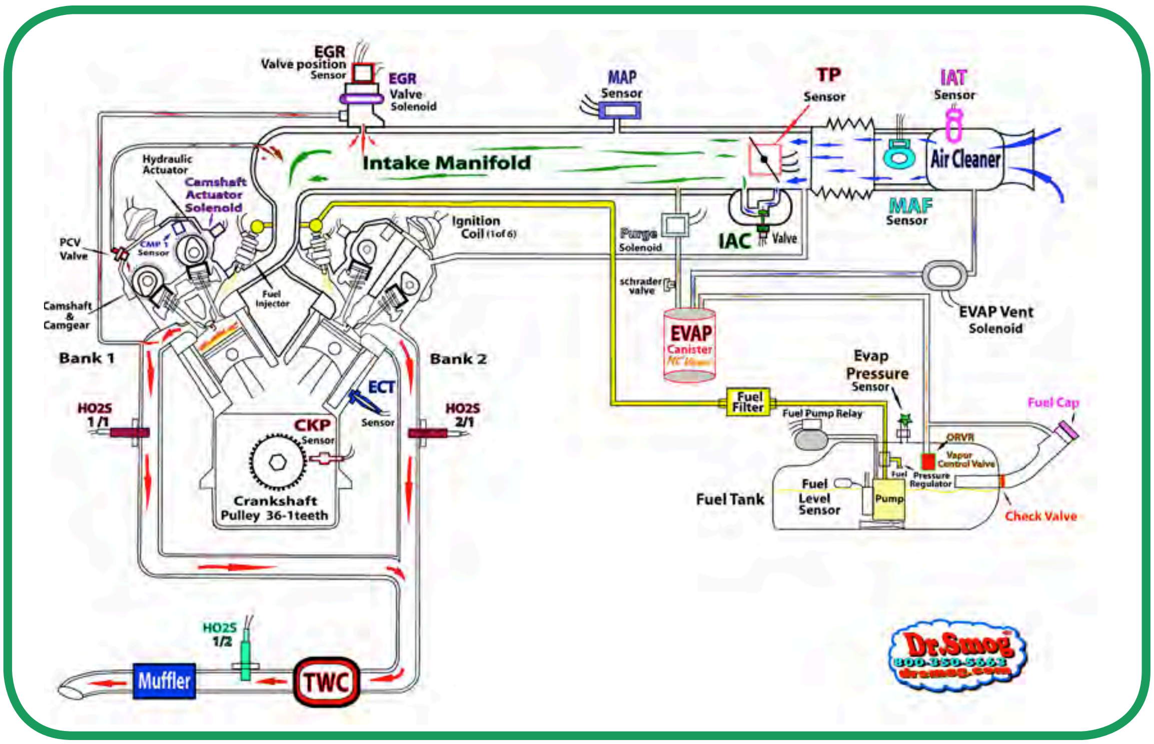
Level 1
Engine and Emission Control Training



by

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Certified Training

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Safety Notice

Always follow repair manual procedures. You will not go wrong. Take safety precautions when repairing vehicles. Your sight, hands, back, and lungs depend on it. CO Carbon Monoxide causes a reduction in mental alertness, headaches and death in high enough quantities. HC Hydrocarbons cause cancer in animals. NO_x irritates lungs and eyes, affects the growth rate of crops and plants and rapidly deteriorates rubber products. Electricity is dangerous. It can give you a nasty shock and cause a fire. Always wear eye protection.

Follow all safety procedures.

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SECTION 1
Vehicle Safety Practices

Introduction

Safety and accident prevention must be the top priority in automotive shops. The probability of an industrial accident is high because of the equipment used. The automotive industry is rated as one of the most dangerous occupations in the USA. Vehicles and equipment are very heavy. Components become hot during operation. High fluid pressures build up inside cooling and fuel systems. Batteries contain highly corrosive and potentially explosive acids. Fuels and cleaning solvents are flammable. Exhaust fumes are poisonous. Technicians are exposed to harmful dust particles and vapors. Good safety practices help to eliminate these dangers. Technicians with a careless attitude and poor work habits run the risk of serious injury, temporary or permanent disability, and even death. Safety needs to be taken very seriously. Employer and employees must work together to protect the health, safety and welfare of technicians who work in automotive shops. Finally, when working on automobiles, always follow safety guidelines given in service manuals and other technical literature.
They are there for your protection.

Shop Safety

The following is a list of safety precautions.
1). No smoking in an automobile shop.
2). Before starting work remove all jewelry, watches, rings and bracelets.
3). Do not wear loose clothing.
4). Long hair should be tucked up or wear a suitable hat.
5). Always wear safety glasses when working where an eye hazard may exist.
The best practice is to wear safety glasses all the time while working around vehicles in the shop.
6). Wear hearing protection. Slamming hoods shut will damage your hearing.
7). Make sure that all safety equipment is installed and in operating condition on any machine that you are about to operate.
8). Never leave any equipment running unattended.
9). Keep the shop floor clean and clear of tools.
10). Before you start an engine, make sure the parking brake is set: manual transmissions in neutral and automatic transmissions in park.
11). Do not start an engine if someone is under the hood or leaning into an engine compartment.
12). Never run engines in a closed environment. Make sure there is adequate ventilation.
Hydrocarbons cause cancer, and Carbon Monoxide is poisonous.
13). Keep you hands away from hot engine parts like exhaust manifolds, exhaust parts and radiators.
14). Drive vehicles extra slowly (3 MPH) around the shop area.
15). Pick up and set down heavy objects by bending at the knees. Do not bend at the waist and lift heavy objects using you back.
16). Before you power up any equipment, make sure that all personnel are clear and that all the machine setups and adjustments are correct.
17). Know the location of the shop fire extinguishers and emergency first aid kit including eyewash.
18). Know the phone number of where you can get emergency treatment should that be necessary.

Fires

Each technician should know the location of shop fire extinguishers and how to use them. In addition, each technician should know which Class of fire extinguisher to use on which Class of fire.

Class A fire extinguisher can be used on wood, paper and cloth.
Class B fire extinguisher can be used on flammable liquids such as gasoline or oil.
Class C fire extinguisher can be used on electrical fires.
Class D can be used only on fires of combustible metals…Magnesium for example.
Using wrong Class fire extinguisher can be hazardous. Using a water based fire extinguisher on an electrical or gasoline fire is highly dangerous. A Carbon Dioxide (CO_2) extinguisher can be used on oil and electrical fires, but will not work on paper or wood fires.

Electrical

1). Always make sure electrical power cords are not frayed and plugs have a ground terminal.
2). Disconnect the battery ground (negative cable) before replacing any electrical parts.
3). Do not short-circuit any solid-state electronic parts. Do not short-circuit any electrical terminals. Do not apply battery voltage to any electrical part unless called for in the service manual.
4) Keep all tools away from exposed electrical terminals.
5) Batteries gas off explosive hydrogen gas. Keep open flames, sparks and hot objects away from batteries to avoid an explosion. Never short circuit battery terminals. Battery electrolyte contains sulfuric acid, which can be neutralized with baking soda and water.

Engine Compartment

1). Keep hands, face, hair, clothing and tools away from the cooling fan and other moving parts.
2). Wear safety goggles when working around an engine that is running.
3). Keep in mind engine parts remains hot for a considerable time after an engine is shut down.

<u>The most important thing is to be aware of your surroundings at all time.</u>
<u>Protect you eyes, ears, face and hands.</u>
<u>Wear protective gear which should include gloves.</u>

Cooling System

A loose belt will make a squealing sound when it slips. A loose belt can cause an engine to overheat since the water pump of an engine is belt driven by the crankshaft. Be aware that this is a safety hazard as the belt may break or just fly off if it is loose.

Ignition System

Ignition systems are high voltage. Be aware of worn insulation which may result in a high voltage electrical shock that may or may not be fatal to you.

Exhaust System

Exhaust systems parts are hot. Keep hands and other body parts away from hot exhaust manifolds. Any burn resulting from touching a manifold will be severe.

Moving Parts

Keep hands and clothing away from moving parts.

Working under a vehicle.

Wear a hard hat when working under a vehicle to avoid head injury.

SECTION 2

Engine Theory Design and Operation

Basic Automobile Engine Operation

Automobile engines burn fuel to change chemical energy to heat energy to kinetic energy. Kinetic energy is the energy an object possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest. Both spark ignition and compression (diesel) ignition engines have pistons that move up and down in a cylinder. An internal combustion engine burns fuel in cylinders and uses the heat energy to produce mechanical power. Automobile engines are internal combustion engines. In an internal combustion engine a mixture of air and fuel is compressed, ignited, and burned to create pressure and force. This pressure and force create mechanical power. To get the maximum energy from a liquid fuel, it must be atomized and compressed into a small volume before it is burned. If there was no compression, the air fuel mixture would burn in a manner that produces no pressure, force or power. Most automobile engines are reciprocating engines. A reciprocating engine is one in which a piston moves up and down or back and forth in a cylinder compressing a air fuel mixture. When the mixture ignites, it burns and produces a high pressure that moves the piston in the cylinder. This linear motion of the pistons is converted into rotational motion by the crankshaft to drive an automobile. These are called 4-stroke engines because it takes 4 strokes for every power stroke. Both gasoline and diesels are 4-stroke engines.

Automobile Engine Parts

The engine block is the large piece of metal that holds the engine together and forms the heart of the engine. See fig. 2-1.Most engines have four, six, or eight cylinders. Cylinders can be arranged in various configurations. See Fig 2-2.
The cylinders can be:
1). In a row.
2). Two rows or banks set at an angle called a V configuration. This would typically be a V-6 or V-8 configuration.
3). Two rows opposing each other. This would be an opposed cylinder engine.

The block has cylinders for pistons to move up and down in and has a crankshaft and camshaft. Refer to figure 2-3. When pistons are pushed down by the pressure of combustion inside a cylinder, they push on connecting rods which push on the crankshaft and force it to turn. See fig 2-3. The block also has cooling passages filled with anti freeze to cool the engine by taking away some of the heat of combustion in the cooling system. Some engines are air-cooled. Examples of air-cooled engines are Volkswagen beetles and some Porsches. Air-cooled engines use air forced over cooling fins to cool the engine.

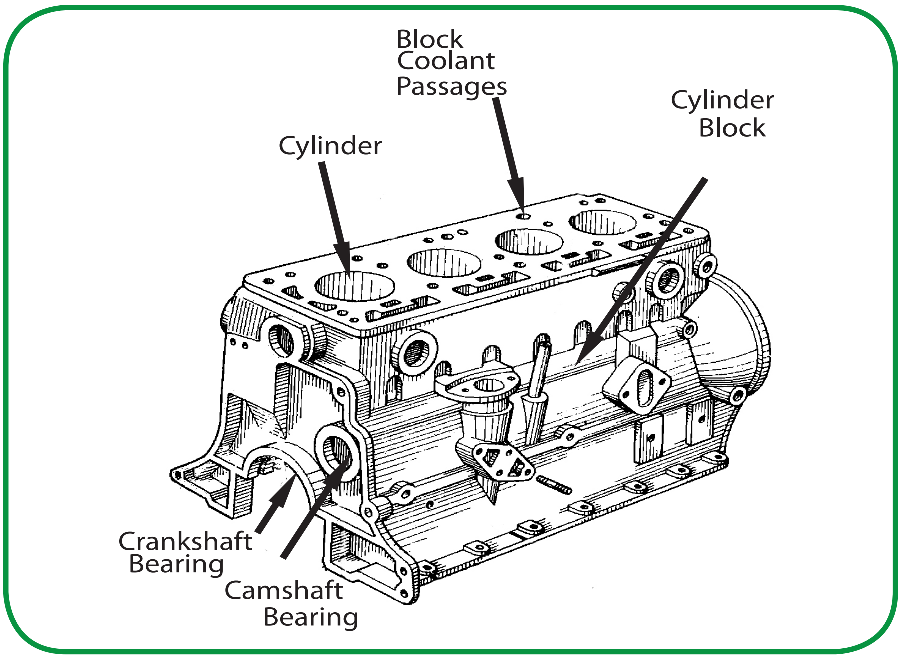


Fig. 2-1. Example of a cylinder Block

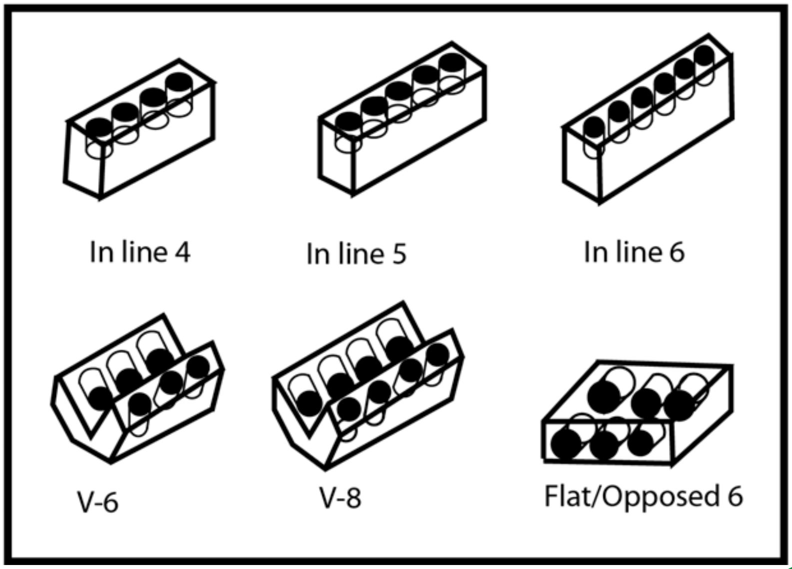


Fig 2-2. Engine blocks in various cylinder configurations.

A connecting rod attaches each piston to a crankshaft. See fig. 2-3 and fig. 2-4. The crankshaft is supported on bearings by the crankcase of the block which allows it to rotate. There is a flywheel at one end of the crankshaft to provide rotating inertia for the engine. See Figure 2-6. Pistons have compression and oil rings to seal them in the cylinder and prevent exhaust gasses from escaping into the crankshaft case and oil from getting into the cylinders. See figure 2-7. See fig.2-8 for an example of a connection rod assembly.

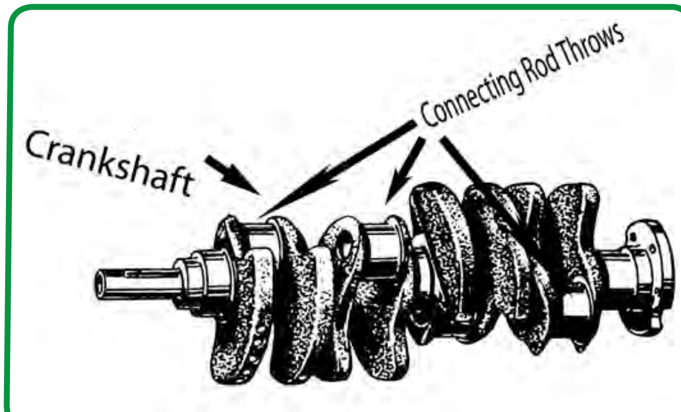


Fig. 2-3. A Crankshaft showing the crankshaft throws where the connecting rods are attached.

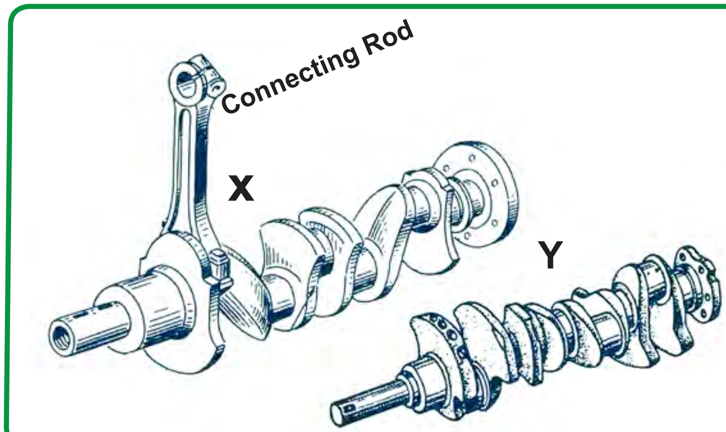


Fig. 2-4. X.-Is a four-cylinder crankshaft with a connecting rod attached. Y.-Is a V-8 crankshaft.

