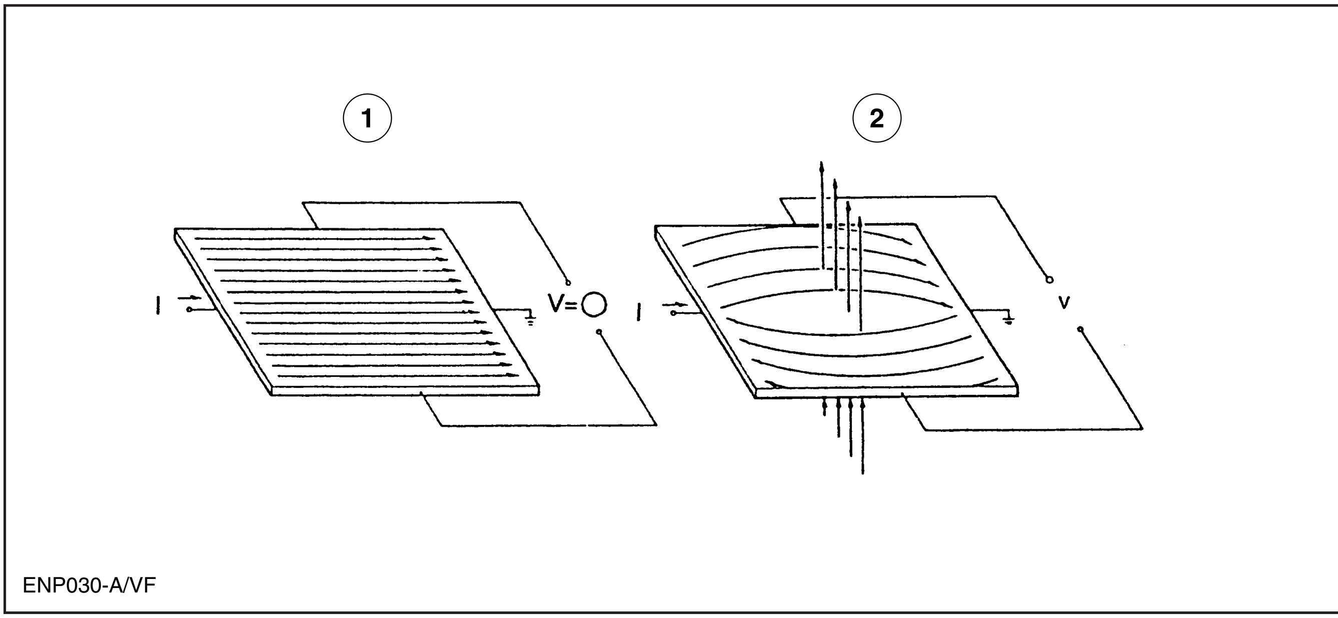
As the solid parts of the rotor pass by the Hall sensors, the sensor creates NE signals corresponding to the number of cylinders and one G signal. Each rotation of the distributor (two turns of the crankshaft) creates one group of signals. The NE signal indicates the position of the crankshaft relative to compression TDC. The G signal indicates compression TDC of the No. 1 and No. 4 cylinders.



Hall-effect sensor

1 Rotor
2 Crank position sensor

Hall effect



The Hall effect

1 Hall element at normal current
2 Hall element showing Hall effect

When a magnetic field comes near an electrically charged semiconductor at a 90 degree angle, it creates a distortion in current flow. This distortion is the Hall effect, and a semiconductor used for this effect is a Hall element. Attaching two wire leads vertically to either side of the semiconductor allows measurement of the Hall-effect as a change in voltage.

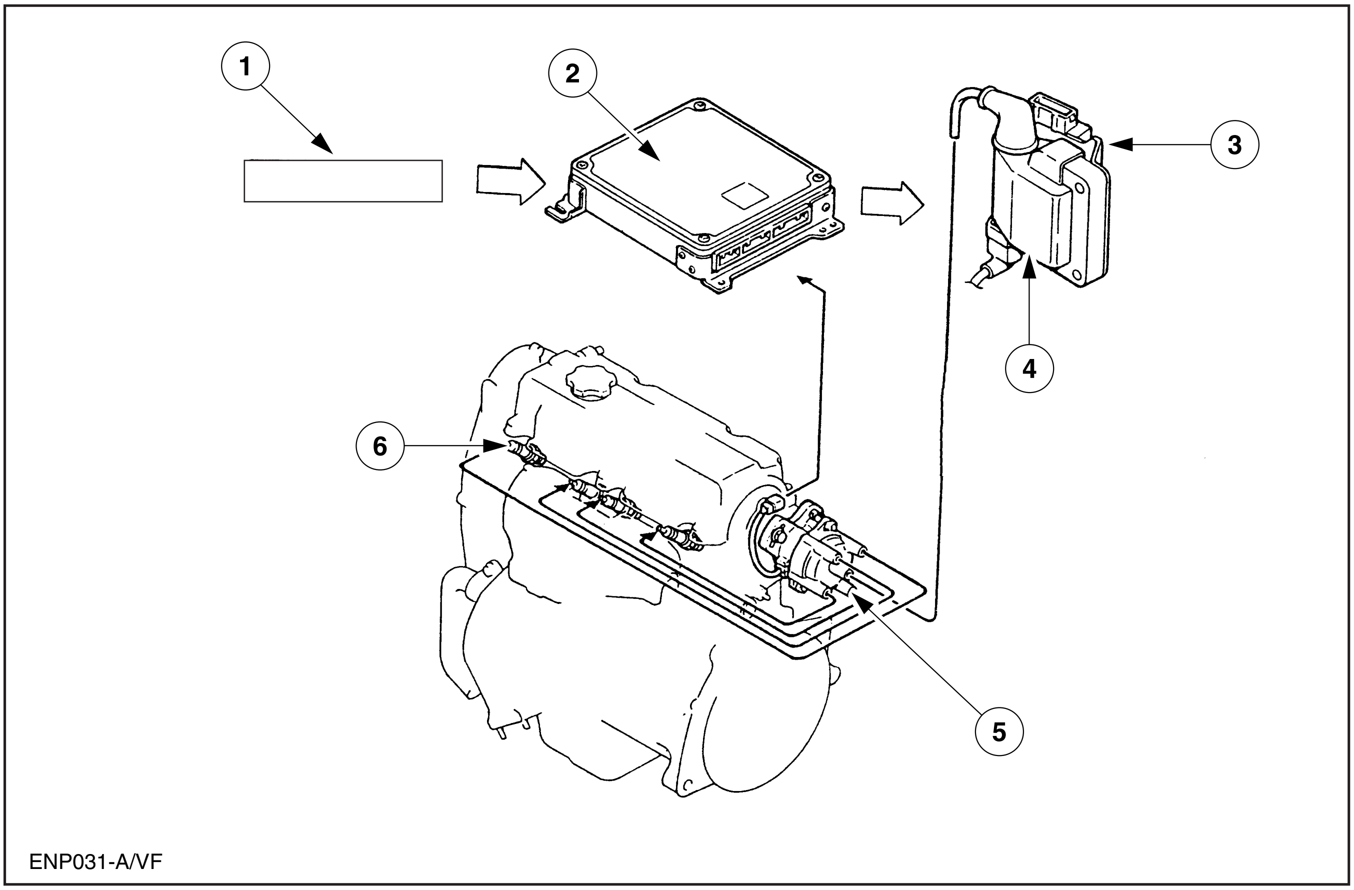
If there is no magnetic field, the current value is constant and there is no voltage difference between the output terminals.

However, when there is a magnetic field nearby at right angles to the current, the current flow distorts, causing a voltage difference between the output terminals.

Ignition systems use the voltage signal created to control a power transistor in the distributor.

Ignition control systems (continued)

Ignition control circuit with distributor



Ignition control circuit with distributor

1 Input signals from sensors
2 PCM
3 Igniter (power stage)
4 Ignition coil
5 Distributor
6 Spark plugs

The PCM determines the ignition timing based on the G and NE signals and signals from other sensors. After determining the ignition timing, the PCM sends an ignition timing signal (IGT) to the igniter.

When the ignition timing signal stops, the igniter shuts off, interrupting the primary current to the ignition coil and generating a high voltage. The ignition coil sends this high voltage to the distributor. In the distributor, the rotor transmits the high voltage to each cylinder. The spark plug sparks, igniting the air/fuel mixture in the combustion chamber.

There are two types of igniters:

1. Igniter with dwell angle control circuit: receives ignition timing signals from the PCM, sets dwell angle (current flow time to ignition coil), and sends current to the ignition coil.
2. Simple igniter: incorporates the dwell angle control circuit into the PCM, simplifying design.

Distributorless Ignition Control Operation

The distributorless ignition system (DIS) uses the CKP sensor and other sensors used by the distributor-type systems to precisely control ignition timing.

DIS systems do not use a distributor, a distributor cap, or distributor rotor for secondary ignition distribution. In a DIS system, each individual cylinder (or pair of cylinders) has a separate ignition coil, and the coil directly ignites the spark plug.

Each cylinder (or pair of cylinders) in a DIS system has its own ignition coil, which contains an igniter. Applying the voltage generated by the ignition coil directly to the spark plug reduces wear to high-voltage parts and eliminates regular service traditionally needed to replace the distributor cap and rotor. Fuel economy and emission performance are also improved.

A DIS system is generally more reliable than a distributor-type ignition system because there are no moving parts on the output side of the DIS system. In addition, a DIS system can control each cylinder (or pair of cylinders) individually. Ignition timing precision is improved and the need for ignition timing adjustment is eliminated.

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of emission control devices.
- Describe emission control devices and identify the types of emission control devices.
- Identify the components of emission control.
- Describe the theory and operation of emission control devices.