A cylinder head is attached to the top of the block by bolts. The cylinder head provides a way for the air fuel mixture to enter the engine and the burned mixture (exhaust gasses) to leave the cylinders. See fig.2-5.

Each cylinder has at least two ports (holes) in the cylinder head some have more. The ports are opened and closed by intake and exhaust valves. The intake valve opens just before the intake stroke begins. This is when the air fuel mixture enters the cylinder. The exhaust valve opens just before the exhaust stroke begins. A stroke of a 4-stroke internal combustion engine refers to the intake, compression, combustion (power), and exhaust cycles that occur during two crankshaft rotations per power cycle of four-cycle engines. The cycle begins at Top Dead Centre (TDC), when the piston is farthest away from the axis of the crankshaft. A cycle refers to the full travel of the piston from Top Dead Centre (TDC) to Bottom Dead Centre (BDC).

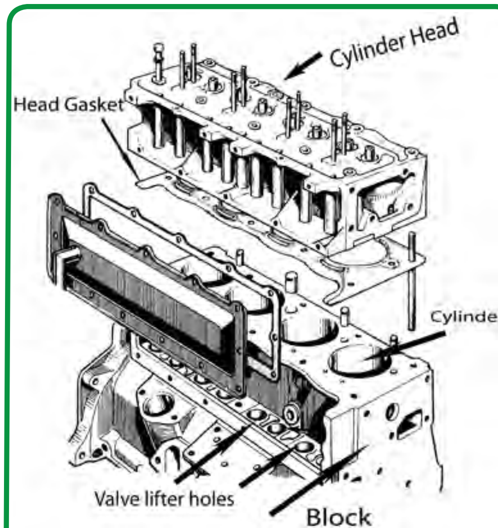


Fig 2-5. Cylinder head.

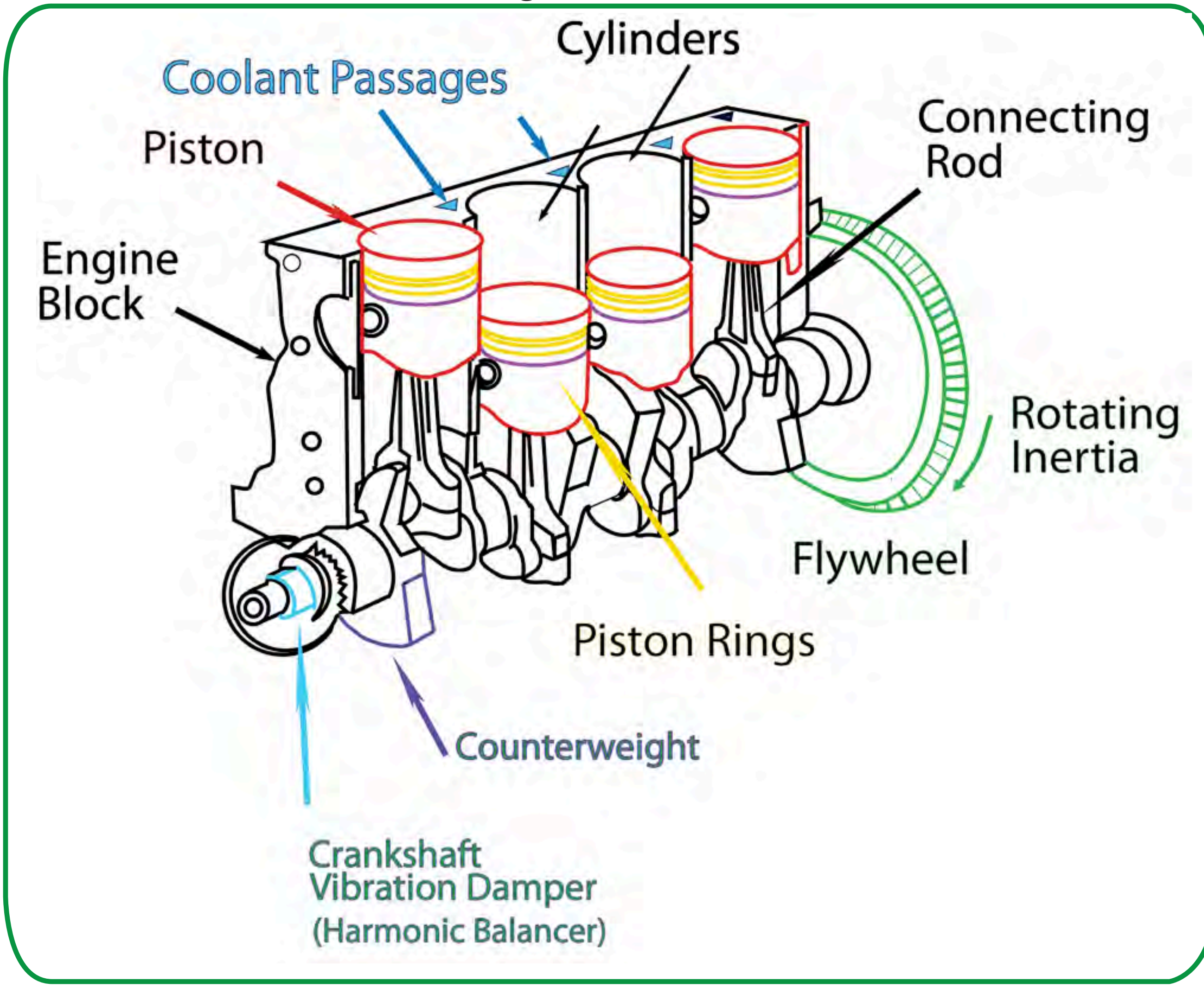


Fig. 2-6. Pistons connected to a crankshaft. Pistons have compression and oil rings to seal them in the cylinder and prevent exhaust gasses from escaping into the crank case and oil from getting into the cylinders.

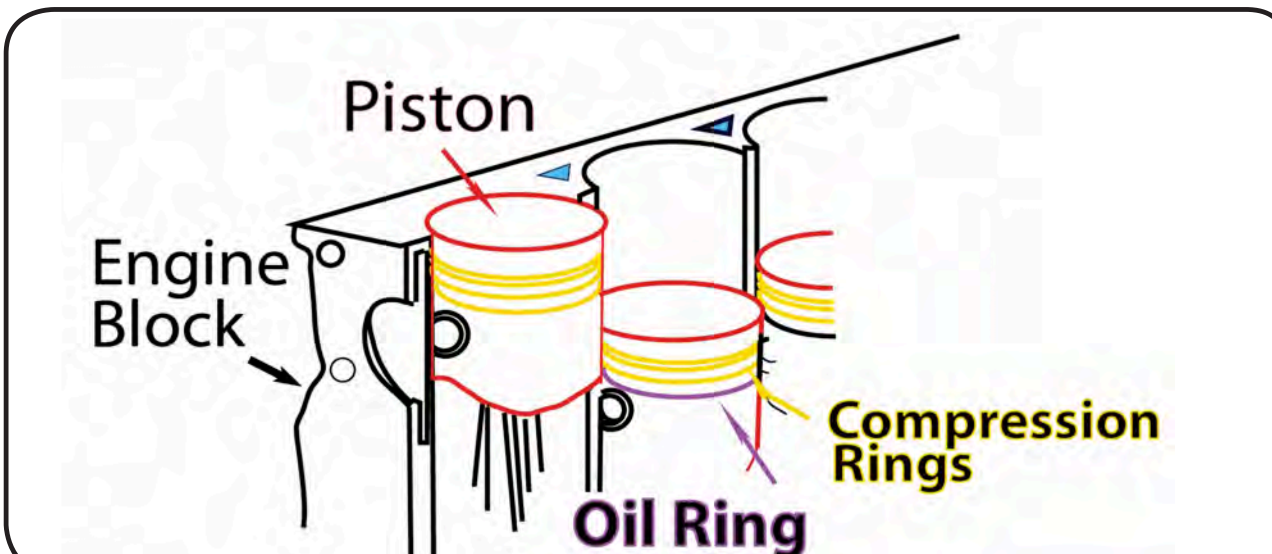


Fig. 2-7. Pistons have compression and oil rings to seal them in the cylinder and prevent exhaust gasses from escaping into the crankshaft case and oil from getting into the cylinders.

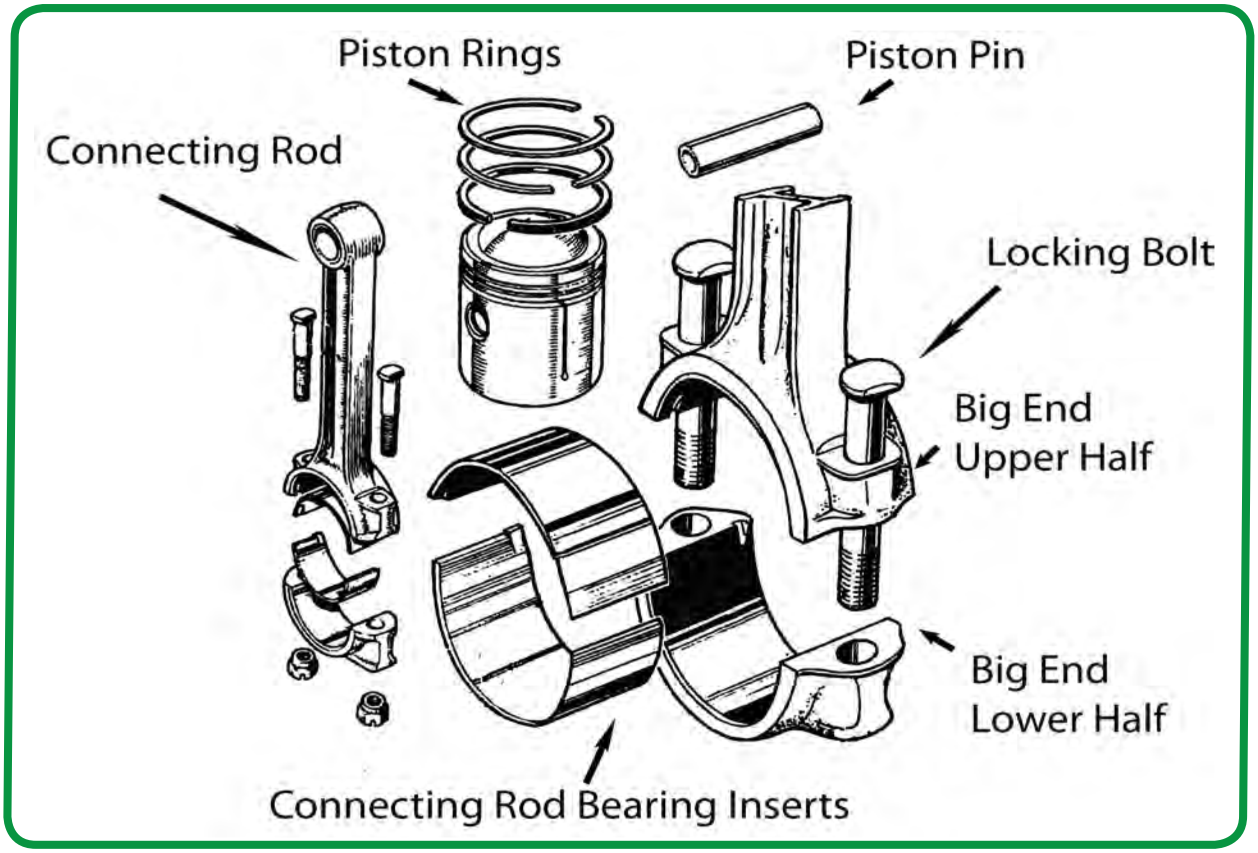
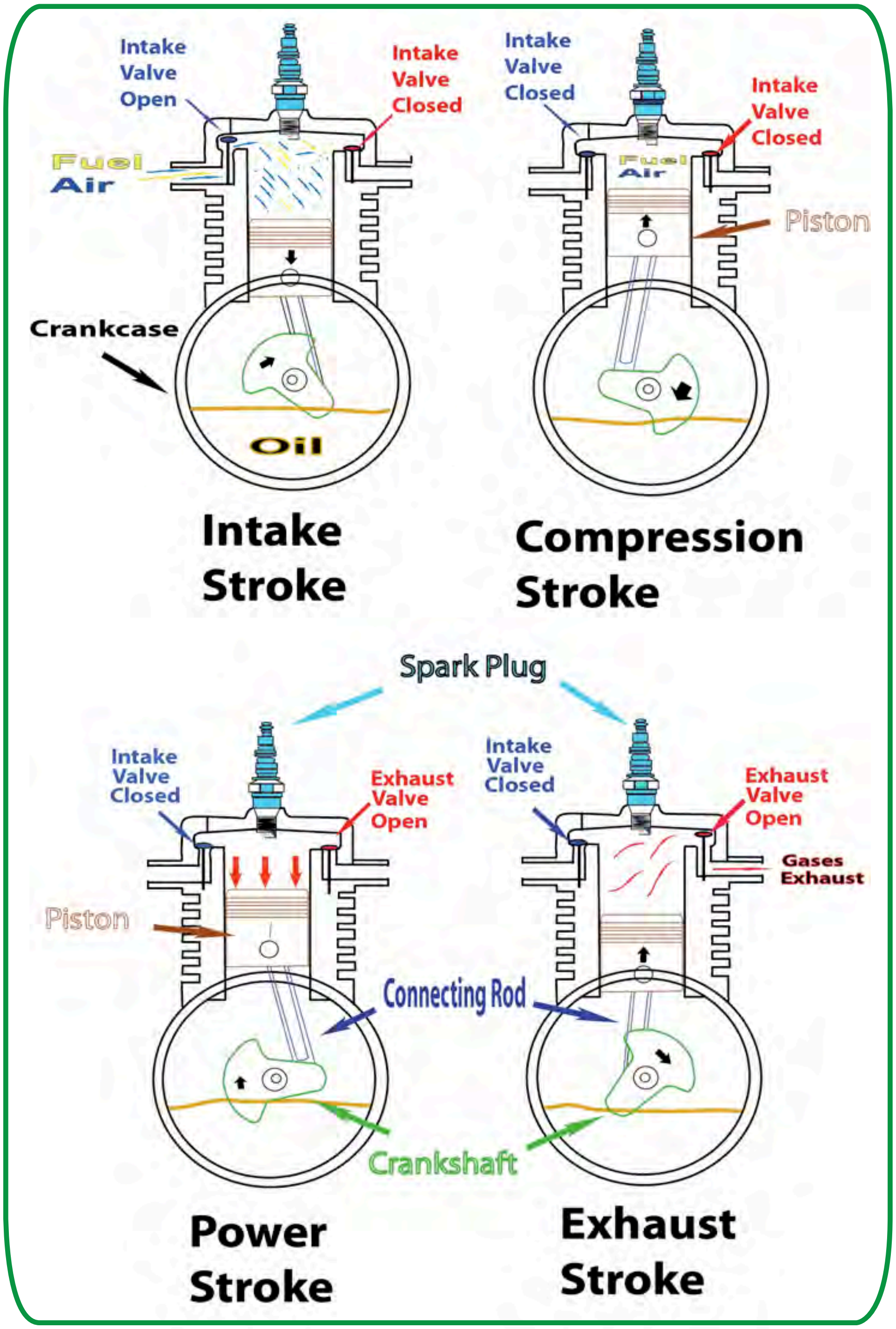


Fig 2-8. Connecting rod assembly.

When valves open and close, it is called 'valve timing'. Valve timing has an effect on power, emissions and fuel economy. Valves must open and close at the appropriate time and seal perfectly. Otherwise engine performance will be affected, and emission will be high. Each valve opens and closes once in each 4-stroke cycle of a cylinder. Refer to figure 2-9. To do this, the camshaft is geared to make one revolution for every two revolutions of the crankshaft. The crankshaft drives the camshaft using a timing belt, chain, or gear to synchronize valve opening with piston position. The mechanism which is used to open and close valves is called the "valve train". The valve train is what opens and closes the valves. Camshaft(s) which are the heart of the valve train are located in the cylinder block or on the cylinder head. An engine which has the camshaft in the cylinder block is called an overhead valve (OHV) or pushrod engine. Refer to fig. 2-10. If the camshaft is on or in the cylinder head, the engine is called an overhead camshaft engine (OHC), refer to figure 2-11. There are also twin overhead camshaft engines. Refer to figure 2-12. Camshafts are driven by timing gears, a timing chain, or some combination of a timing chain and timing belt. These gears, belts or chains are called timing belts.



In a four-stroke engine, each piston has a power stroke every other crank rotation. See figure 2-9.

A cylinder head is bolted to the block above the cylinders and pistons. The purpose of the cylinder head is to create a combustion chamber for each cylinder. The cylinder head also holds the intake and exhaust valves and provides a method to actuate them.

Fig. 2-9. This is an example of a four-stroke cycle engine. 1). Intake stroke -As the piston moves down or towards the crankcase, the intake valve opens and a partial vacuum is created in the cylinder. A vaporized air fuel mixture is drawn into the cylinder.
2). Compression stroke -The intake valve closes. As the crankshaft rotates, the piston moves up in the cylinder and compresses the air fuel mixture. 3). Power stroke -The ignition system fires the spark plug to ignite the air fuel mixture just before the piston reaches the top of its stroke. The expanding gases created by the combustion of the air fuel mixture force the piston down to turn the crankshaft. 4). Exhaust- When the air fuel charge is burnt the exhaust valve opens. Burned gases are forced out of the cylinder by the upward movement of the piston. This series of events is called a four stroke cycle. As long as an engine is running, the cycle repeats itself. A four-stroke cycle engine fires once every four strokes. A cycle requires two turns of the crankshaft.

Gears or chains are used by the crankshaft to drive the camshaft. This ensures the correct timing of the opening and closing of the valves in relation to position of the piston. Refer to fig. 2-13 for an example of belt driven timing and fig.2-14 for an example of a gear driven camshaft.

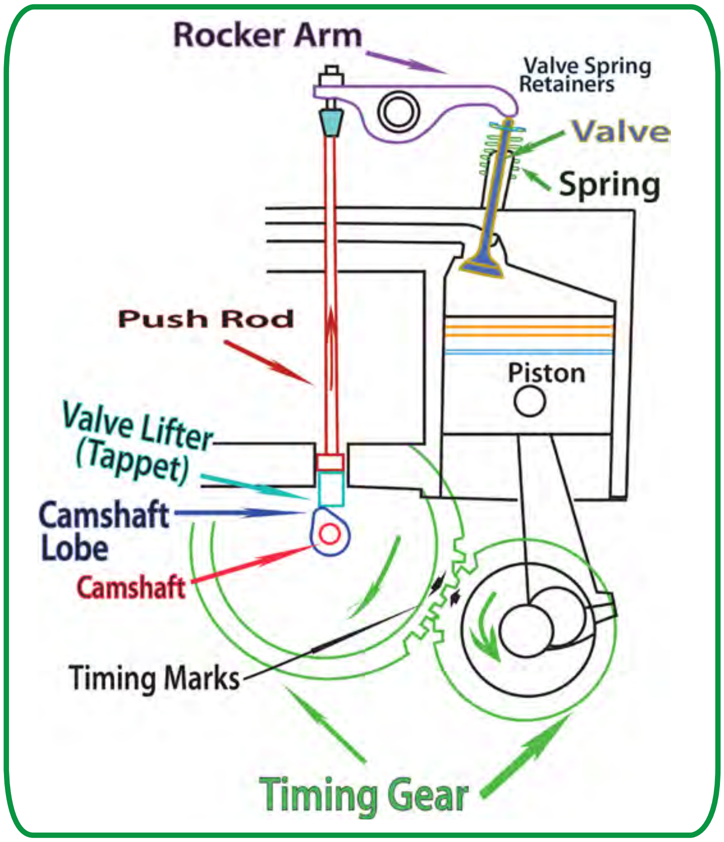


Fig. 2-10. Valve train of a of an overhead-valve engine (push rod). Camshaft in the block.

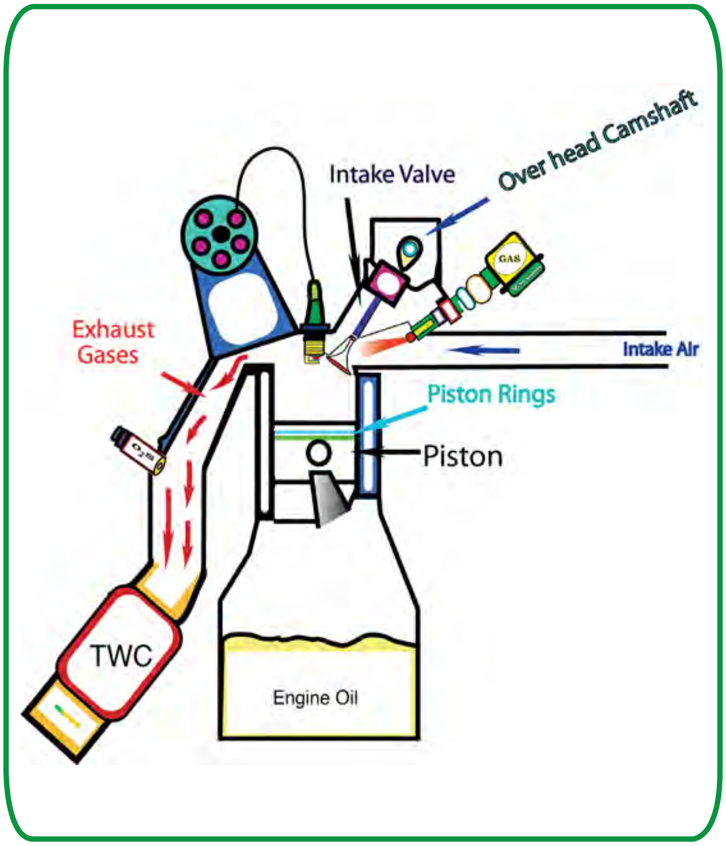


Fig. 2-11. Single overhead camshaft engine.

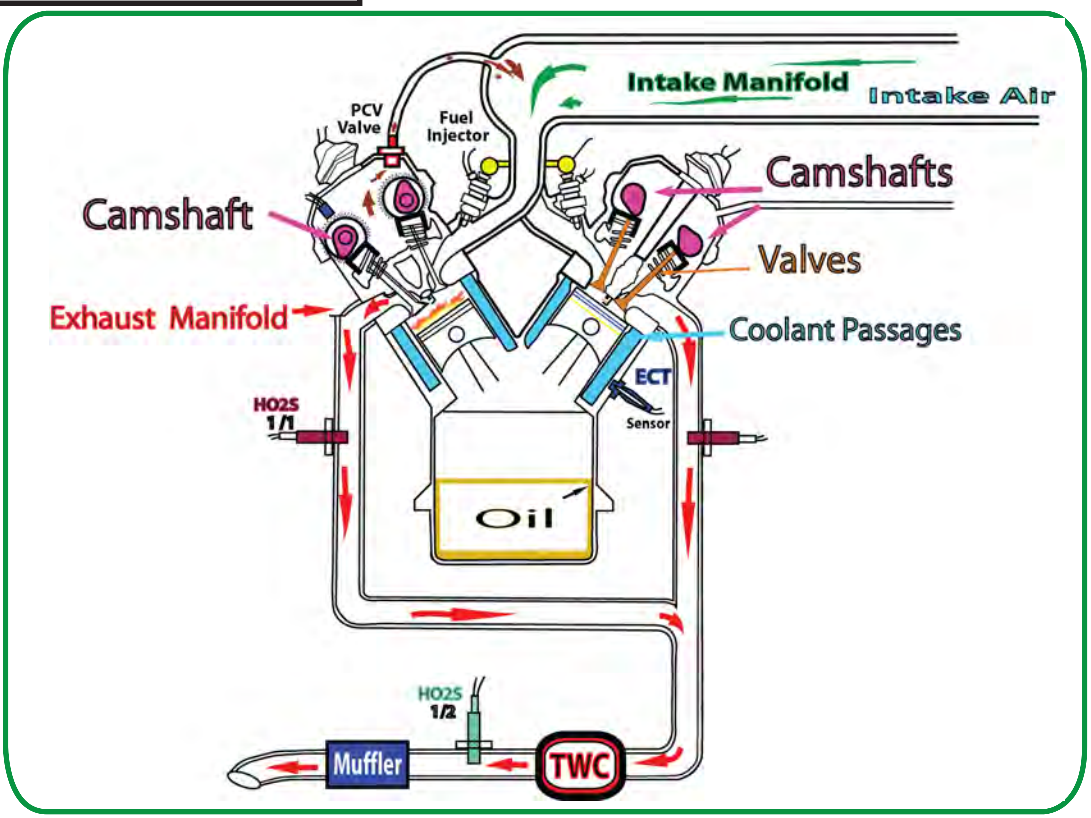


Fig. 2-12. Twin overhead camshaft engine.

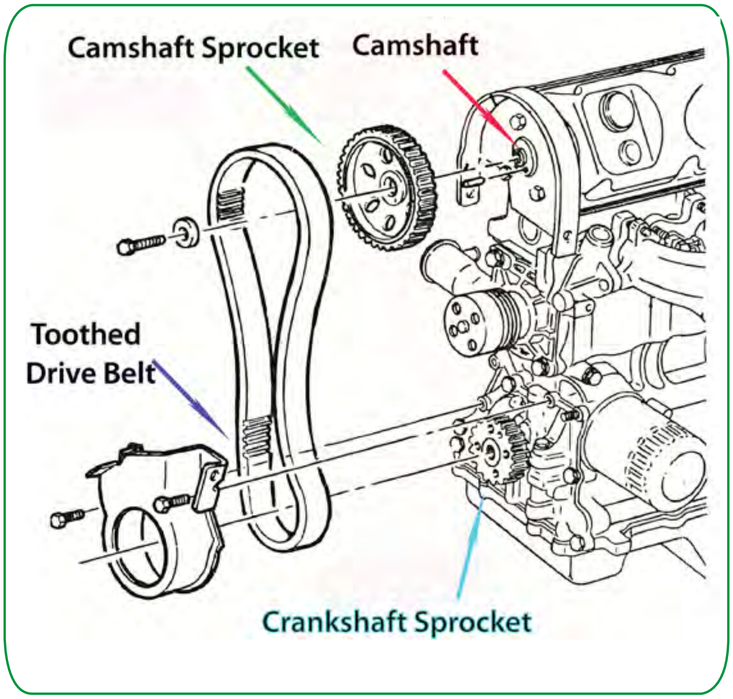


Fig. 2-13. Belt driven timing gear.

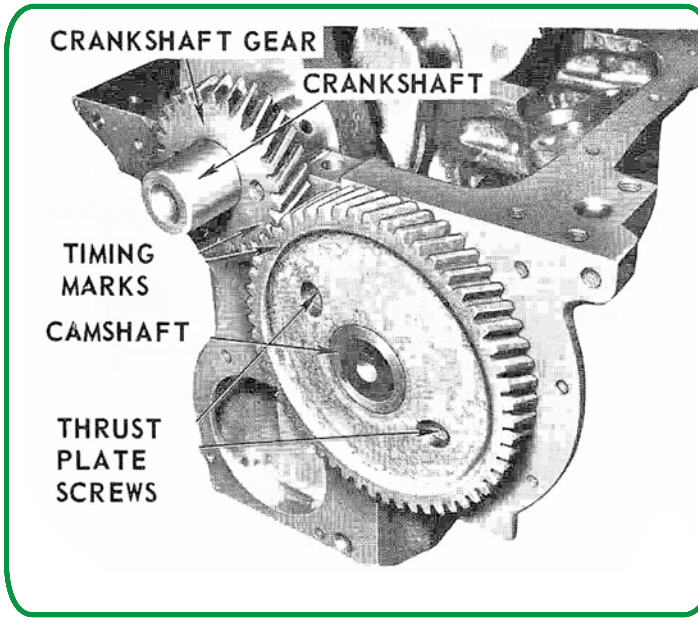


Fig. 2-14. Gear driven timing camshaft.

Valve Timing

Exhaust and intake valves open for longer than it takes a piston to make a stroke. Valve opening and closing is measured in degrees. The exact number of degrees that a valve opens or closes before top (TDC) or bottom dead center (BDC) varies with the individual engine design. When a valve opens or closes, how fast it opens or closes, how long it stays open, and how long it stays closed depends on the shape of the cam lobe and the position of the camshaft in relation to the crankshaft. Incorrect valve timing will raise emissions and may cause engine damage. Many engine manufacturers have developed engines with more than one exhaust and one intake valve. Many engines have two intakes and exhaust valves. Smaller and lighter valve train parts used in 4 valve engines facilitate higher engine speeds and more power.   Refer to figure 2-15 for an example of a valve timing diagram.

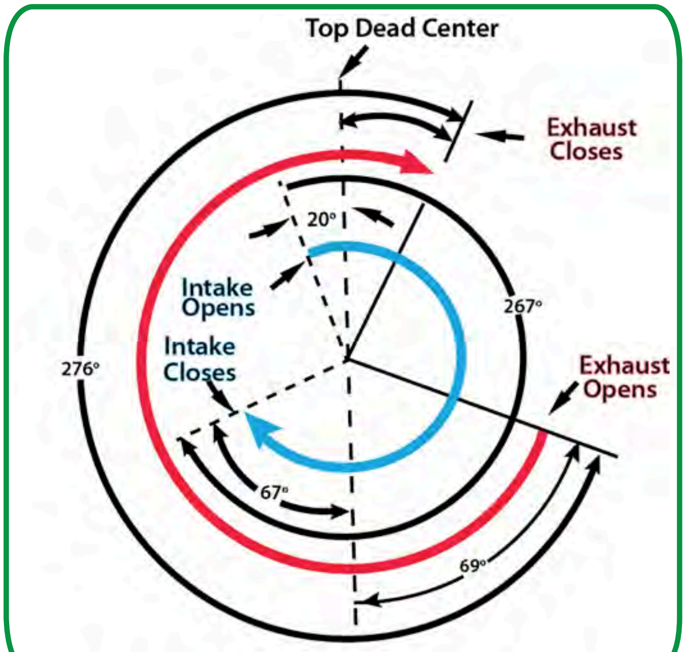


Fig.2-15. Valve timing diagram. The angles vary depending on the engine design. The length of time a valve stays open is referred to as valve duration.

Intake and Exhaust Manifolds

An intake manifold is a metal casting with passages that route intake air or air fuel mixture from a central inlet to each cylinder. The exhaust manifold is a metal casting with passages that route exhaust gases away from each cylinder to a central exhaust system. It is easy to recognize since the manifold is attached to the exhaust system.

Engine Displacement

Engine displacement refers to the size of an engine. Displacement is the total volume of each cylinder when each cylinder is at Bottom Dead Center (BDC).

Compression Ratio

An engine compression ratio is the ratio of total cylinder volume when the piston is at BDC to combustion chamber volume when the piston is at TDC.