Emission control devices

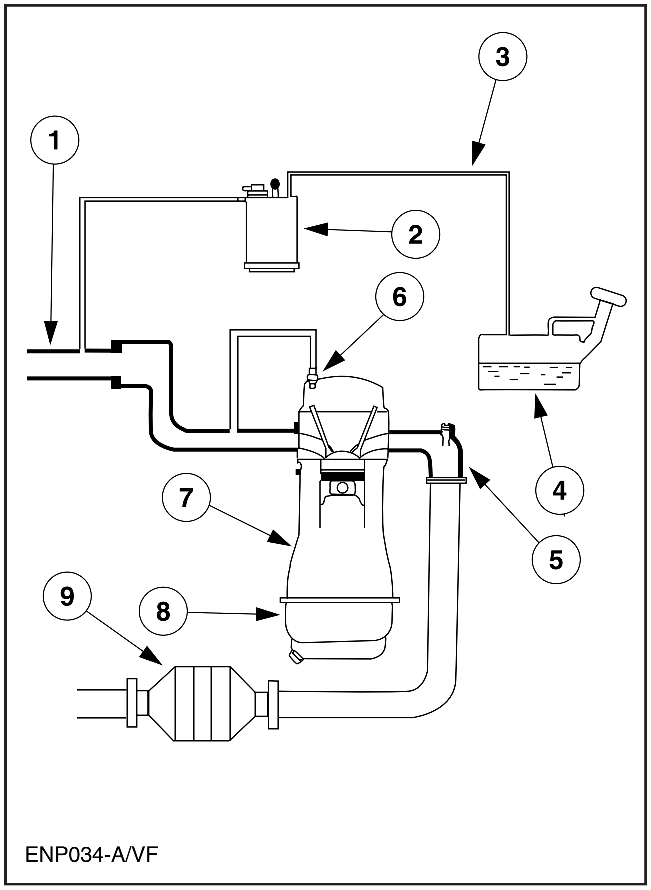
Emission control devices work to control one or more specific emission sources. There are several devices for each emission source, as shown.

Emission control systems are a combination of individual devices and complex control systems engineered to reduce harmful emissions. While the controls are highly computerized, the devices work on basic chemical and mechanical principles. This section describes three types of emission control systems:

- Positive crankcase ventilation (PCV) system
- Exhaust gas recirculation (EGR) system
- Evaporative emissions control (EVAP) system

Crankcase gases

Crankcase gases are controlled by the positive crankcase ventilation (PCV) valve and by pressure in the intake manifold. The PCV valve returns crankcase vapors to the engine to be burned.



Emission control devices

1 Intake manifold
2 Charcoal canister (or carbon canister)
3 Fuel vapor line
4 Fuel tank
5 Exhaust manifold
6 PCV valve
7 Crankcase
8 Oil pan
9 Catalytic converter

Emission control devices (continued)

Exhaust gases

Exhaust gases are controlled directly by the catalytic converter and the EGR system. The catalytic converter neutralizes hydrocarbons, carbon monoxide, and oxides of nitrogen as the exhaust gases pass through it. The EGR valve decreases oxides of nitrogen by sending some exhaust gases back to the engine, lowering combustion chamber temperature.

Evaporation

Fuel vapors are controlled by the charcoal canister and special sealing devices on the fuel system. The charcoal canister soaks up vapors from the fuel system while the vehicle is parked and during certain driving conditions.

Special sealing devices on the fuel system prevent vapors from leaving the system. They include:

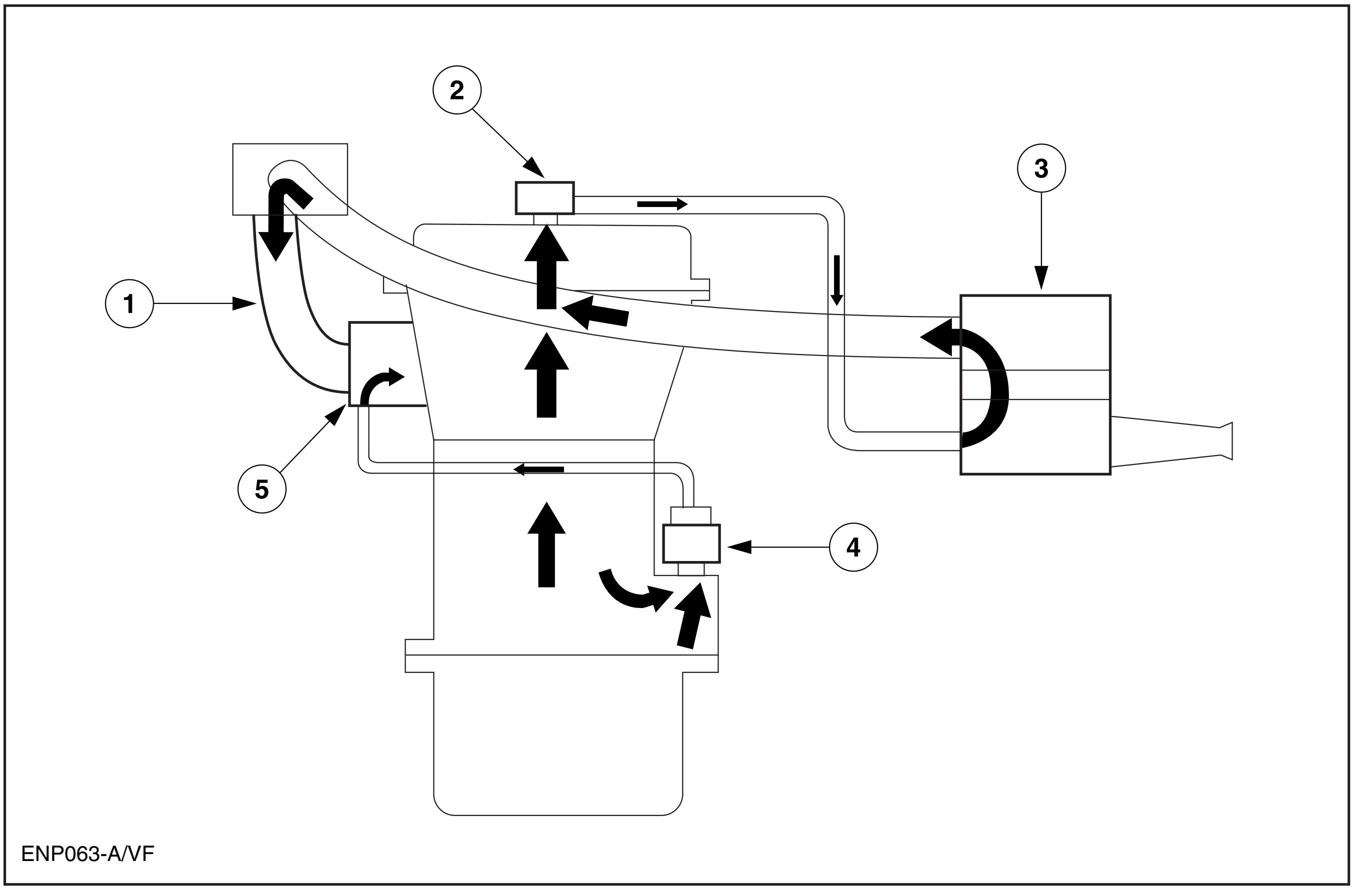
- A sealed fuel tank
- A purge control valve that routes stored evaporative fumes into the engine
- A specialized fuel cap and filler hardware designed to prevent fumes from escaping during driving and refueling
- Charcoal canister to store fumes

The following table explains some of the common characteristics of high emissions, listed by type of emission.

Emission	What It Means	If Too High	If Too Low
Hydrocarbons (HC)	A low HC reading is normal. Fuel that touches the cooler metal of the combustion chamber (cylinder walls, head, and piston) does not burn.	HC is the best indicator of a misfire caused by ignition problems or an excessively lean mixture. A constantly misfiring cylinder can push the HC reading above an analyzer's upper rpm limit.	The catalytic converter processes hydrocarbons. It is always better to have as low a reading as possible.
Carbon Monoxide (CO)	Best indicator of air/fuel ratio.	Indicates the air/fuel ratio is too rich (too much fuel/too little air). Insufficient oxygen (or too many hydrocarbons) means a rich mixture.	Cannot be too low. A zero reading means the catalytic converter is operating properly and the air/fuel ratio is correct. The catalytic converter combines CO with an additional oxygen molecule to create O_2.
Carbon Dioxide (CO_2)	Measures the operating efficiency of the engine. Higher readings mean the engine is operating more efficiently. CO_2 below 7% will not support combustion.	Indicates a rich mixture in a vehicle that has a catalytic converter and an air pump. The catalyst combines the CO with additional oxygen to create CO_2.	Ten percent readings mean the air/fuel ratio is rich or lean. Also indicates a misfire or other ignition or fuel delivery problem.
Oxygen (O_2)	Combustion should consume all oxygen. Because perfect combustion is not possible, there will be a little left over (less than 2%).	An air leak, the air injection systems, or a lean mixture can cause an oxygen reading greater than 1.5%. A lean air/fuel ratio contains excessive oxygen (insufficient fuel). The excess oxygen passes through the combustion chamber untouched.	Theoretically, the reading should be zero. Most cars have less than 1.5% O_2 when operating normally.
Oxides of Nitrogen (NO_X)	The only way to minimize NO_X is to keep the combustion temperatures as low as possible. Exhaust gas added to the incoming air stream dilutes the air charge and lowers combustion temperatures.	Typically caused by a non-operating or improperly operating EGR system. The EGR system recycles exhaust gas into the intake. High NO_X may also be caused by detonation, preignition, lean fuel mixtures, increased spark advance, catalyst deterioration, or carbon in the combustion chamber.	Some will always be present in the exhaust gas. Too low a NO_X level may indicate rich air/fuel ratios.

Emission control devices (continued)

Positive crankcase ventilation (PCV) system



Positive crankcase ventilation (PCV) system

1 Intake manifold
2 Oil separator
3 Air cleaner
4 PCV valve
5 Connection to inlet manifold

Unlike other emission control systems, the PCV system is not controlled by the PCM. Intake manifold pressure, which is a vacuum, controls the PCV system.