Engine Pressure

An internal combustion engine is like an air pump that draws air in, compresses it and exhausts it. When gasoline is mixed with the intake air and ignited by a timed spark, pressure inside the cylinders is increased dramatically. It is this increase in pressure that applies force to the piston which in turn, turns the crankshaft. In gasoline engines, ignition is provided by a spark plug. The speed and power of a gasoline engine is controlled by regulating the amount of air fuel mixture that enters the cylinders. This is done using a throttle valve in the carburetor or manifold inlet to vary the size of the opening through which air enters the engine. Fuel is mixed with the incoming air, and the throttle regulates the volume of the combined air fuel mixture. Refer to figure 2-16.

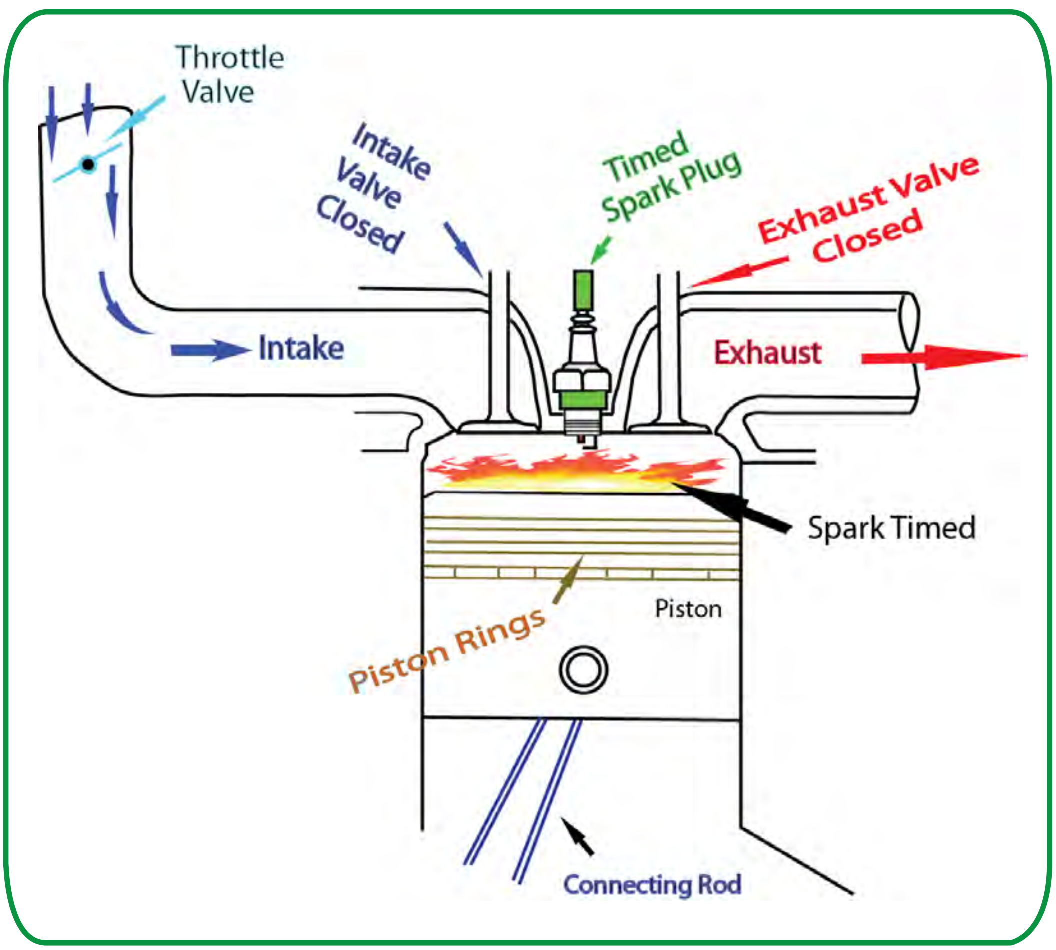


Fig. 2-16. Fuel is mixed with the incoming air, and the throttle regulates the volume of the combined air fuel mixture.

Low compression will cause an increase in HC (Hydrocarbons). When you smell gasoline, you are smelling HC. Possible causes of high HC: 1) Burnt or damaged valves. 2) Worn piston rings. 3) Worn valve guides. 4) Incorrectly adjusted valves.
Worn big ends or connecting rod ends will create a sound called engine “knock.” Loose or incorrectly adjusted tappets will cause a “tapping” sound.

Fuel System

Fuel is stored in a fuel tank, and a fuel pump delivers filtered fuel to the carburetor or fuel injecton system. The air that enters the engine is also filtered to keep out foreign particulate matter. Evaporative controls seal the fuel system to keep gasoline emissions (HC hydrocarbons) from escaping into the atmosphere. Hydrocarbon is an organic compound consisting entirely of hydrogen and carbon. The following is a list of the major parts of the fuel system. See figure 2-17.

1. Fuel tank
2. Fuel pump
3. Fuel filters
4. Fuel delivery components (carburetor or fuel injection)
5. Fuel evaporation controls
6. Fuel Cap
7. Air intake and air filter
8. Evaporation controls

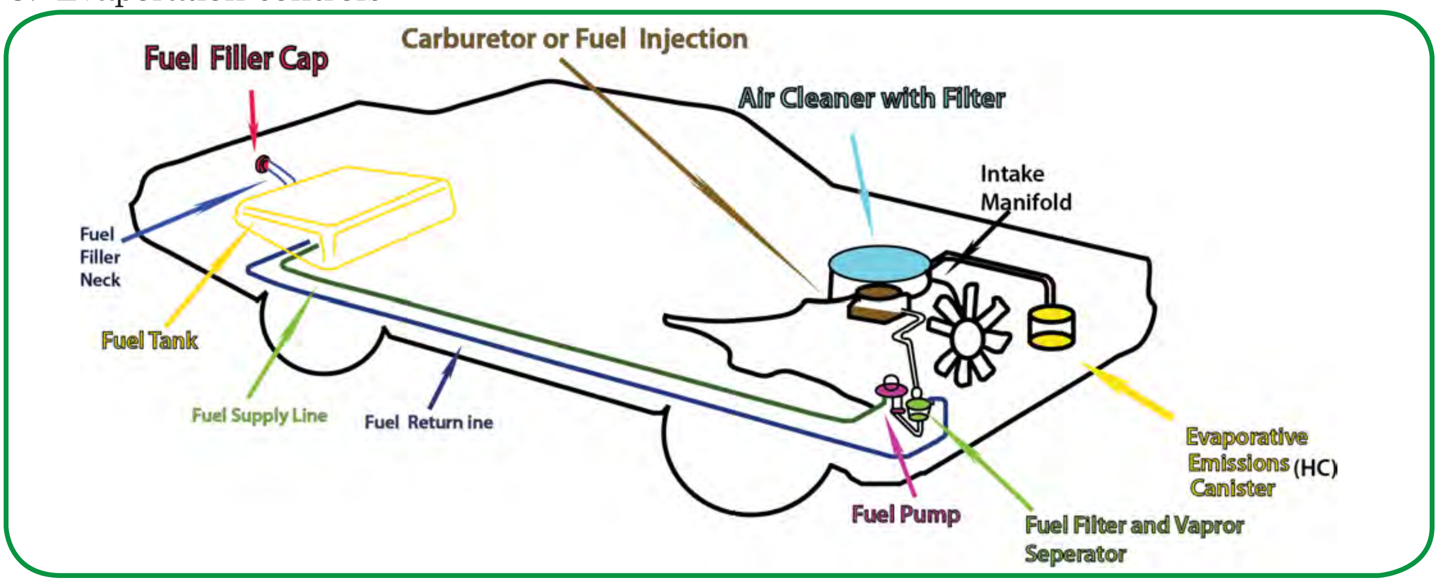
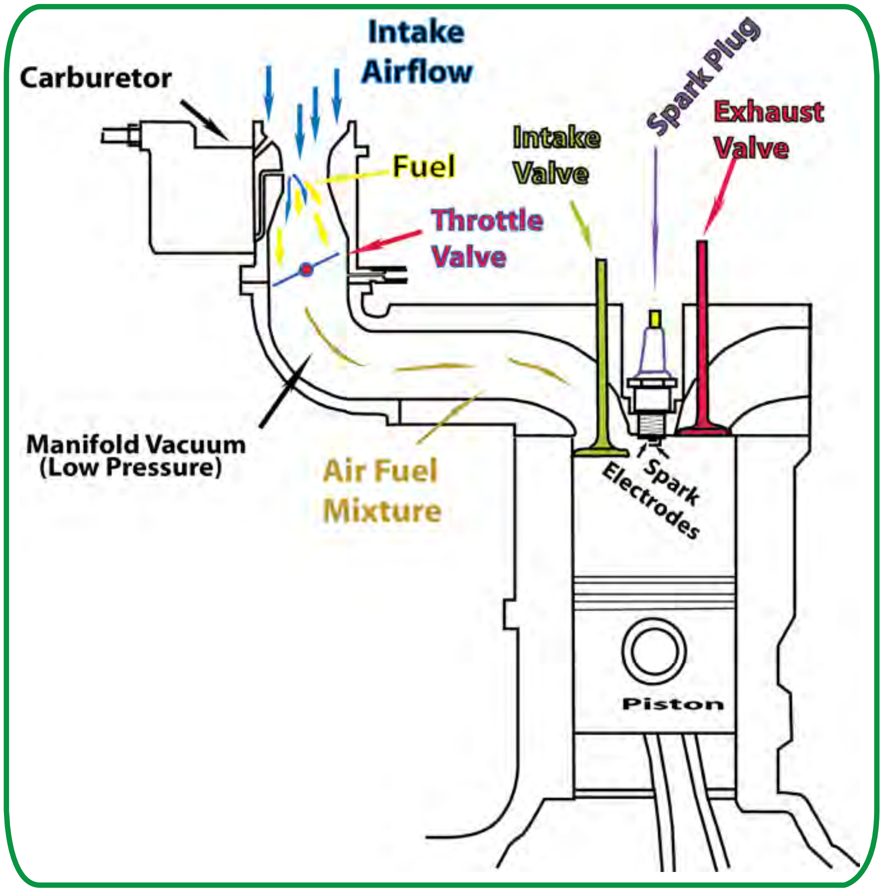


Fig. 2-17. The major parts of a gasoline fuel system.

Air and Fuel Mixing

Carburetors and fuel injectors deliver fuel to be atomized, vaporized and mixed with intake air. See figure 2-18. When the intake valve opens, the piston is on the intake stroke and draws air into the intake manifold and draws the air fuel mixture into the combustion chamber. The air that is going through a carburetor passes through a venturi which speeds up the air this lowers the air pressure drawing gasoline from the fuel bowl through a metered jet(s). As gasoline enters the intake air stream, it is atomized and vaporized. The jet(s) allows the gasoline flow to be precisely metered in the correct air fuel ratio of 14.7 parts of air to 1 part of fuel. This is the so-called Stoichiometric air fuel ratio. At this air-fuel ratio all the available oxygen is used to burn the fuel completely. The fuel injectors inject the required amount of fuel as a function of intake air flow/volume and intake air temperature, which are measured by the fuel injection system. See figure 2-19.

Fig. 2-18. Fuel is vaporized and mixed with air outside the combustion chamber before being drawn in and compressed. Carburetors are fitted with a jet(s) to meter fuel into a metering circuit where it is mixed with air. The gasoline is sucked through a jet (a brass screw with an exactly calibrated drill hole) and thereby atomized.



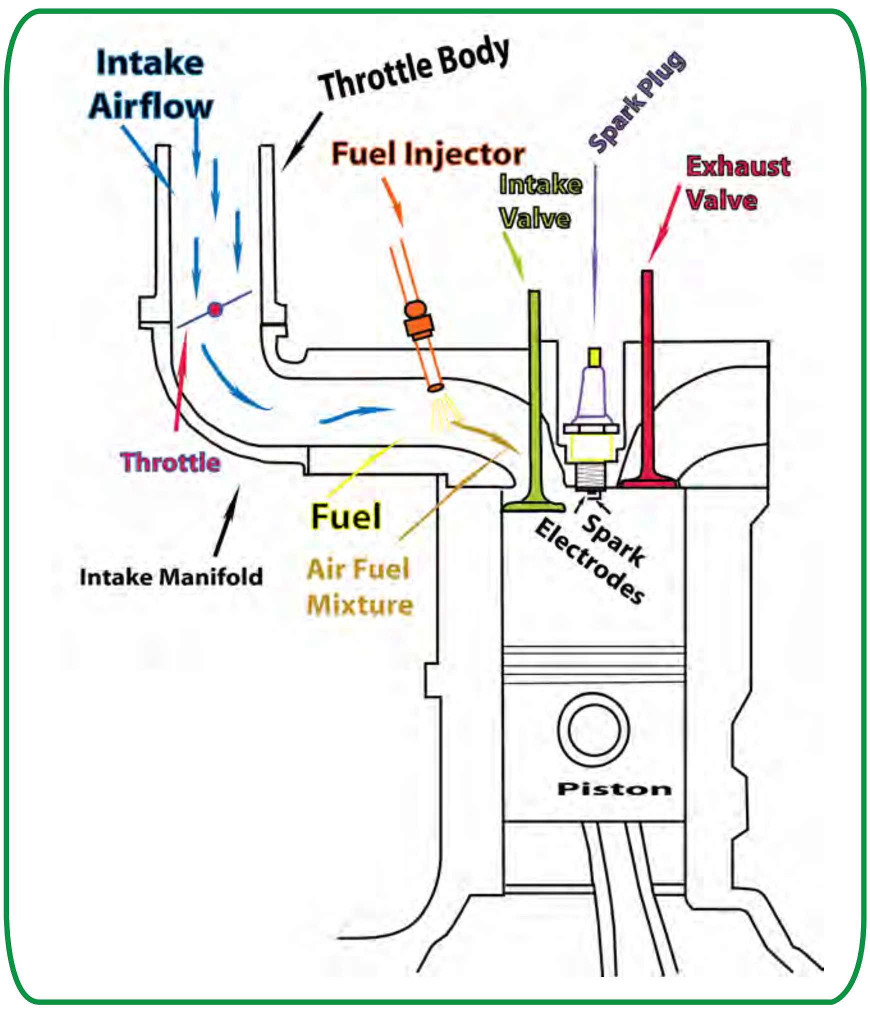


Fig. 2-19. The injector sprays (injects) fuel which is vaporized and mixed with air outside the combustion chamber before being drawn into the chamber, compressed and ignited by a timed spark.

Air Fuel Ratio.

Air fuel ratio is a measurement of the amount of air by weight and the amount of fuel by weight mixed together. At the ideal air fuel ratio, which is called the Stoichiometric air fuel ratio -14.7 parts of air to 1 part of fuel, all the available oxygen is used to burn the fuel completely. The air fuel ratio of a gasoline engine ranges from 8:1 (rich mixture) to 15:1 (lean mixture). At these ratios, fuel will burn but not completely, and there will be unburnt fuel (HC) and partly burned fuel CO (Carbon Monoxide). Both are unwanted and harmful emissions.