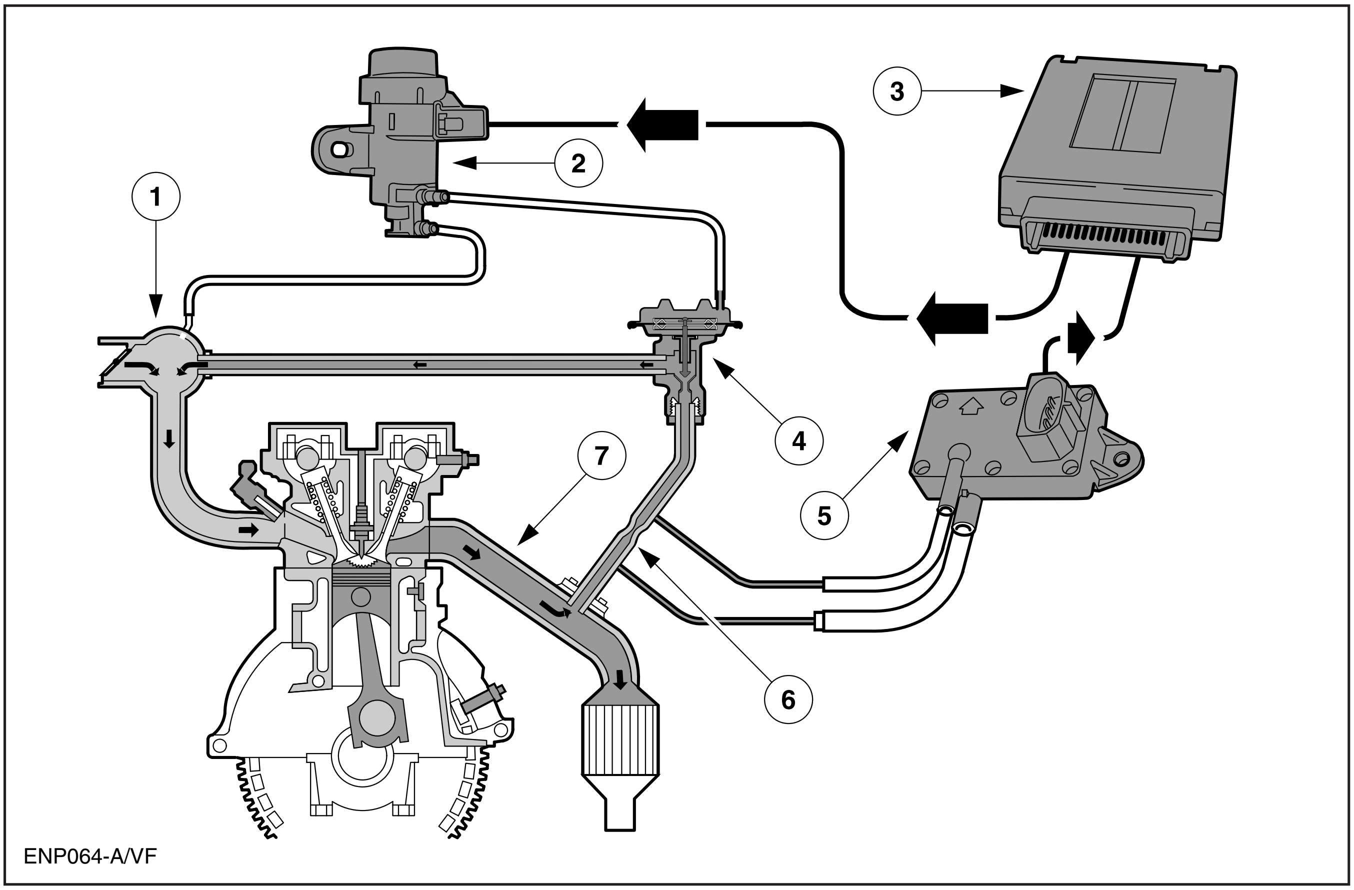
Since no piston rings can provide a complete seal between the combustion chamber and the crankcase, gases with a high concentration of hydrocarbons can pass by the piston rings and collect in the crankcase. Emission control legislation specifies that these gases must not pass into the atmosphere.

All the vapors in the crankcase and the cylinder head are ducted through appropriate hose connections into the intake manifold. The vapors then enter the combustion chamber.

A pressure-sensitive system is used in modern vehicles to meter the amount of vapors removed from the crankcase. At high vacuum in the intake manifold the crankcase gases are passed into the intake manifold through a PCV valve.

At low vacuum in the intake manifold the PCV valve closes. The crankcase gases pass through the air cleaner into the inlet system.

Exhaust gas recirculation



Exhaust gas recirculation system (typical)

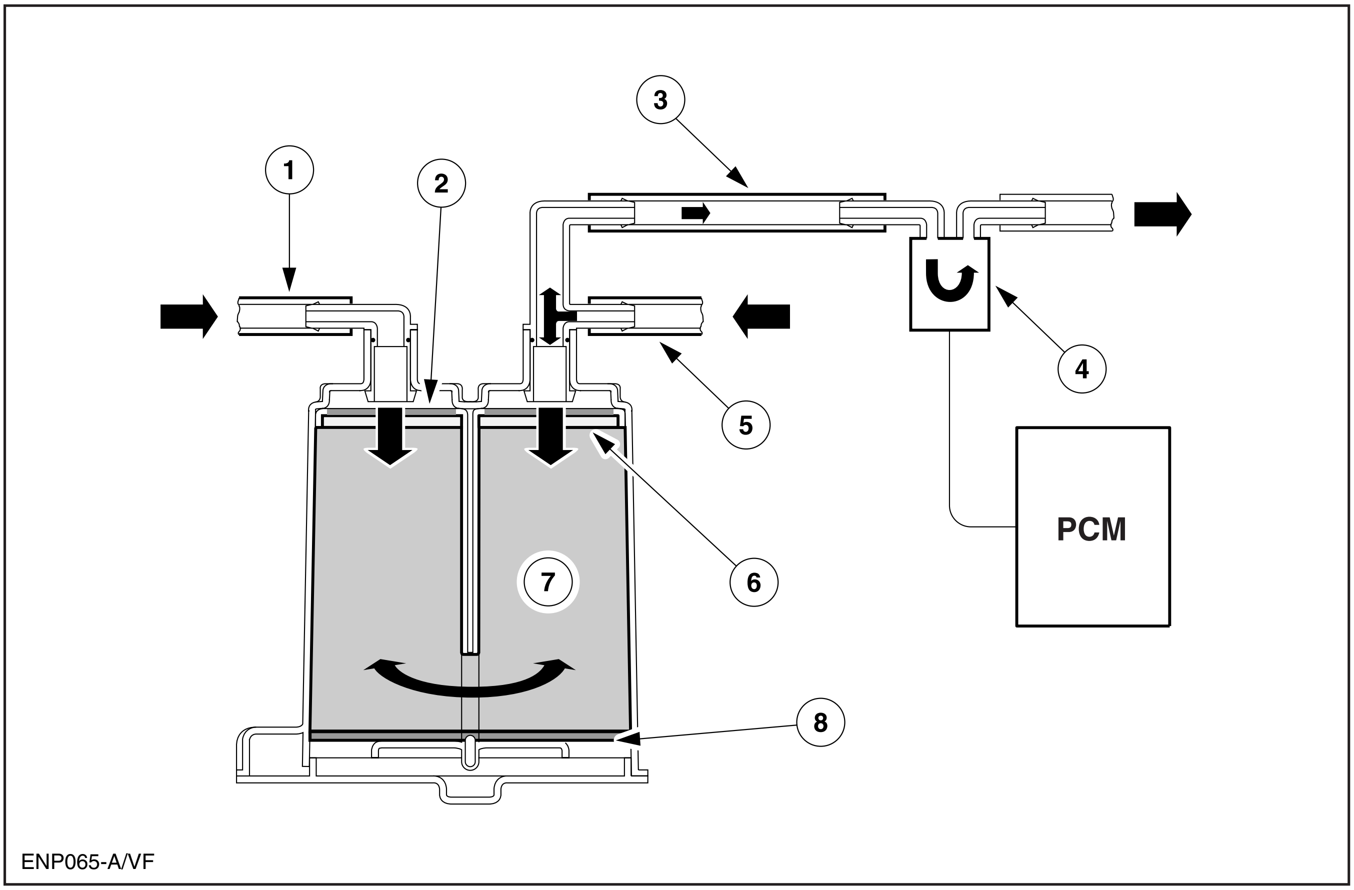
1 Intake manifold
2 EGR vacuum regulator (EVR)
3 PCM
4 EGR valve
5 EGR pressure transducer
6 Throttling point
7 Exhaust manifold

The exhaust gas recirculation (EGR) system recirculates exhaust gas to the air inlet to reduce the temperature inside the combustion chamber. The EGR system comprises an EGR valve located between the exhaust and inlet manifolds. The diaphragm unit opens the valve seat of the EGR valve under vacuum.

The vacuum is drawn from the inlet manifold, and is regulated by the EGR vacuum regulator (EVR) so that the EGR valve opens so far that the recirculation of the exhaust gases in a closed loop corresponds to the set value in the map stored in the PCM.

Emission control devices (continued)

Evaporative Emissions Control (EVAP) System



Evaporative emissions control (EVAP) system

1 Ambient atmospheric pressure
2 Fresh air inlet
3 Connection to canister purge solenoid valve
4 Canister purge solenoid valve
5 From fuel tank
6 Plastic strainer
7 Activated carbon granules
8 Metal strainer

The evaporative emissions system prevents fuel vapor in the fuel tank from entering the atmosphere.

The carbon canister is filled with activated carbon granules and has three hose connections.

The hose from the fuel tank is connected to the rollover safety valve (on the fuel tank) and there is another hose connecting to the canister purge solenoid valve. The fresh air inlet is fed by atmospheric pressure.

The fuel vapor from the fuel tank flows into the carbon canister through the rollover safety valve. The hydrocarbons in the fuel vapor are stored in the activated carbon granules.

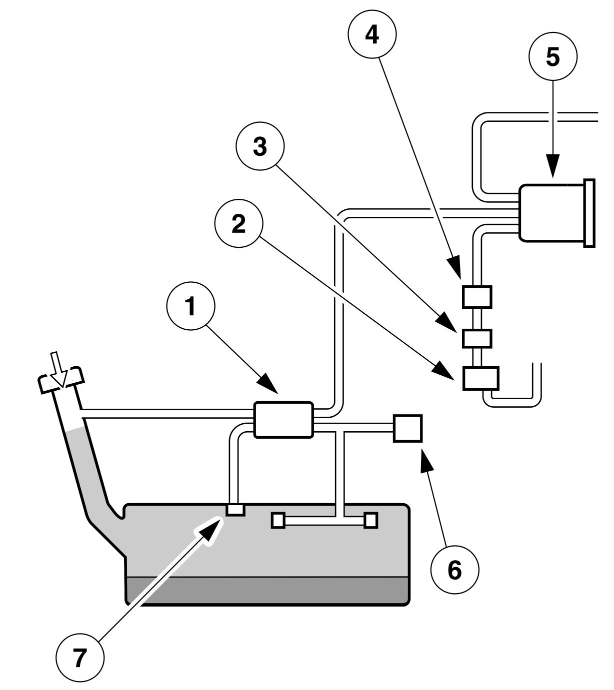
When the solenoid valve controlled by the PCM opens, the vacuum in the inlet system causes the fuel vapor to be drawn into the inlet system from the carbon canister through hose No. 3 and directly from the fuel tank through the hose from the fuel tank. Atmospheric pressure serves to vent the system.