Air Fuel Distribution

Perfect air distribution is not provided by carburetors, fuel injectors, and intake manifolds. When one carburetor mixes air and fuel, the carburetor will not be equidistant from each cylinder, so that each cylinder does not get an equal air fuel mixture. In addition, the curvature and length of intake manifolds slows down the airflow and the temperature of the manifold itself can cause fuel to form fuel droplets. Two or more carburetors or fuel injection can help eliminate some of these problems.
Most 1980 and newer vehicles have an electronic engine control system. This means they use a computer (PCM Power Control Module) to control fuel metering, ignition, and related systems. Electronic fuel injection (EFI) provides precise fuel metering and, hence, air fuel ratios. The result is the best combination of fuel economy, power and emission. There are two types of EFI used on spark ignition engines: Throttle Body Fuel Injection (TBI) and Multiport Fuel Injection (MFI). Refer to figure 2-20 for an example of Throttle Body Fuel Injection (TBI). Refer to figure 2-21 for an example of Multiport Fuel Injection (MFI)

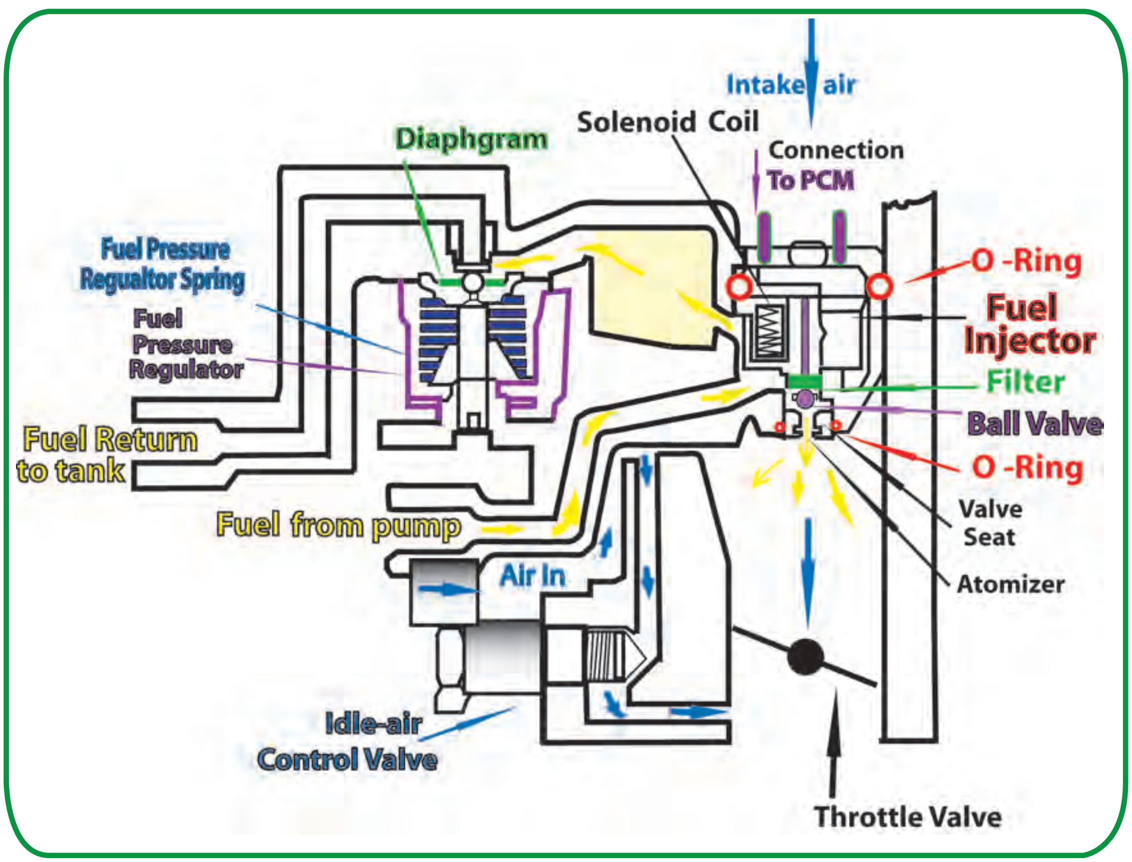


Figure 2-20. This is example of a TBI system. One injector (there may be two) located above the throttle valve.

Volumetric Efficiency

Volumetric efficiency is a ratio (or percentage) of the quantity of air and fuel actually entering the cylinder during induction to the actual capacity of the cylinder under static conditions. Volumetric efficiency changes with engine speed and is rarely 100 percent. For a passenger vehicle engine, volumetric efficiency could be 80 percent at 2500 rpm and drop to 70 percent at 3500 rpm.

Keep in mind that in gasoline engines, speed and power are controlled by regulating the amount of air fuel mixture that enters the cylinders. This is done by throttling the mixture with a throttle valve.

Diesel Engines

Diesel engines, like gasoline engines. operate on a 4-stroke cycle of intake, compression, power, and exhaust. See figure 2-22. The two main differences between gasoline and diesel engines is the way in which the air fuel mixture is ignited and the way speed and power are controlled. In a diesel engine, air enters the cylinder when the intake valve opens. The piston compresses the air to 450 to 850 psi. This raises the temperature to between 1350^{0}F to 1600^{0}F (732^{0}C to 871^{0}C). This is hot enough to ignite the diesel fuel. Fuel must be kept out of the hot compressed air until its ignition will create the maximum power.

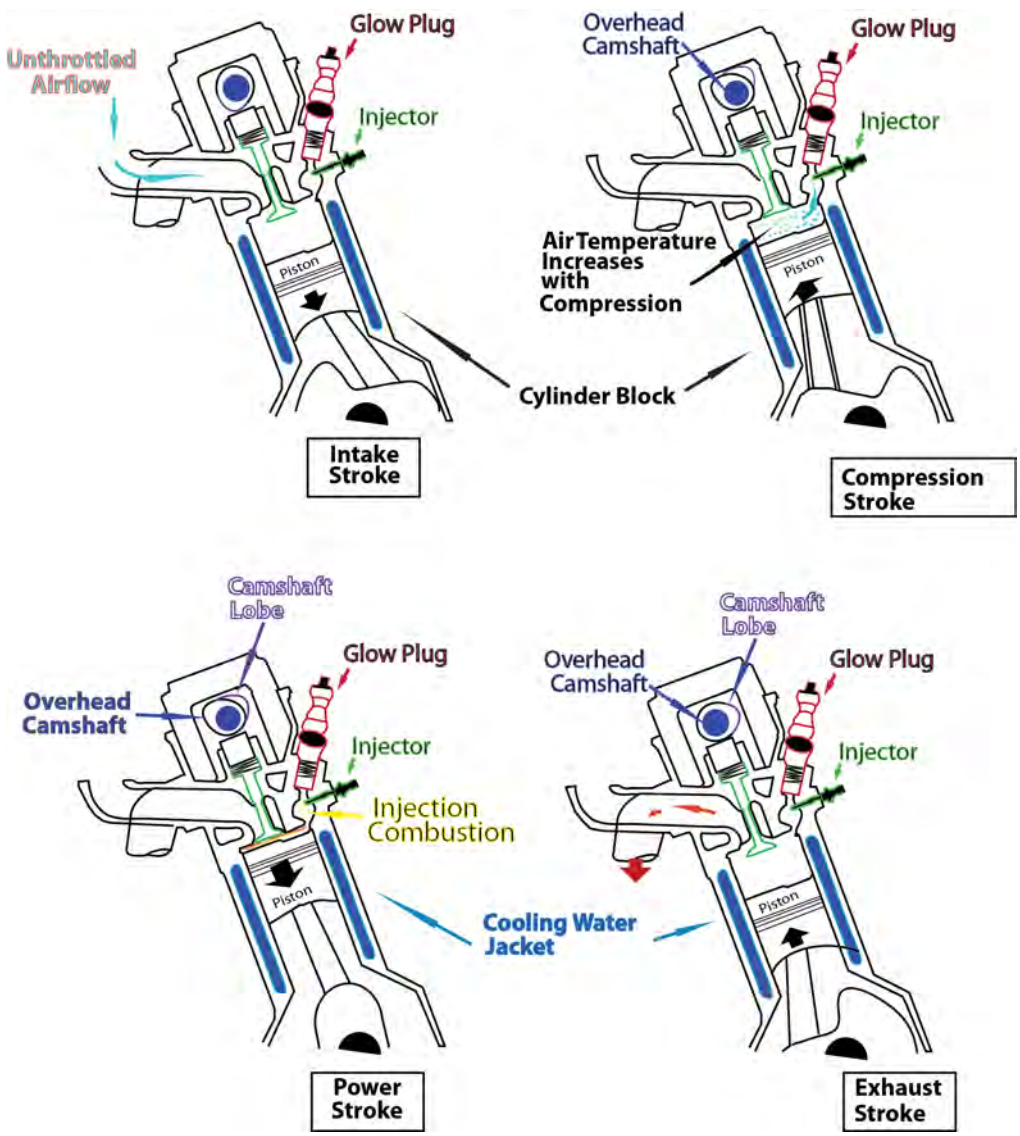


Figure 2-21. A diesel engine is a four-stroke cycle engine with an intake, compression, power and exhaust strokes. Combustion is by compression.

The result is that ignition timing in a diesel engine is controlled by injecting fuel into the combustion chamber at the exact time that will produce maximum combustion efficiency. See figure 2-22. Diesel engines run with an unthrottled air intake.

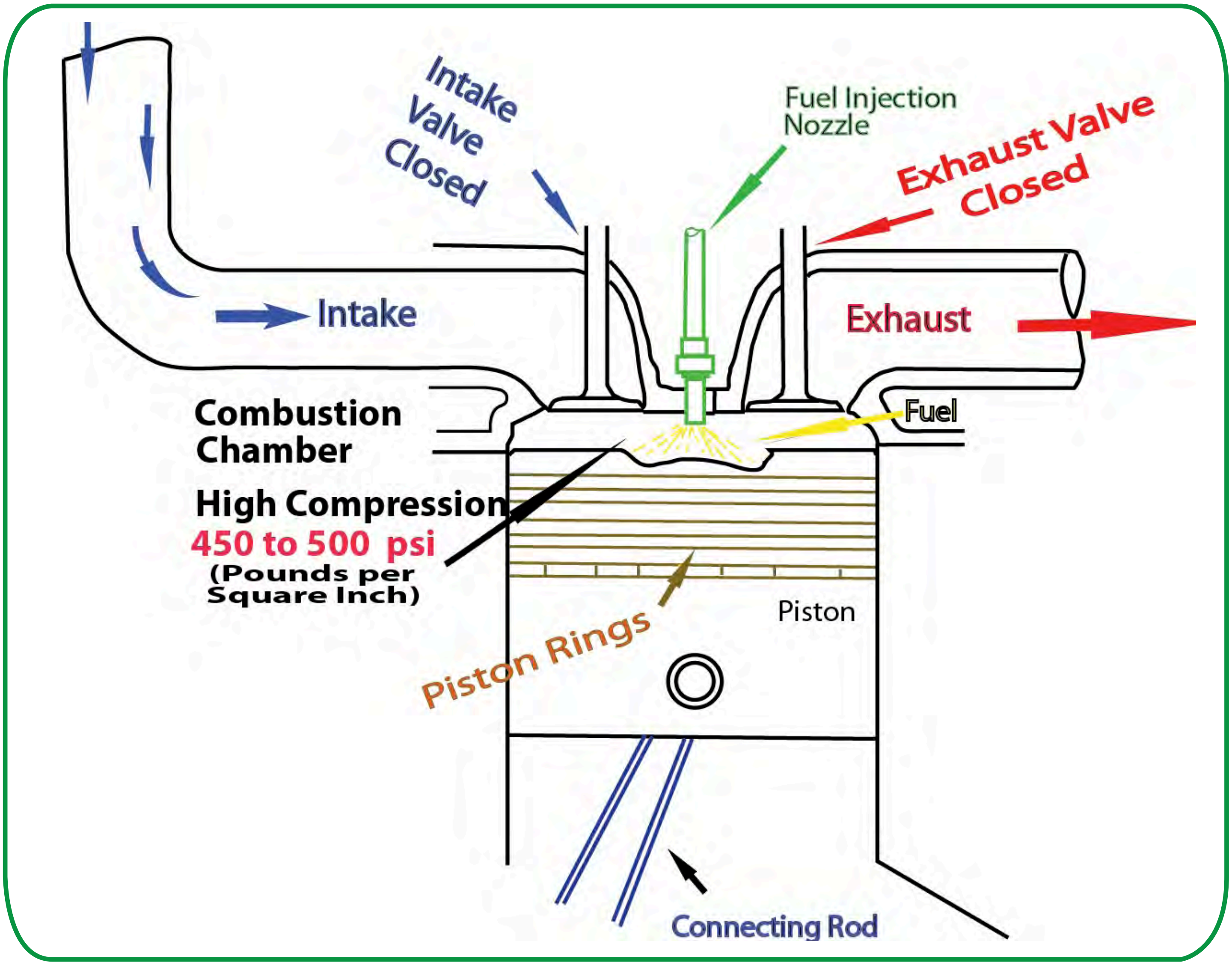


Figure 2-22. In a diesel engine, ignition takes place with the timed injection of diesel fuel into highly compressed air in the cylinder.

The volume of air in a diesel cylinder for any given intake stroke is relatively constant at all engine speeds. This has to be the case to keep uniform combustion temperatures at all speeds because only air volume and compression pressure result in ignition.

A diesel engine's power and speed are controlled by changing the amount of fuel injected into the compressed air in the cylinder. Gasoline engines can operate with an air fuel ratio of from 8:1 (rich) to 18:1(lean). Throttling varies the volume of the mixture from idle to full throttle.

Diesel engines operate with a constant volume of air and an air fuel ratio from 20:1(rich) at full power to 85:1(lean) at idle. If there is an excess of air in a diesel's fuel mixture, the result is that diesel engine will emit very little HC and CO. Almost all the fuel combines with the available O_2 (oxygen) to produce heat. On the other hand, the high temperature of combustion in diesel engines produces NO_X (nitrogen oxides). NO_x emissions from diesel engines are marginally higher than from a gasoline engine. However, diesels emit higher rates of particulate emissions than a gasoline engine. Diesels also emit more sulfur oxides than a gasoline engine.

Ignition Timing

Once the gasoline air fuel mixture is compressed in a cylinder, it must be ignited by a spark timed to produce maximum power combined with the lowest emissions. The ignition system delivers the spark to ignite the air fuel mixture. Electricity jumps the gap between the two electrodes of a spark plug, and when it does, there is a spark. That spark ignites the air fuel mixture. See figure 2-23 or an example of the electrodes of a spark plug removed from an engine with correct mixture and ignition. The result is the air fuel mixture ignites, expands and creates high pressure, which forces the piston down in the cylinder and through the connection rod, turning the crankshaft. This process repeats itself over and over in each cylinder as long as the engine is running.

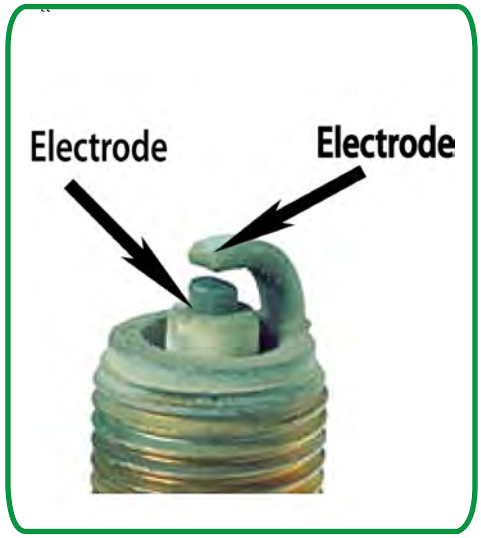


Fig 2-23 Example of the electrodes of a spark plug removed from an engine with correct mixture and ignition.

The time in the cycle when ignition occurs is called the ignition timing. Ignition timing is by spark ignition for carburated or fuel injection gasoline engines. Diesel engines use timed fuel injection . Correct ignition timing is essential to low emissions and driveability. Ignition must be at exactly the correct time, or the engine will not develop full power and exhaust emissions will be high.

During each cycle of a gasoline engine, the spark plug in each cylinder fires once. A four-cylinder engine has four power strokes every 720^0. The ignition interval is the number of degrees of crankshaft rotation between ignition strokes for each cylinder of an engine. Firing order is the sequence in which ignition occurs in various cylinders. In order for each cylinder to fire once every 720^0,the crankshaft throws are arranged in a particular order. The crankshaft throw arrangement dictates the firing order and the firing order changes with the number of cylinders and block design. Cylinders are numbered for identification, but firing order is rarely in cylinder number order. The most common firing order for a 4 cylinder in line engine is 1-3-4-2 and for a 6-cylinder in line engine 1-5-3-6-2-4.