EVAP canister

Gasoline vapors are potentially explosive and contain hydrocarbons. If allowed to leak from the fuel system, the vapors could cause an engine fire.

There are always fuel vapors in the fuel tank. The fuel tank must allow room for fuel expansion, and vapors fill the open space. The evaporative emissions control system captures vapors from the fuel tank and returns them into the engine to be burned. The system works continuously whether or not the engine is running.

The evaporative emissions control system consists of a canister filled with activated charcoal, lines from the fuel tank to the canister and from the canister to the intake manifold, a two-way valve, purge control solenoid valves, and a special fuel tank cap. However, configuration and specific components vary by model and year.



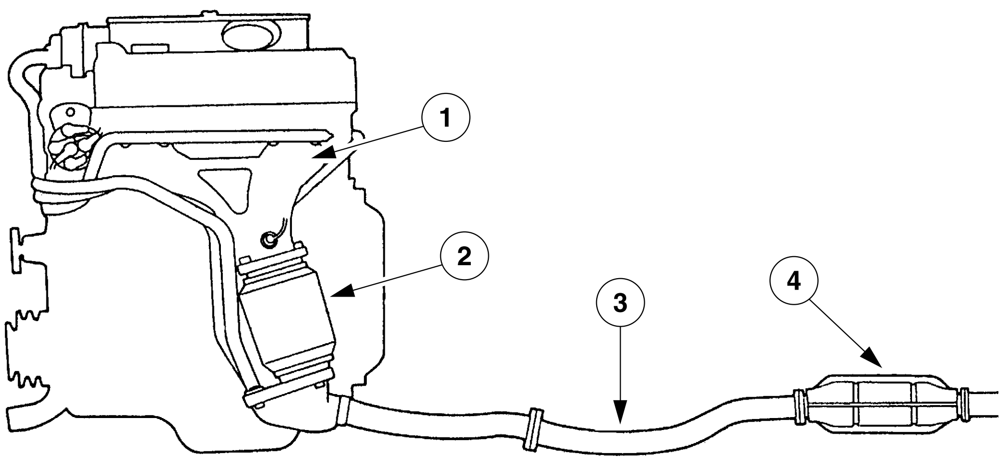
ENP046-A/VF

EVAP system components

1 Pressure control valve
2 Evaporative gas check valve (two-way) to catch tank and purge solenoid valve
3 Air filter
4 Canister drain cut valve
5 Charcoal canister (or carbon canister)
6 Fuel tank pressure sensor
7 Fuel shutoff valve

Emission control devices (continued)

Catalytic converter



Exhaust system

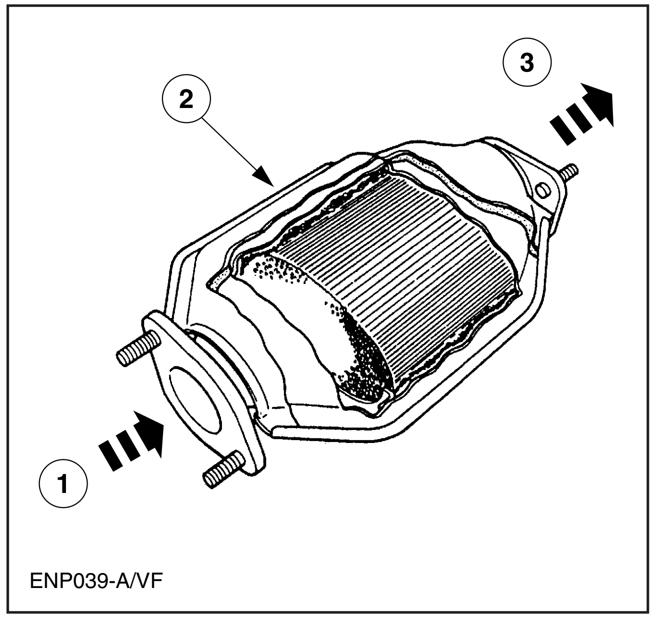
1 Exhaust manifold
2 Front catalytic converter
3 Exhaust pipe
4 Rear catalytic converter

A catalyst is a substance that supports or triggers a chemical reaction. The catalyst is reusable because the reaction does not consume it.

The catalytic converter is part of the exhaust system. The catalytic converter uses a chemical reaction to convert harmful combustion by-products into harmless ones. This conversion takes place continuously as exhaust gases pass through the converter.

Catalytic converters are very sensitive to changes in air/fuel ratio. The PCM sets a stoichiometric (14.7:1) ratio during normal cruising conditions because that is where the catalytic converter is most efficient. Catalytic converters are also temperature-sensitive and must reach 260º C to 538º C (500º F to 1,000º F) for peak operating efficiency.

The emission control system uses the front and rear oxygen sensors to measure catalytic converter efficiency. Because the oxidation process consumes oxygen, the rear oxygen sensor reading should be much lower than the front oxygen sensor reading. If the two readings match or come close to matching, the emission control system records a catalytic converter malfunction.



Catalytic converter operation

1 Hydrocarbons, oxides of nitrogen, and oxygen enter converter.
2 Catalyst breaks down compounds.
3 Carbon dioxide, water, nitrogen, and oxygen exit converter.

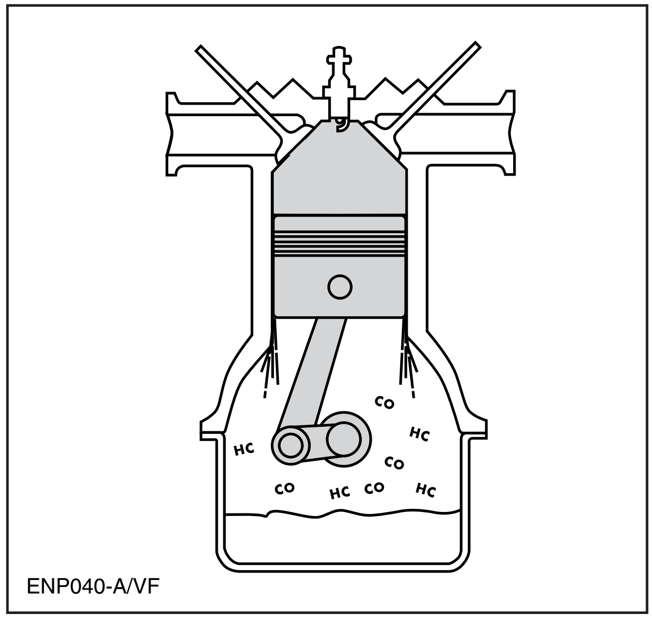
Emission control devices (continued)

PCV valve

Some combustion gases leak around the piston rings and escape from the combustion chamber. These gases, called blow-by gases, collect in the crankcase. Because these gases contain unburned fuel and oil vapors, blow-by gases are potentially explosive.

Blow-by gases that leak out of the crankcase cause emissions of hydrocarbons and carbon monoxide in addition to the explosion danger. The PCV system prevents emissions and eliminates the explosion danger.

The PCV system circulates blow-by gases from the crankcase to the intake manifold. From there, the blow-by gases mix with intake air and return to the combustion chamber.



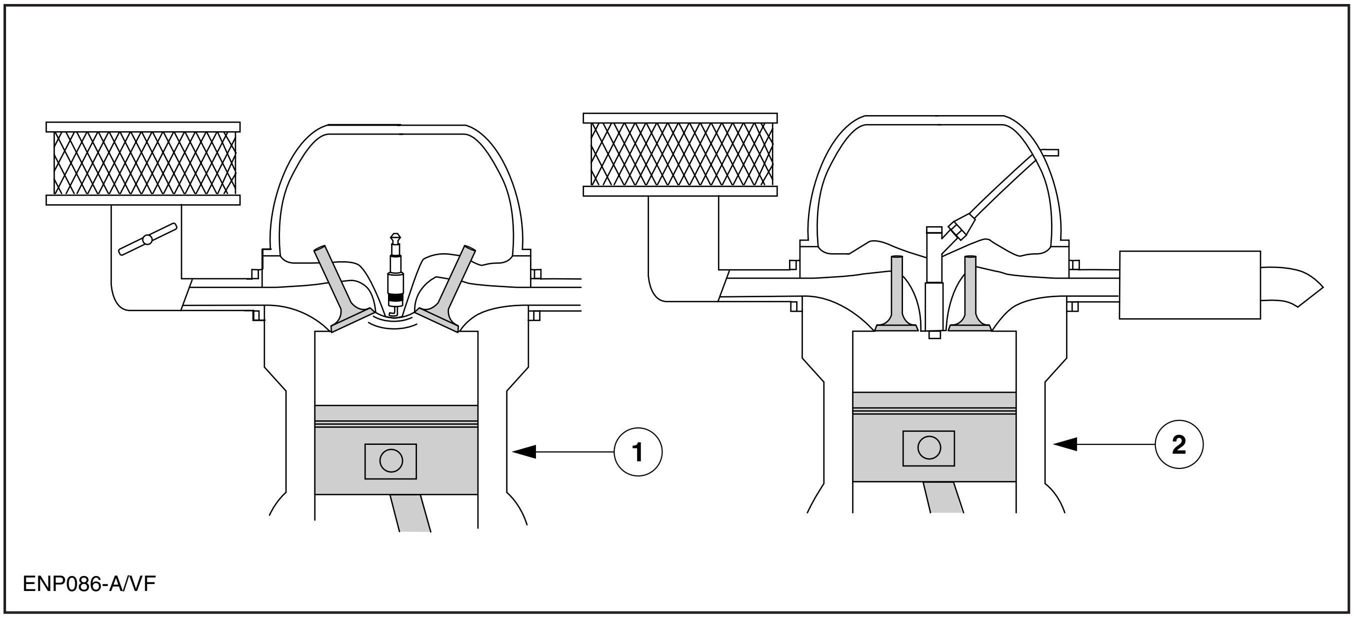
Creation of blow-by gases

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of the diesel engine fuel injection system.
- Describe the diesel fuel injection system and identify the types of diesel fuel injection systems.
- Identify the components of diesel fuel injection.
- Explain the theory and operation of the diesel fuel injection system.