Refer to figure 2-24 for an example of most common cylinder numbering configurations for V-type engines.

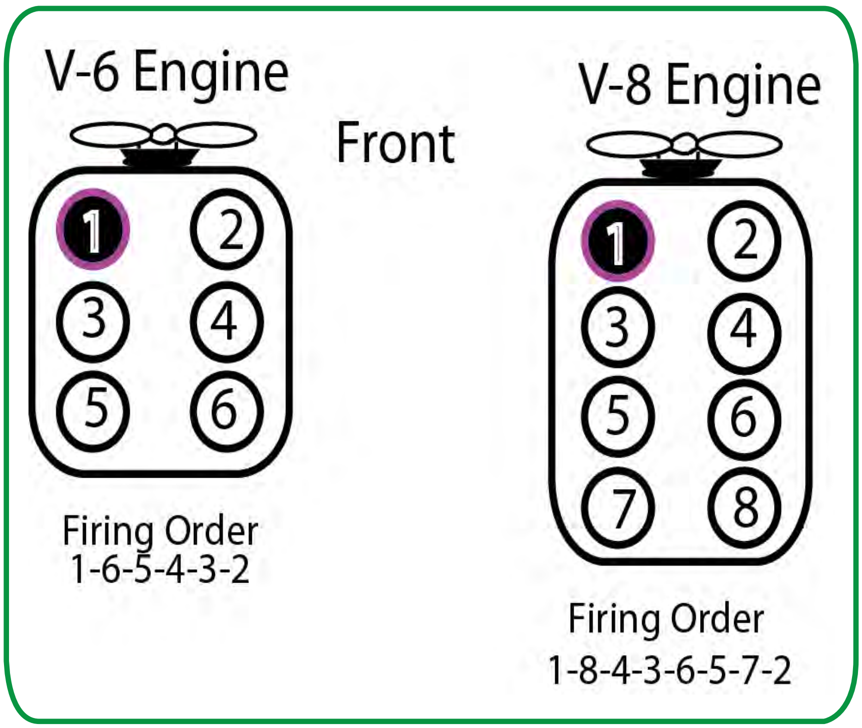
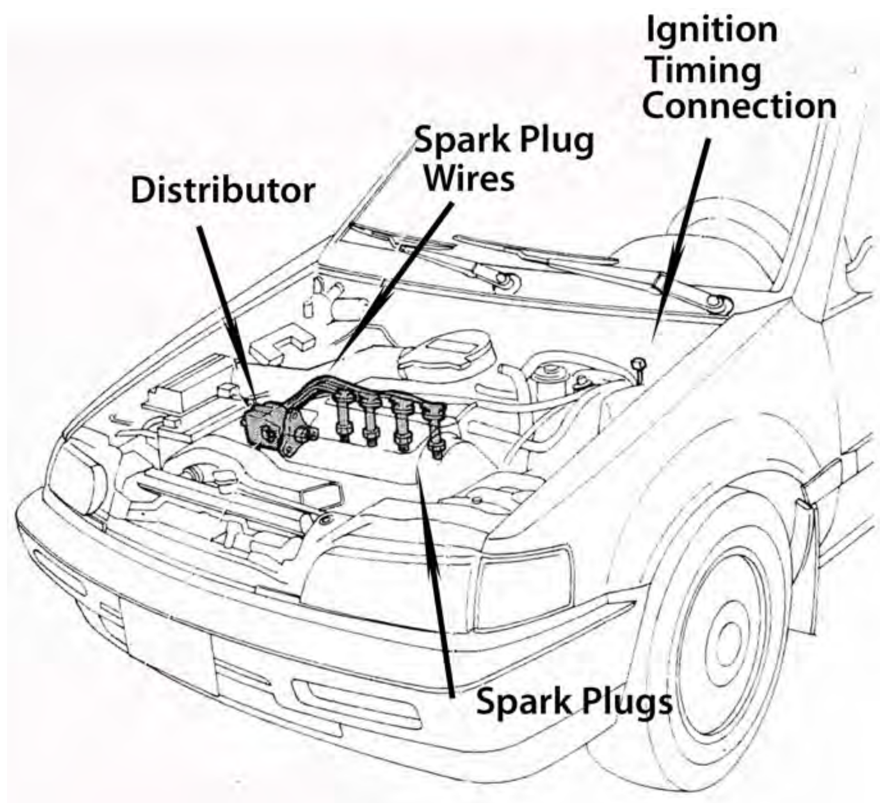


Fig 2-24. Example of the most common cylinder numbering and firing order configurations for V-type engines.

Refer to figure 2-25 for the location of the ignition parts on a 4 cylinder engine.
The spark plug wires carry the high voltage electricity necessary to cause a spark at the electrodes of the spark plug necessary to ignite the air fuel mixture. They are heavily insulated. Touching worn wires can cause a technician to receive a high voltage shock. While not usually deadly, it is best avoided.

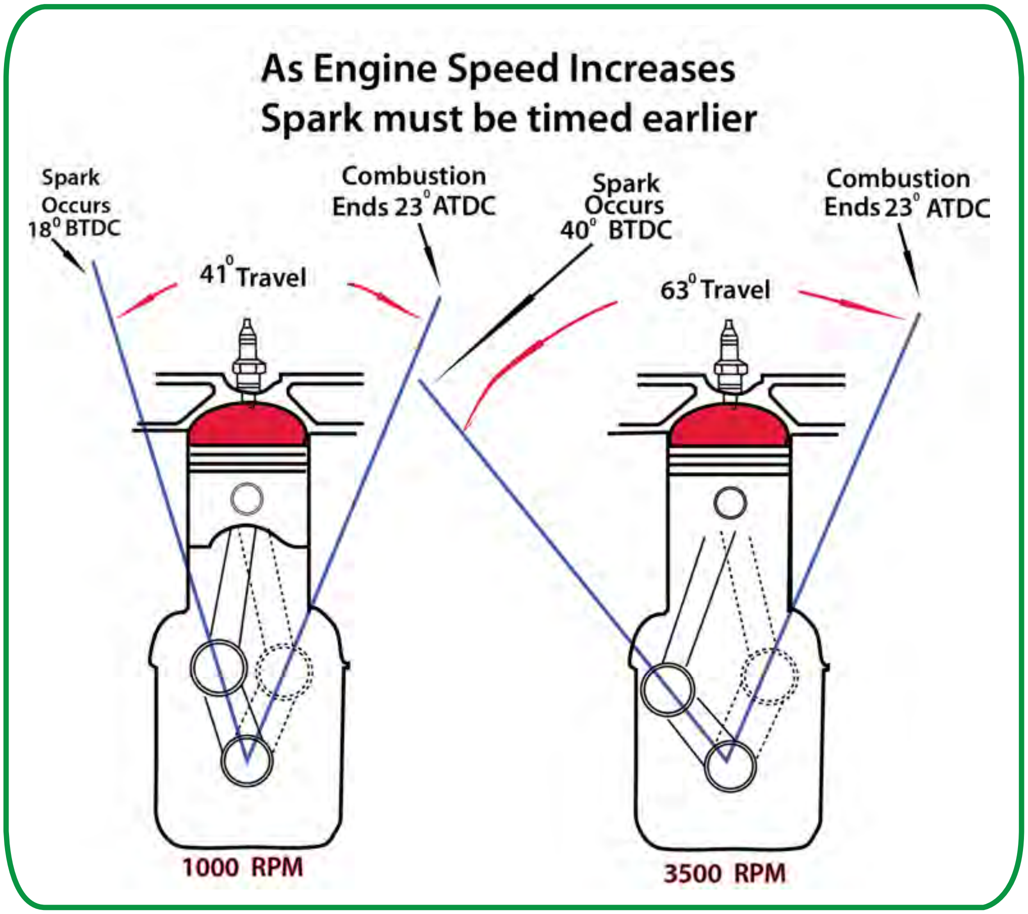
Refer to figure 2-25 for an example of the location of ignition parts on a four cylinder engine.



The function of the ignition system is to ignite the compressed air fuel mixture in the combustion chambers. This must occur at the right time and intensity (voltage) for good driveability and low emissions. If the spark arrives at the wrong time or if the spark does not have enough voltage(weak spark), maximum combustion pressure does not occur. In either case, emission of HC, CO and/or NOx may increase. NOx (Nitrogen Oxide) is a by-product of combustion in automobile engines.
Automotive ignition systems are either: Distributor Type or Distributorless/Electronic Type.
Ignition timing is the time expressed in crankshaft degrees rotation either BTDC (Before Top Dead Center) or ATDC (After Top Dead Center) when high voltage jumps the spark plug gap and ignites the air fuel mixture in the cylinder. Ignition must take place early enough so that the maximum combustion pressure is developed when a cylinder is just starting down on it's power stroke.
The ignition timing of an engine at idle is called base timing. Base timing is normally a few degrees BTDC or ATDC. As engine RPM (Revolutions Per Minute) increases, ignition must occur earlier and earlier BTDC. This is called timing advance. As engine speed decreases from high rpm to idle, timing must be retarded from its advance position back to basic timing. Depending on the operating conditions, timing is often retarded ATDC to reduce emissions. Spark ignition systems have devices to advance and retard ignition timing as engine speed changes.

To make this happen correctly in distributor ignition systems, the distributor is connected by a shaft to the crankshaft so that it turns at one half crankshaft speed. There are centrifugal weights and vacuum diaphragms connected to the intake vacuum to control ignition timing at various engine loads and speeds. Distributorless/Electronic ignition systems control timing electronically by using engine speed sensors (RPM) and other sensor inputs. These inputs are then processed by a central computer called the PCM (Power Control Module) or ICM (Ignition Control Module). Refer to figure 2-26.

Diesel engines have devices that advance or retard injection timing as a function of engine load and RPM. The timing of many injector pumps can be adjusted.



Refer to figure 2-26. When engine speed increases, spark must be timed sooner. Note that only 41^0 crankshaft travel is required at 1000 RPM. However, at 3500 RPM 63^0 is required.

Most engines have a line or some mark on the rim of the vibration damper. A pointer is attached to the timing cover. When the mark is directly under the pointer, the engine is ready to fire on thr number one cylinder. Some engines have a timing mark on the flywheel. Timing is usually set dynamically using a strobe/timing light. The strobe/timing light is operated using high voltage surges from the number 1 spark plug wire. Refer to figure 2-26. To check the timing, the timing light is aimed at the pointer over the vibration damper. Every time the number one cylinder fires, the timing light illuminates. Each time the number one spark plug fires with the damper in the same position in relation to the pointer, the damper timing mark looks as though it is standing still. When the timing mark on the damper is aligned with the pointer or the degrees marked on the timing cover are the same as specified by the engine manufacturer, the engine is timed correctly. Refer to figure 2-26.

SECTION 3

Cooling Systems

Cooling System

When fuel is burned, engine coolant temperatures normally reach about 200⁰F. Much of the heat is exhausted. However, cylinder head(s), pistons, cylinder walls, and valves absorb heat to the point where the vital oil film between parts breaks down and would destroy the engine if it were not for the cooling system. On the other hand, a cold engine is inefficient, contaminates oil, has high emissions, forms deposits, increases engine wear, has poor driveability, low HP (horsepower), and high fuel consumption. Refer to figure 3-1. The job of the cooling system is to remove unwanted heat. It must maintain an efficient temperature under all operating conditions. This includes bringing an engine to operating temperature from a cold start. There are two types of automobile cooling systems used: air cooled and the more widely used water-cooled.

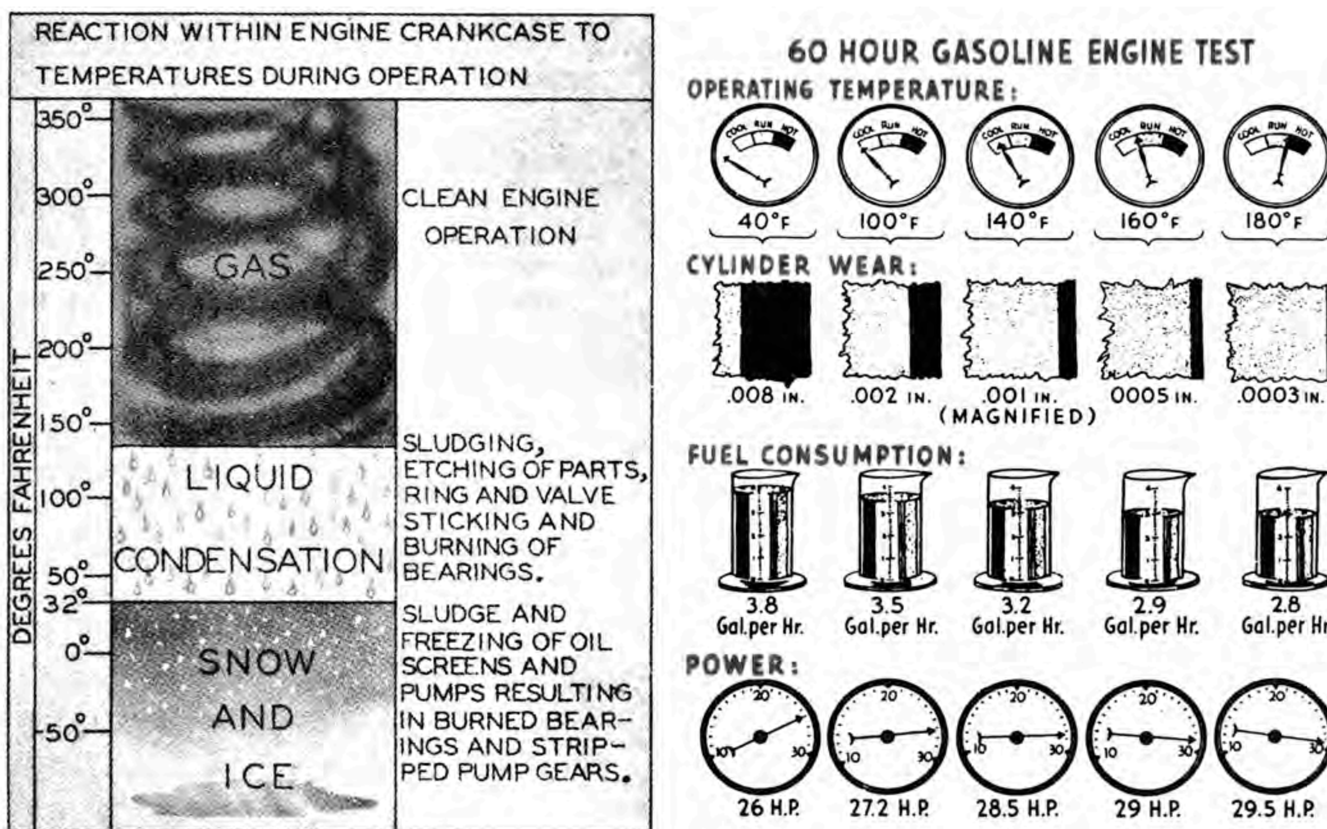


Figure 3-1. The above diagram shows the relationship between engine temperature and its effect on engine life (cylinder wear), fuel consumption and performance.

In water cooled engines (actually cooled by Ethylene Glycol Anti-freeze), the coolant temperature varies by engine between 200⁰ F (94⁰C) to 212⁰F (100⁰C) being normal.