Major operating differences between diesel and gasoline engines



Gasoline versus diesel engine fuel injection

1 Gasoline engine
2 Diesel engine

There are a number of items that are different between a diesel and a gasoline engine. The most obvious is the lack of an ignition system on the diesel engine. The diesel is a compression-ignition type engine, as opposed to a spark-ignition type. There are no spark plugs, wires or igniting coil. Heat generated from compression is used to ignite the air/fuel mixture in the cylinders. The diesel engine has a much higher compression ratio than a gasoline engine. The diesel compresses air into a tighter space in a cylinder, creating the higher temperatures needed to ignite the air/fuel mixture.

Diesel engine fuel injection system

The diesel engine fuel injection system must control:

- fuel metering
- high-pressure delivery
- correct timing and timing advance
- rate of fuel flow
- atomization of fuel

The development of the automotive diesel engine is governed primarily by requirements for clean exhaust emissions, improved fuel economy, and the optimization of driveability.

These stipulations are placing increasingly stringent demands upon the fuel injection system, namely:

- ability to process additional parameters
- tighter tolerances and increased accuracy even over very long periods of operation

These demands are fulfilled by the introduction of the electronic engine control.

The electronic engine control provides electronic measurement as well as flexible data processing and closed control loop with electrical actuators.

In the diesel engine, operating characteristics and combustion are influenced by:

- injected fuel quantity
- start of injection
- exhaust gas recirculation
- charge air pressure

These controlled variables must be precisely adjusted for every working mode in order to ensure efficient diesel engine operation. To this end, the electronic engine control system incorporates automatic control loops for the main parameters.

Diesel engine fuel injection system operation

On mechanical distributor-type fuel injection pumps, fuel injection is controlled with a timing advance device for the fuel injection timing and a fuel lever for the quantity of fuel.

Additional devices are provided for adjustments which mechanically alter the fuel injection timing and quantity of fuel at the fuel injection pump.

The new generation of distributor type fuel injection pumps have electronic control modules with sensors and solenoid controlled valves allowing very precise control of fuel injection timing over the entire range in a closed loop.

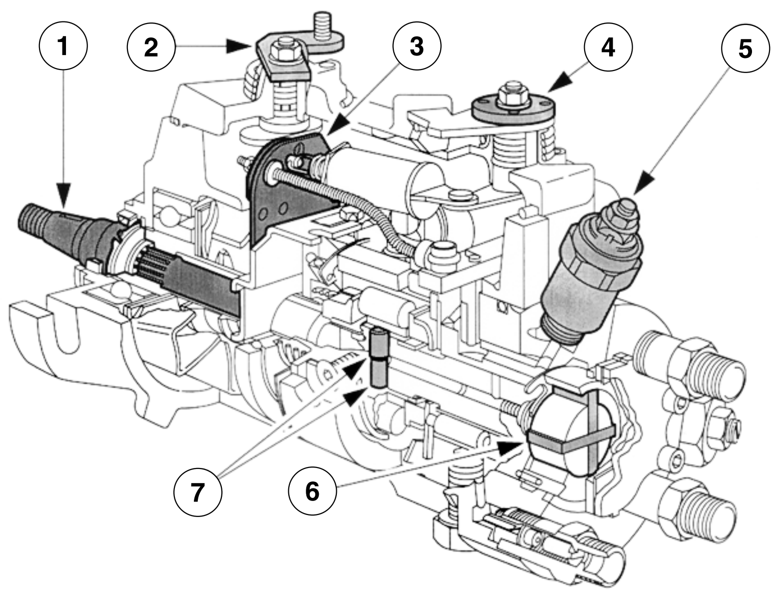
The PCM provides optimum control of the engine through the enhanced capability of the microprocessor.

The PCM has two major divisions: hardware and software. The hardware includes the PCM, sensors, switches, actuators and interconnecting terminals.

The software in the PCM provides the strategy control for outputs (engine hardware) based on values of the inputs to the PCM.

The PCM receives information from a variety of sensors and switch inputs. Based on the strategy and calibration stored within the memory chip, the PCM generates the appropriate output.

Fuel injection pump



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Fuel injection pump assembly

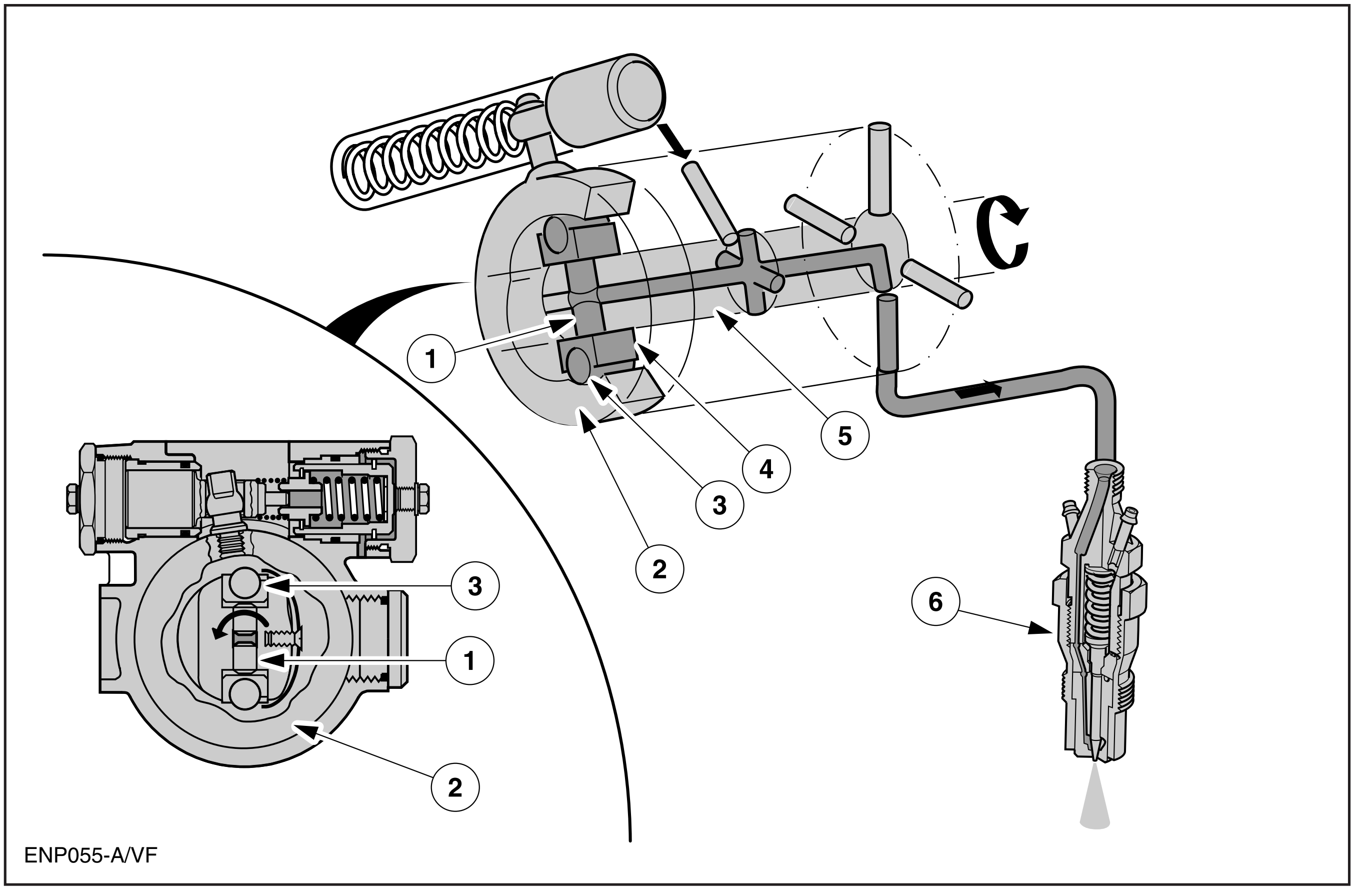
1 Driveshaft
2 Idle lever
3 Control lever
4 Fuel lever
5 Shutoff solenoid
6 Transfer pump
7 High pressure plungers

The fuel injection pump performs the duty of both the carburetor and the distributor. The fuel injector pump must enter an exact amount of fuel to each cylinder at precisely the right time at an extremely high pressure.

The fuel injection pump is the most complicated part of a diesel engine and is the most carefully manufactured. The fuel injection pump should not be serviced until all the possible problems have been checked out.

Diesel engine fuel injection system operation (continued)

Distributor injection system

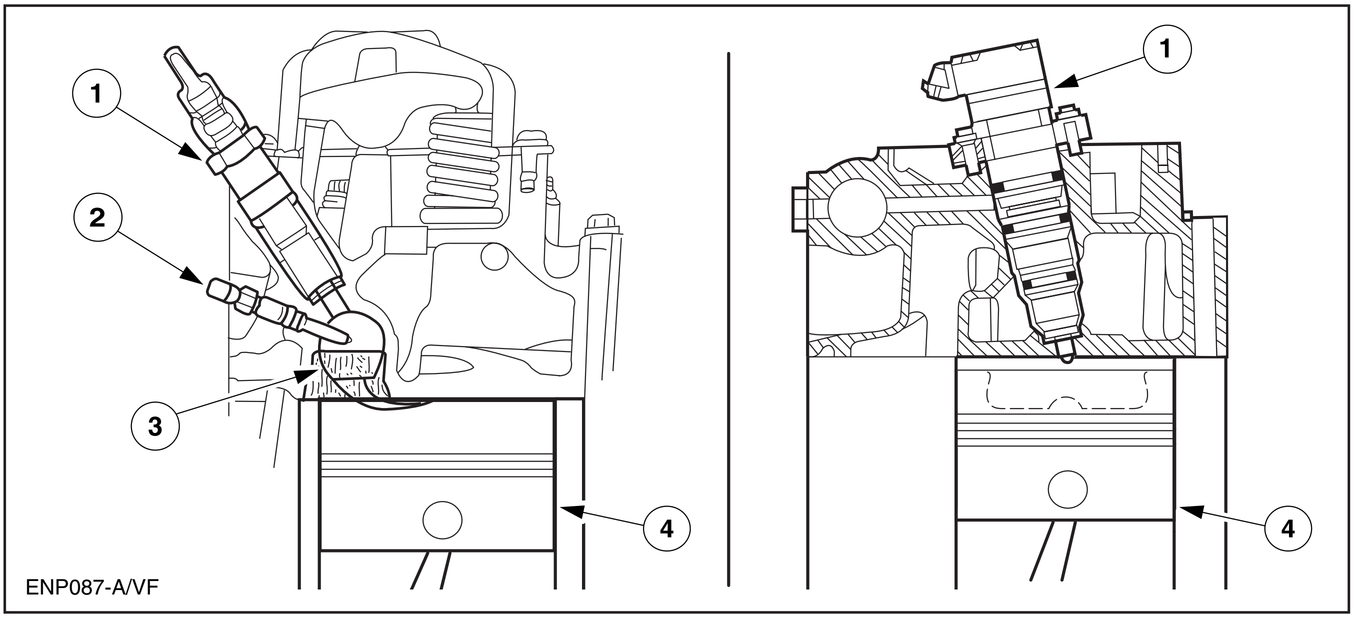


Distributor injector

1 High-pressure plunger
2 Cam ring
3 Rollers
4 Roller shoes
5 Distributor roller
6 Injector

The operation of this pump is similar to that of an automotive distributor. In addition, the hydraulic head of the pump resembles a distributor cap.

The fuel enters the pump through the center tube in the hydraulic head and goes through a metering valve controlled by the accelerator pedal and a governor.



Fuel injection (diesel compared to gasoline engine)

1 Fuel injector
2 Glow plug
3 Swirl chamber
4 Piston

The fuel is fed through a charging port to the two pumping plungers. These plungers are actuated by a rotating circular cam, which has two lobes on it for each cylinder in the engine.

The cam pushes the two plungers together, pressurizing the fuel. The pressurized fuel opens the delivery valve, exposing it to a rotor.

The fuel is then distributed to the proper injector by the alignment of the ports on the rotor to the head of the pump.

The distribution of the fuel is similar to the way a rotor distributes the high tension voltage to the different spark plugs in an automotive distributor. From the head of the pump, the fuel flows through the high pressure lines to the injector.

Diesel engine fuel injection system operation (continued)

Fuel injectors

The injectors used with the pump are of the pintle nozzle design. This type of injector produces a conical spray pattern which provides the best fuel vaporization.

A spray pattern is produced which changes as the needle is lifted off its seat. This is accomplished by the specially designed throttling pintle.

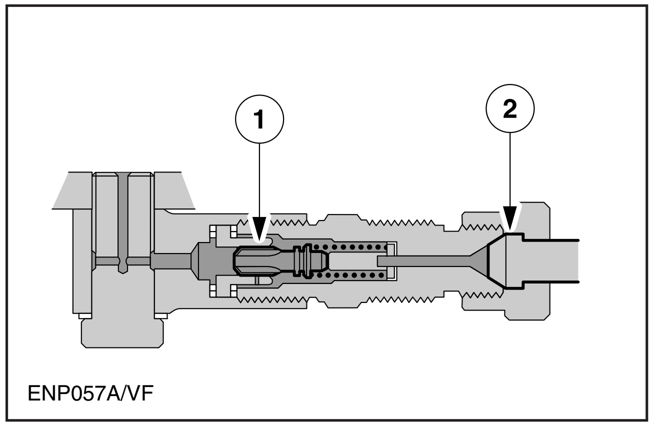
The injectors operate in a two stage sequence as the pintle is moved off its seat:

- The first stage begins when the injector opens and fuel is injected in a tiny spray pattern.
- As the second stage begins, the seat moves upwards to permit more fuel. The tiny spray pattern increases to a fully conical spray pattern.

This two-stage sequence produces a less violent combustion.

Pressure valves

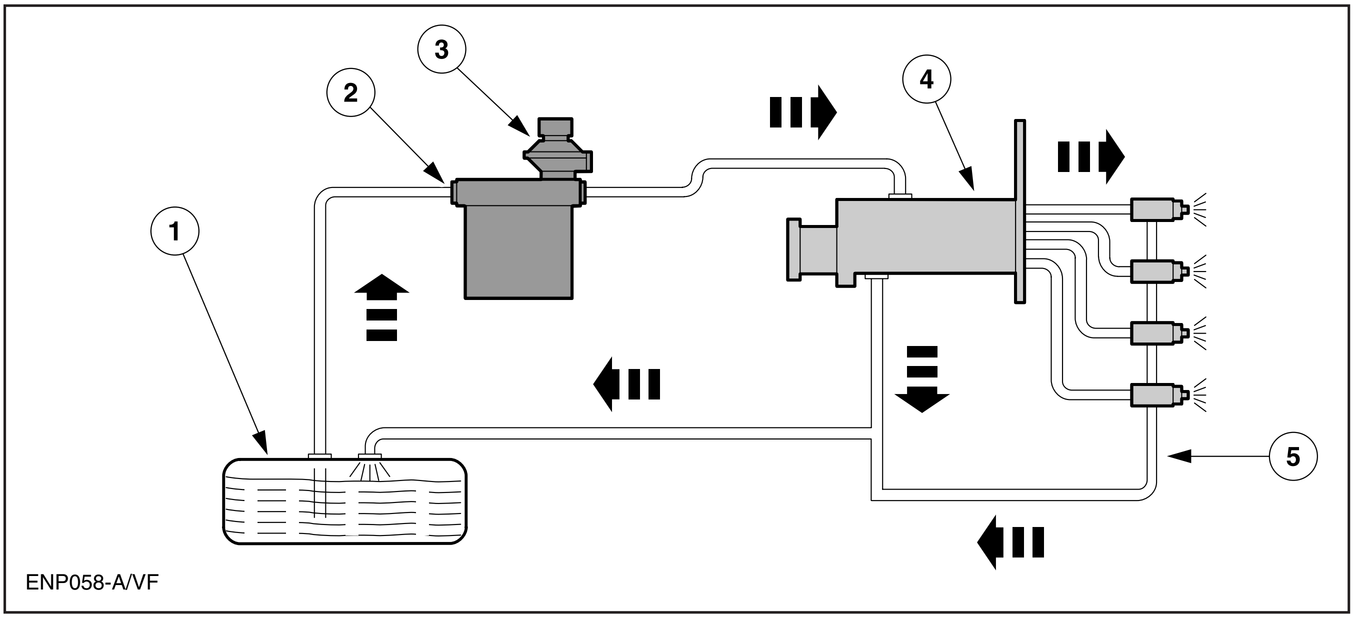
The fuel outlets of the injection pump are fitted with high-pressure valves. These valves prevent fuel pressure in the pipes from increasing to a point where the injector might otherwise open when not required.



Pintle nozzle type injector

1 Valve seat pinion
2 Fuel injector pipe

Low pressure recirculation system



Low pressure recirculation system (typical)

1 Fuel tank
2 Fuel filter
3 Hand priming pump
4 Transfer pump (located inside the fuel injection pump)
5 Fuel return line

The low-pressure recirculation system consists of:

- fuel tank
- fuel filter and hand priming pump
- transfer pump (located inside the fuel injection pump)
- fuel return line

The transfer pump brings fuel from the tank to the injection pump. The pump supplies only low-pressure fuel. The pump may be located in several different places and is sometimes a part of the fuel injection pump itself.

The fuel return line returns the unused fuel back to the tank. Normally, only about 10% of the fuel that is brought from the fuel tank by the transfer pump to the fuel injection pump is burned in the combustion chamber. The rest of the fuel is used to cool and lubricate the fuel injection pump and injectors.

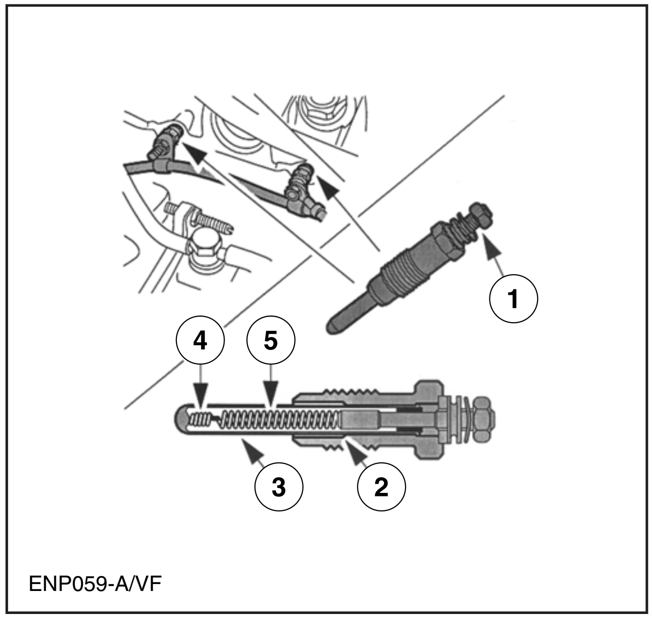
Diesel engine fuel injection system operation (continued)

Cold starting aids

When starting a diesel engine from cold, the charge air must be heated to obtain a sufficient compression temperature for self-ignition.