Coolant System Parts

The parts of the cooling system are:

- Water jacket
- Coolant
- Water pump
- Radiator
- Radiator cap
- Hoses
- Fan
- Belt drives
- Coolant
- Heater
- Coolant recovery system

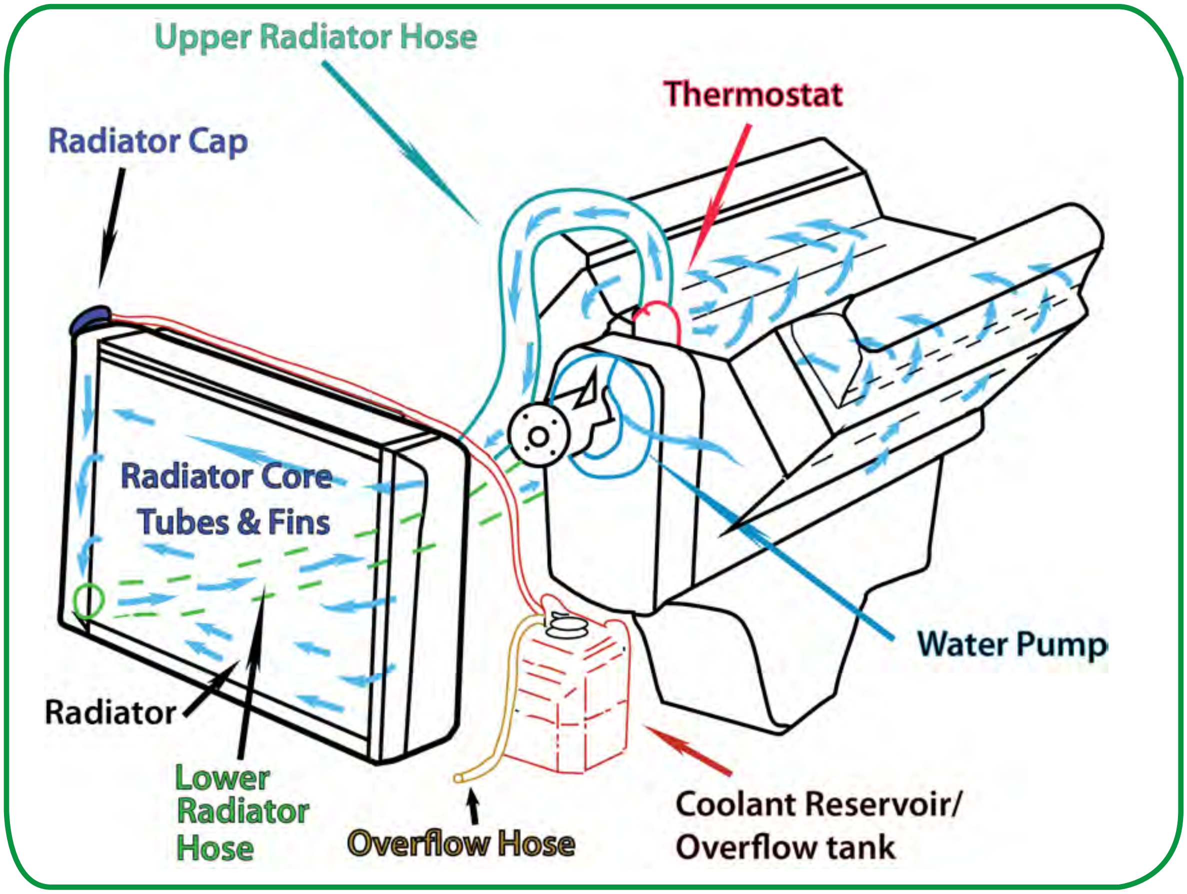


Figure 3-2. This is an example of the coolant flow path in a coolant system using a cross flow radiator.

Coolant Circulation

Liquid cooling systems work by circulating the coolant through the engine to absorb heat then through the radiator. The air absorbs heat from the coolant in the radiator. The coolant then returns to the engine to absorb more heat. See figure 3-2. Coolant circulates through the engine water jackets and through hoses and the radiator. A water pump is needed to circulate the coolant through the engine. The water pump is belt driven off a pulley on the front of the crankshaft. The same V belt may be used to drive the alternator. In order for the coolant to be effective, it must flow around the cylinders and up through the cylinder head on its way to the radiator. Coolant must reach every part of the system, and there must be no 'dead spots' without coolant circulation.

There are two ways in which coolant is circulated in an automotive engine to maintain correct engine temperature. Outside the engine, the coolant circulates through the radiator and hoses; inside the engine, it circulates through the water jacket. Thermostat temperature sensitive valves open and close to control these two circulation paths and maintain correct engine temperature.

When the engine is cold, it must be warmed up to operating temperature quickly. If the coolant were allowed to circulate through the radiator when the engine was cold, it would take a long time to warm up the engine, so the thermostat stays closed. This keeps the coolant circulating in the engine and stops it from entering the radiator where it would be cooled. This helps the engine warm up quickly. As the coolant warms up, the thermostat opens allowing hot coolant in to circulate through the system and into the radiator to be cooled. Engine temperature is controlled by the amount of coolant in the system, the size of the radiator, and the opening temperature of the thermostat. Thermostats that open too soon will result high HC and CO emissions and long warm up times.

If the thermostat does not open, the engine will overheat since coolant never reaches the radiator to be cooled. See figure 3-3.

Cooling System Pressure

Automobile engine cooling systems are pressurized to:
Raise the coolant boiling temperature.
Increase water pump efficiency.
If the cooling system was unpressurized, efficiency would drop to 80 to 85 percent. If only a small amount of air is present in the pump when the pump turned, it would mix the air with the coolant resulting in the cooling system liquid becoming aerated and cause bubbles. Bubbles in the cooling system reduce cooling efficiency by reducing heat transfer from the engine to the coolant. In addition, by pressurizing the cooling system and using a pressure cap, the boiling point of the coolant increases. As pressure increases, the boiling point of water increases. Water boils at 212^{0}F (100^{0}C) normal atmosphere pressure. If the pressure is raised by 15psi (pounds per square inch) above atmospheric pressure, the boiling point of water is increased to approximately 260^{0}F (127^{0}C). As the pressure of the cooling system increases, the boiling point of the coolant goes higher than 212^{0}F (100^{0}C). This means that there is now a greater difference between coolant temperature and the outside air temperature. This aids cooling. The laws of physics state that hot moves to cold, and the greater the temperature the faster the heat transfer.

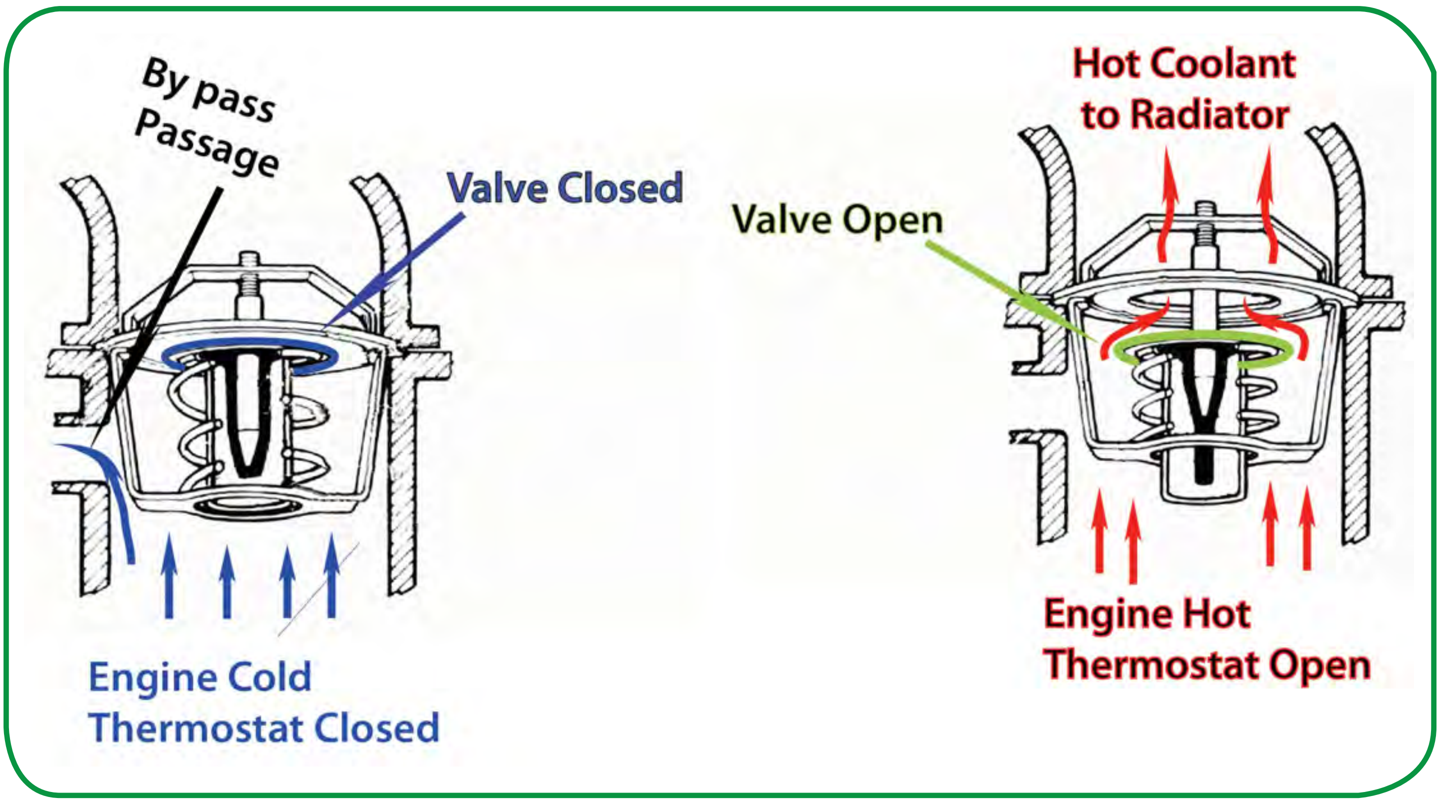


Figure 3-3. Operation of a thermostat.

Pressure Relief Cap

The radiator pressure relief cap seals the cooling system. Refer to figure 3-4. This prevents evaporation of anti-freeze(coolant) and allows the use of an expansion tank. By being a pressure release cap, the boiling point of the coolant is raised. The cap has a pressure relief valve to prevent over pressurization. If the pressure exceeds the spring force, the valve opens, and coolant is routed to the expansion tank. Refer to figure 3-5.

The pressure cap also has a vacuum relief valve. As the coolant cools when the engine is switched off, the volume of coolant in the system decreases and creates a vacuum. This opens the vacuum valve, and the coolant from the expansion tank is drawn back into the cooling system.

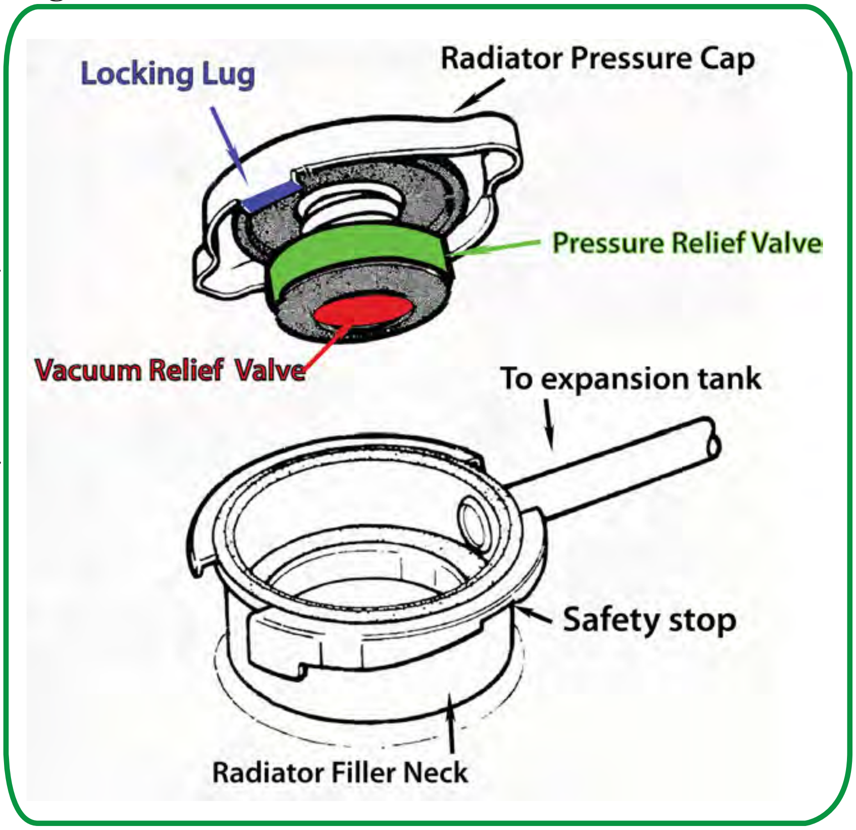


Figure 3-4. Radiator pressure cap.

Warning: Never remove a radiator cap or cooling system pressure cap when an engine is near or at operating temperature. When the pressure is released from the cooling system, the coolant will gush out of the filler neck. The result will be serious burns or scalding. Always wait until the engine cools before removing a coolant system cap.

Antifreeze

Since water freezes at 32^0F (0^0C), every time the outside air dropped below freezing the water would freeze. The frozen water would not circulate. In addition, water expands about 9 percent when it freezes. This expansion would crack the cylinder head as well as block and split the radiator at the seams. A mixture of ethylene glycol and water is commonly used as an anti freeze.

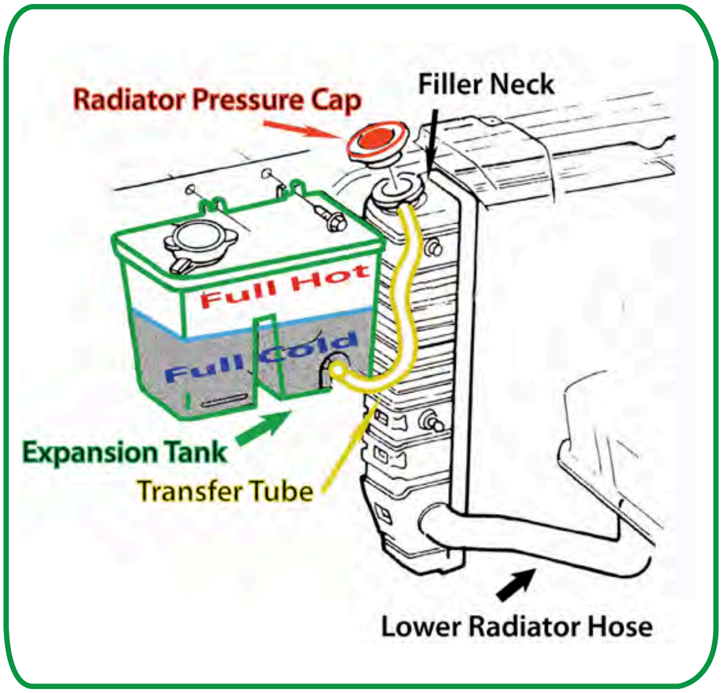
The mixture prevents the coolant from freezing. The ratio of antifreeze to water depends on the lowest expected air temperature.

Radiator

A radiator is a heat exchanger with two sets of passages. One set of passages is for coolant, and one set is for air. Engine heat transfers from the hot coolant to the cooler outside air by passing through the radiator.

Water Pump

The water pump is attached to the front of the engine and is usually driven by a belt from the crankshaft pulley. See figure 3-6.