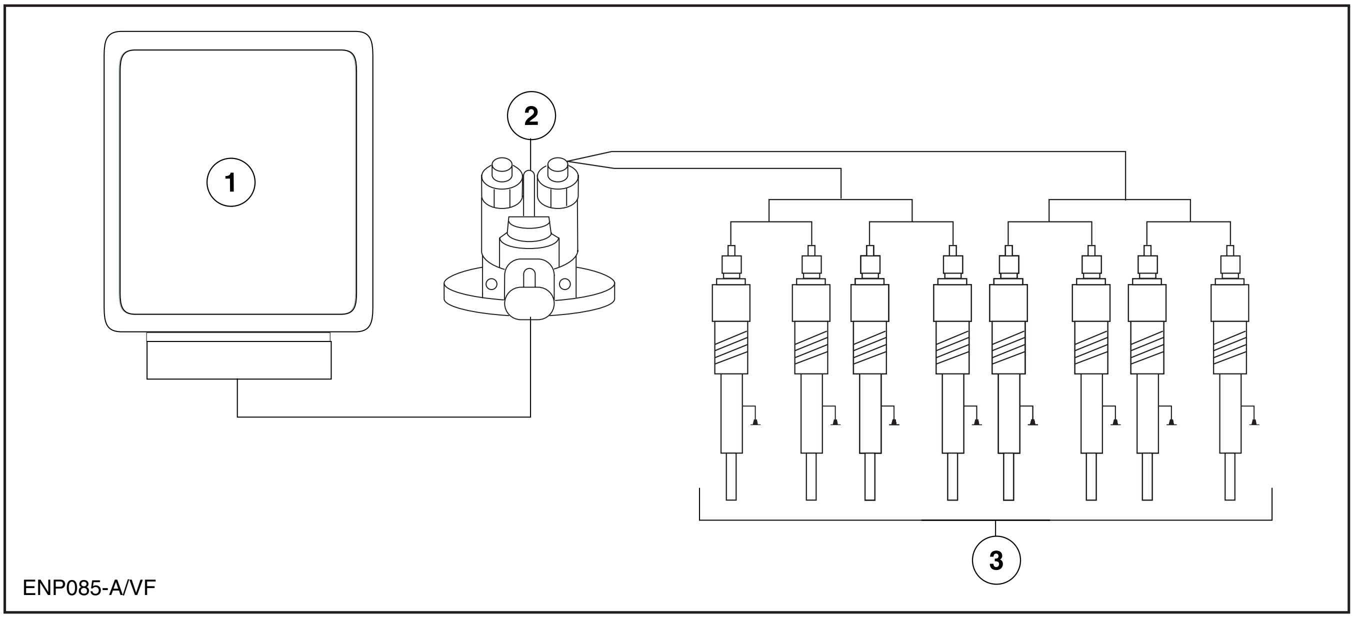
Glow plugs

The glow plug in the swirl chamber heats the combustion chamber according to the engine temperature before starting. The heating time is determined by a glow plug relay which indicates when the engine is ready to be started by means of a warning light in the instrument panel. After starting, the glow plug continues heating for a few seconds to ensure that the engine runs satisfactorily when cold.



Glow plug

1 Electrical connection
2 Annular gap
3 Tube
4 Heating coil
5 Regulating coil



Glow plug wiring

1 Powertrain control module
2 Glow plug relay
3 Glow plugs

The glow plug consists of a tube which is heated by a heating coil in the tip. In front of the heating coil there is a regulating coil whose electrical resistance increases as its temperature rises (positive temperature coefficient). The variable resistor maintains a uniform temperature of approximately 1,000º C (1,832º F) by regulating current to the heater coil.

Diesel engine fuel injection system operation (continued)

Fuel for diesel engines

Even though both diesel fuel and gasoline are made from crude oil, each has different characteristics that should be considered. The primary characteristics of diesel fuel are:

- heat value
- specific gravity
- cloud point and pour point
- viscosity
- volatility
- ignition quality (cetane rating)
- carbon residue
- sulphur content
- oxidation and water

Heat value

The heat value of any fuel is measured in BTUs. One BTU is the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.

Power from an engine is created by converting the fuel to heat. The more heat produced by a fuel, the more energy available to be changed into usable power.

Specific gravity

Specific gravity of a fuel is a measurement of the fuel's weight as compared to water. Diesel fuel is heavier than gasoline, so it has a higher specific gravity.

The importance of specific gravity to diesel fuel is that it must be heavy enough to achieve adequate spray penetration into the combustion chamber.

Cloud and pour points

Diesel fuels are affected by temperature much more than gasoline because diesel fuels contain paraffin, a wax substance.

As temperature drops past a certain point, wax crystals begin to form in diesel fuel, giving it a cloudy appearance. This temperature is the cloud point.

Not all fuels have the same cloud point – high quality diesel fuel is able to withstand a much lower temperature than can low quality diesel fuel.

As temperatures drop, diesel fuel begins clotting as the wax crystals grow larger. As the wax crystals grow larger, the fuel has difficulty flowing through the filters and the fuel system.

As the fuel gets even colder, it reaches a temperature where it is insoluble and will no longer flow. This temperature is the pour point. A high pour point rating for fuel indicates that in cold weather the diesel fuel does not flow easily through the fuel system.

Viscosity

Viscosity is the property of a fluid that makes it resistant to flow. The warmer the fluid, the less resistance there is to flow.

The viscosity of diesel fuel affects the spray pattern of the fuel into the combustion chamber. High viscosity results in a fuel dispersion that contains large droplets which are hard to burn.

If the viscosity of the fuel is low, it is sprayed in a fine, easily burned mist. Low viscosity leads to lower lubrication capabilities of internal pump components, possibly causing parts to seize.

Volatility

Volatility is the ability of a liquid to change into a vapor. Gasoline is extremely volatile compared to diesel fuel.

Ignition quality (cetane rating)

The temperature at which fuel burns is referred to as the ignition point. Diesel fuel which has a low ignition point has good ignition quality.

Fuels with good ignition qualities burn soon after being injected into the combustion chamber.

Diesel fuel cetane ratings are the opposite of gasoline octane ratings. A high quality diesel fuel with a high cetane rating ignites the moment it enters the combustion chamber. If there is a delay in ignition of the fuel, performance of the engine suffers.

Carbon residue

Carbon residue is the material left in the combustion chamber after burning. It is found not only in diesel engines, but in any engines that burn a hydrocarbon fuel.

Sulphur content

Sulphur content is common in fuels made from low quality crude oil.

Excessive sulphur content increases ring and cylinder wear, causes formation of varnish on piston skirts, and is a prime cause of sludge in the oil sump.

Oxidation and water

Water entering the precise fuel system components, specifically the fuel injection pump and fuel pump injectors, can cause damage because water does not provide the required lubrication and causes corrosion. These fuel system components have very tight tolerances and are easily destroyed by lack of lubrication and/or corrosion.

Objectives

Upon completion of this lesson you will be able to:

- Explain the purpose and function of forced induction systems.
- Describe the forced induction system and identify the types of forced induction.
- Identify the components of forced induction.
- Explain the theory and operation of forced induction systems.

Forced induction

The internal combustion engine is a machine that requires specific amounts of air and fuel to operate properly. The amount of power that can be obtained from a given engine is determined by the amount of air that is available to mix with fuel for combustion. In a naturally aspirated engine, air intake to the engine is restricted by the amount of vacuum created in the cylinders. Adding more fuel to the same amount of air (volume) only results in excessive fuel consumption and smoke from the unburned fuel.

A comparison of the amount of air that an engine could draw in to the amount that it actually draws in under normal operating conditions is called volumetric efficiency. The power output of an engine is directly linked to its volumetric efficiency. A naturally aspirated engine usually has about an 80% volumetric efficiency, meaning that the engine draws in about 80% of the air it could draw in. By streamlining passages and increasing port sizes, the volumetric efficiency of a naturally aspirated engine can be improved, but the air still has difficulty reaching the cylinder.

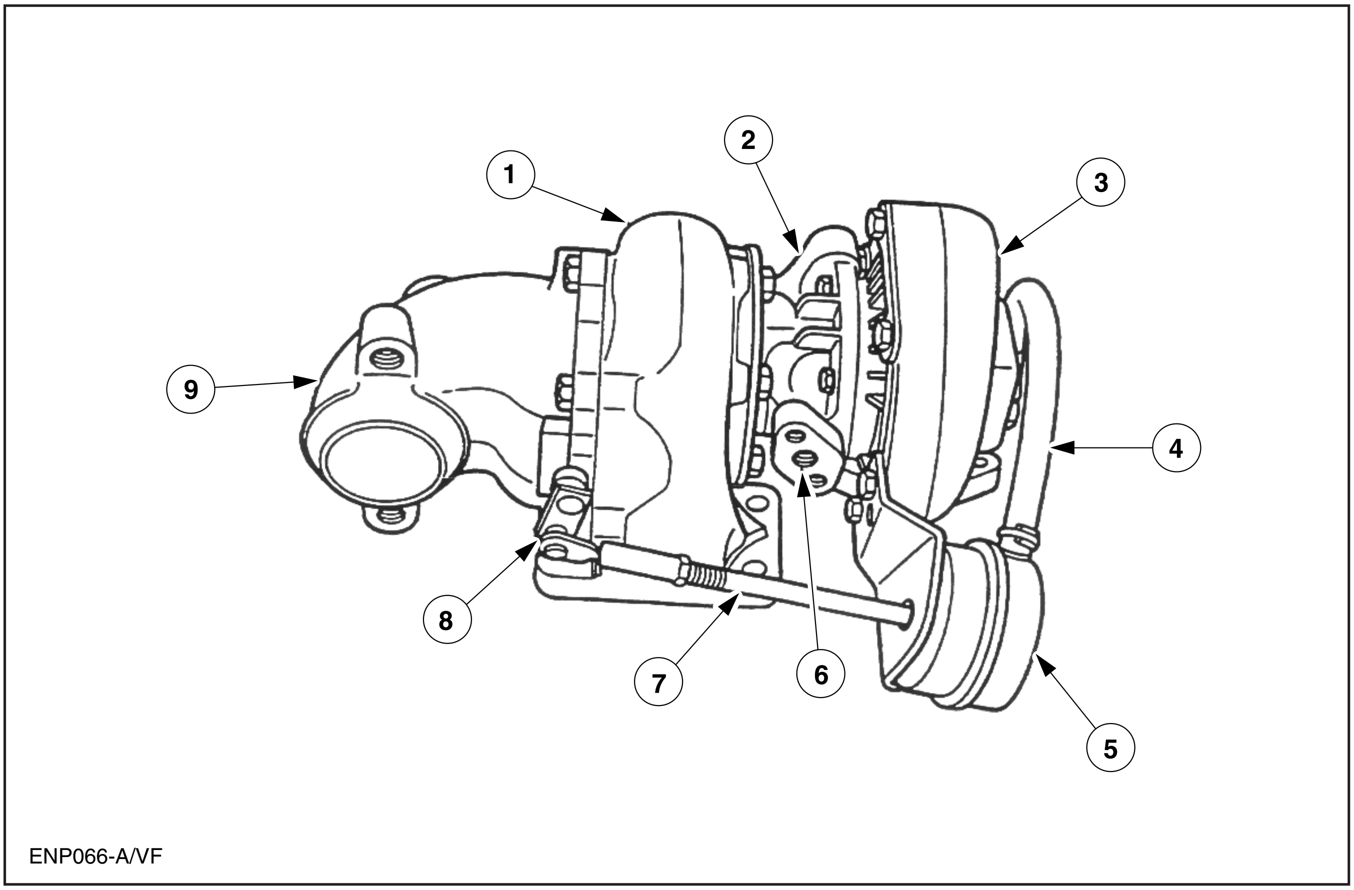
The air intake system of an automobile can be modified to produce an increase in available power. The piston and cylinder of an internal combustion engine act basically as an air pump. Air is drawn in and mixed with the fuel. This mixture of air and fuel is often called an air/fuel charge. The more air/fuel charge given to an engine, the more power it is able to produce.

Without external help an engine receives only a partial air/fuel charge. This is due mainly to bends and restrictions along the intake path and the presence of leftover exhaust in the cylinder. The air/fuel charge of an engine can be increased by pumping air into the cylinders. This forcing of more air into the cylinder allows the engine to fill its cylinders with a charge which meets or exceeds 100% volumetric efficiency of a naturally aspirated engine.

There are two different devices used to pump air into the engine: a turbocharger and a supercharger. The difference between the two is the power source which drives them.

Forced induction (continued)

Turbocharging



Turbocharger

1 Turbine housing
2 Center housing
3 Compressor housing
4 Actuator pressure sensing hose
5 Actuator
6 Oil passage outlet
7 Actuator rod
8 Wastegate linkage
9 Exhaust outlet elbow

A turbocharger is powered by the energy from engine exhaust gases. These gases produced by the engine are redirected and used to drive a vaned wheel called a turbine.

The turbine is connected by a shaft to another vaned wheel called the impeller. The turning of this impeller draws the air into the turbocharger and directs it into the cylinders. The amount of exhaust available to drive a turbocharger depends on the engine speed among other factors.

One drawback to turbocharging is that an idling engine does not pump enough exhaust to sufficiently drive the turbocharger. This drawback is most noticeable when a turbocharged vehicle accelerates from a standstill. There is a short interval of time before the turbocharger begins to pump a large amount of air into the engine. This short period of time is called turbo lag. During this period of turbo lag, the vehicle does not receive the extra power that a turbocharger helps provide at higher speeds.

The power increase resulting from the installation of a turbocharger varies with different engines and turbochargers. The power of an engine can typically increase by approximately 35-60% over the same size naturally aspirated engine.

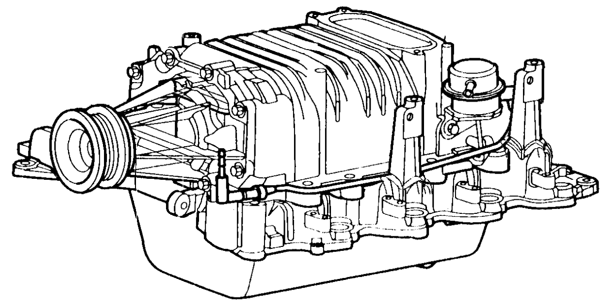
Forced induction (continued)

Supercharger

Like a turbocharger, a supercharger acts as an air pump and has many of the same features of the turbocharger. The major difference is the method of driving the pump. While the turbocharger is driven by the heated exhaust gases, the supercharger is driven from the crankshaft through belts, gears, or chains. The advantages of increased power that are present with a turbocharger are also present with a supercharger. However, because a supercharger is driven off the crankshaft rather than exhaust gases, the problem of turbo lag does not exist. This lack of turbo lag is the main advantage of a supercharger. Unlike the turbocharger, the amount of air charge delivered per revolution of the positive displacement supercharger is basically the same for each revolution of the engine regardless of specifications.

The advantage of this type of supercharger is that this constant air charge delivers roughly the same manifold pressure at all engine speeds; the disadvantage, as with any supercharger, is that it is driven by the engine crankshaft, requiring the use of engine power. In most cases, a supercharger uses from 8-10% of the total engine power it develops.

While the positive displacement supercharger delivers the same amount of air charge for each revolution of the engine, the amount of power available to drive a supercharger depends on engine speed. However, even an idling engine produces enough power to pump a large amount of air. When accelerating from a standstill, a supercharged engine immediately receives extra power. Though it takes engine power to drive a supercharger, a supercharger helps an engine produce much more power in return.



Supercharger assembly

Objective

Upon completion of this lesson you will be able to:

- Explain the symptom-to-system-to-component-to-cause diagnostic process and provide an example.

Symptom-to-system-to-component-to-cause diagnostic process

Diagnosis requires a complete knowledge of the system operation. As with all diagnosis, a technician must use symptoms and clues to determine the cause of a vehicle concern. To aid the technician when diagnosing vehicles, the strategies of many successful technicians have been analyzed and incorporated into a diagnostic strategy and into many service publications.

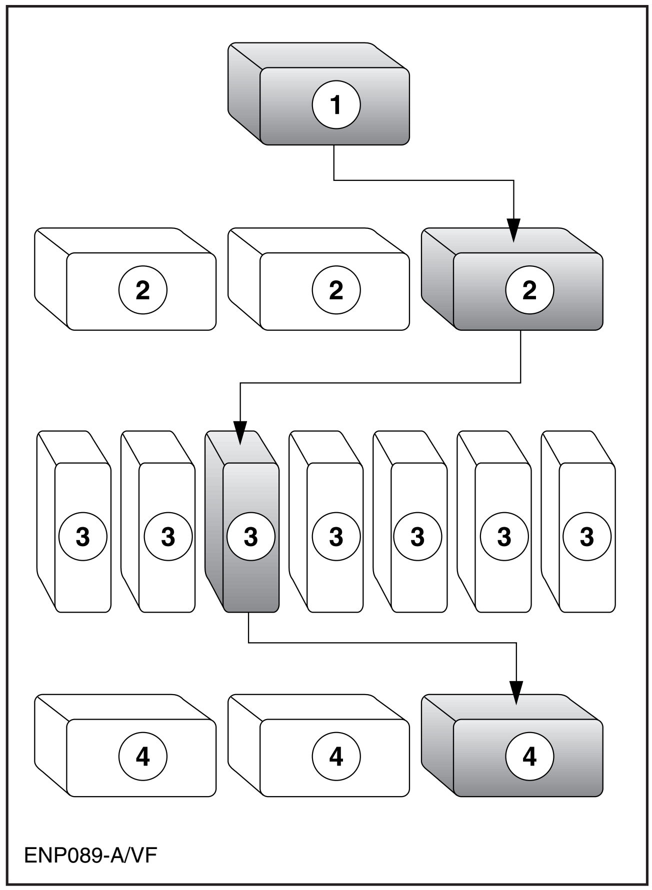
Symptom-to-system-to-component-to-cause diagnostic process

Using the Symptom-to-System-to-Component-to-Cause (SSCC) diagnostic process provides you with a logical method for correcting customer concerns:

- First, confirm the “Symptom” of the customer’s concern.
- Next, determine which “System” on the vehicle could be causing the symptom.
- Once you identify the particular system, determine which “Component(s)” within that system could be the cause for the customer concern.
- After determining the faulty component(s) you should always try to identify the cause of the failure.

In some cases parts just wear out. However, in other instances something other than the failed component is responsible for the problem.

For example, a customer’s car is brought in with a “no start” condition. The symptom is the vehicle will not start. During diagnosis you find that there is no fuel pressure at the fuel rail. Therefore, you determine that the fuel system is where the problem is. By performing diagnostic routines found in the workshop manual, you determine that component at fault is the fuel pump. You would replace the fuel pump and verify the repair as the last step.



SSCC diagram

1 Symptom
2 Vehicle systems
3 Components
4 Causes

Workshop literature

The vehicle workshop literature contains information for diagnostic steps and checks such as: preliminary checks, verification of customer concern, special driving conditions, road tests and diagnostic pinpoint tests.

The abbreviations conform to the standard SAE J1930 except those marked with an asterisk (*).

A/C	**A**ir **C**onditioning
BTU*	**B**ritish **T**hermal **U**nit
C*	Carbon
CKP	**C**rankshaft **P**osition
CMP	**C**amshaft **P**osition
CO_2*	Carbon dioxide
DIS	**D**istributorless **I**gnition **S**ystem
ECM*	**E**ngine **C**ontrol **M**odule
ECT	**E**ngine **C**oolant **T**emperature
EGR	**E**xhaust **G**as **R**ecirculation
EVAP	**E**vaporative **E**missions **C**ontrol
EVR	**EGR V**acuum **R**egulator
H*	Hydrogen
HC*	**H**ydrocarbons
H_2O*	Water
IAC	**I**dle **A**ir **C**ontrol
IAT	**I**ntake **A**ir **T**emperature
LED*	**L**ight **E**mitting **D**iode
MAF	**M**ass **A**irflow
MAP	**M**anifold **A**bsolute **P**ressure
MFI	**M**ultiport **F**uel **I**njection
MIL	**M**alfunction **I**ndicator **L**amp
MTBE*	**M**ethyl **T**ertiary **B**utyl **E**ther
N*	Nitrogen
NO_2*	Nitrogen dioxide
NO_X*	Oxides of nitrogen
O_2*	Oxygen
OBD	**O**n-board **D**iagnostics
PCM	**P**owertrain **C**ontrol **M**odule
PCV	**P**ositive **C**rankcase **V**entilation
P/N	**P**ark/**N**eutral
RFG	**R**e**f**ormulated **G**asoline
RPM	**R**evolutions **P**er **M**inute
SFI	**S**equential Multiport **F**uel **I**njection
SSCC	**S**ymptom-to-**S**ystem-to-**C**omponent-to-**C**ause
TBI	**T**hrottle **B**ody **I**njection
TP	**T**hrottle **P**osition
TPS	**T**hrottle **P**osition **S**ensor
VSS	**V**ehicle **S**peed **S**ensor