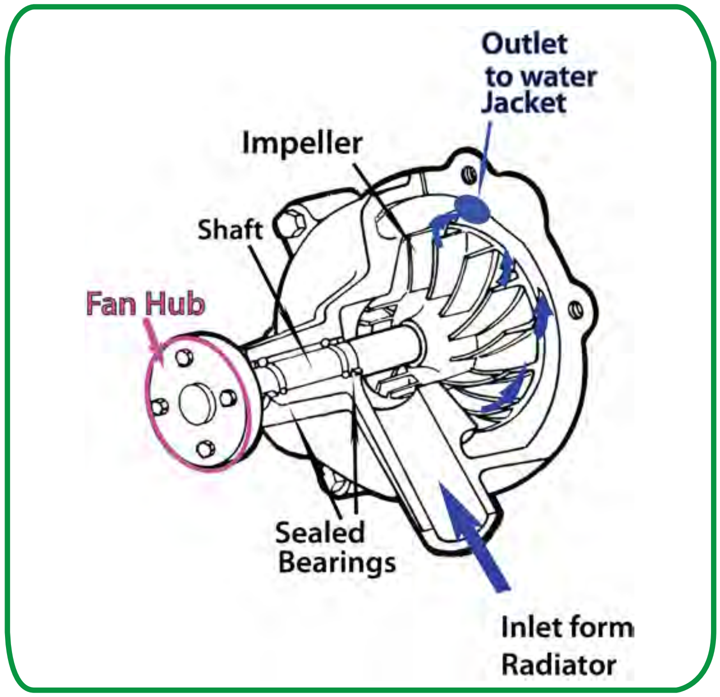


Figure 3-5. Expansion Tank.

Figure 3-6. An Impeller water pump.

Engine Fan

At cruise, the outside air flowing through the radiator is enough to keep it cooled. However, when the engine is at idle or moving slowly in traffic additional airflow is needed. Fans are either driven by the engine or are electrically driven.

Variable speed fans are usually mounted on the water pump pulley and driven through a fan clutch. A fan clutch is a temperature controlled fluid coupling (connection) that is mounted between the water pump pulley and the fan. The clutch fan and the fan are mounted on the water pump pulley and driven off the crankshaft pulley by a belt. Air that passes though the radiator flows over a thermostatic blade or spring on the front of the clutch fan. The temperature of air causes the thermostatic device to bend. When it bends, it opens a valve that allows oil to enter or leave the fluid coupling. When the engine is cold, the valve is closed, and the coupling slips so the fan does not turn. When the engine warms up, the valve opens, and oil enters the coupling which causes the fan to turn.

Electric fans use an electric motor to turn the fan. A thermostatic switch turns the fan motor on and off as a function of coolant temperature.

The majority of automotive engine fans are pull type fans. That is they are mounted behind the radiator and pull air though it. Electric fans have the advantage of drawing less power from the engine and create less noise than mechanical fans. In addition, there is no fan belt to break. Fan shrouds are attached to the radiator to improve fan performance. Refer to figure 3-7.

Warning: When an engine is running, never stand directly in line with the fan. Blades can break, fly off and cause serious injury. Keep hand, tools and clothes clear of fan blades. Electric fans can start up at any time.

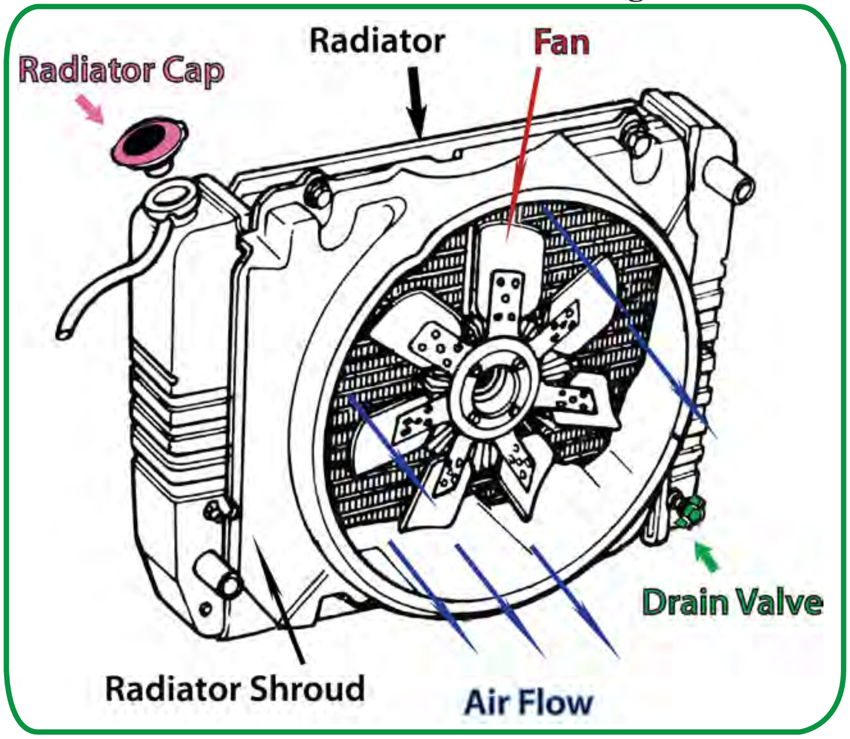


Figure 3-7. A shroud increases radiator fan efficiency.

Heat from the engine coolant is also used to warm the passenger cabin. An electrical fan blows air through the heater core, which is a small heat exchanger built much like a radiator but with no cap.

Refer to figure 3-8 which shows the circulation of coolant when the engine and coolant are cold. Refer to figure 3-9 which shows the circulation of coolant when the engine and coolant are hot. Note the position of the thermostat when cold (closed) and hot (open).

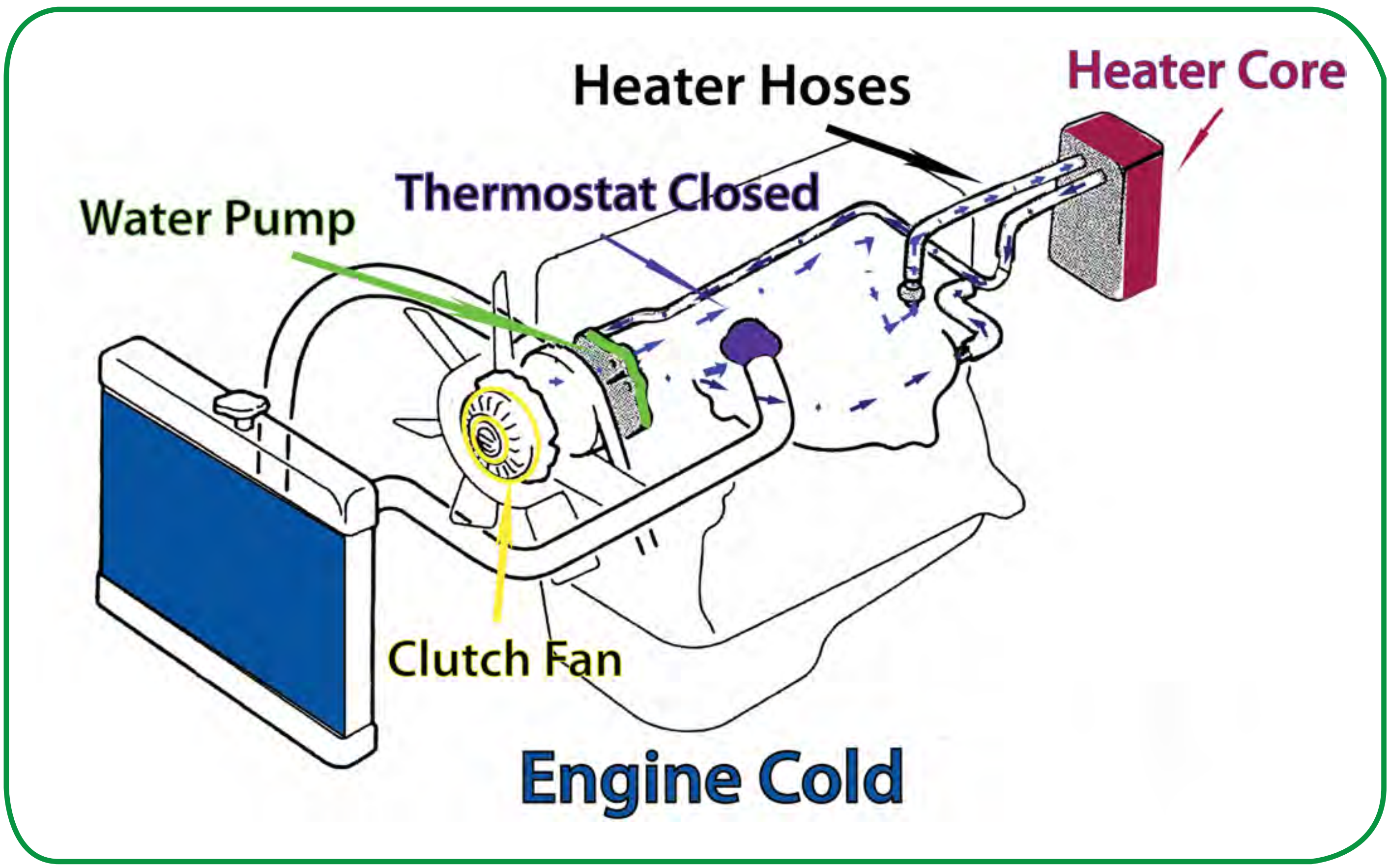


Figure 3-8. Coolant circulation of a cold engine.

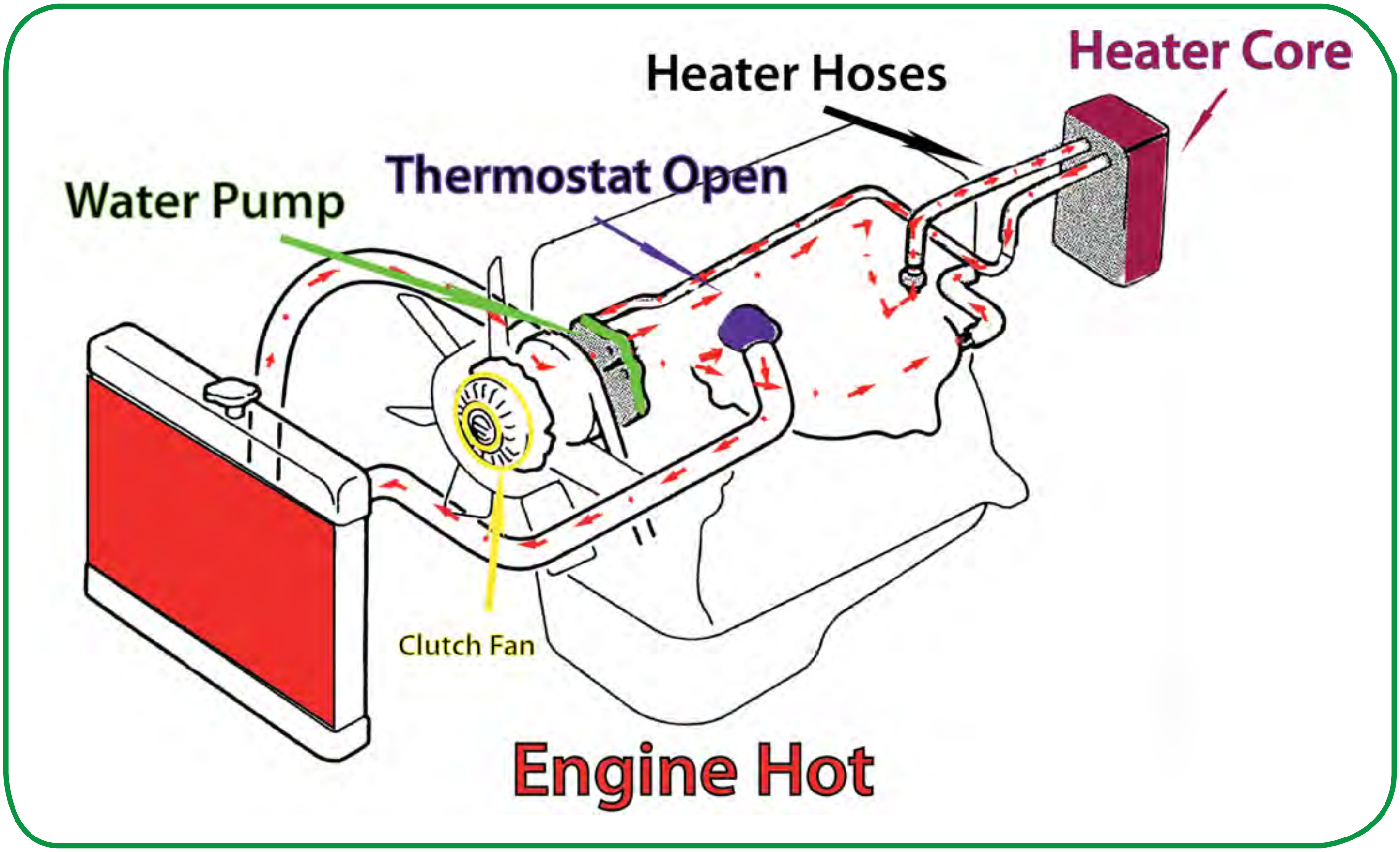


Figure 3-9. Coolant circulation of a hot engine.

Heat Exchangers

There are several other types of heat exchangers used in vehicles. Refer to figure 3-10.

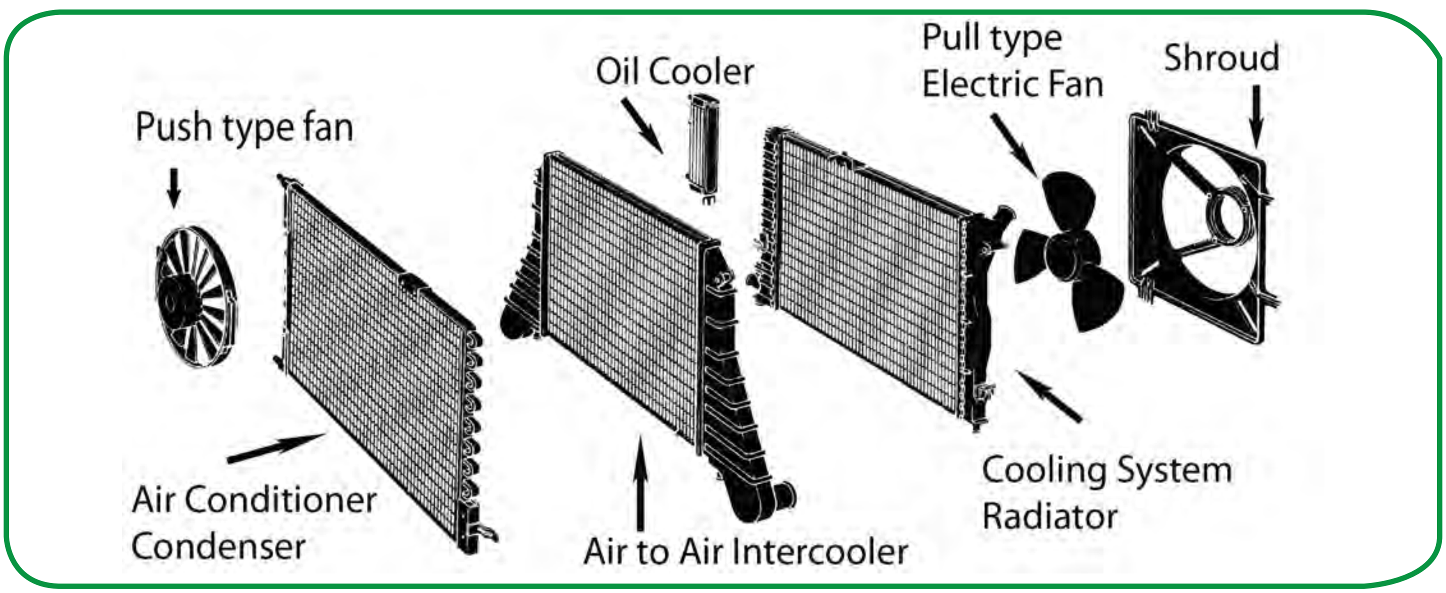


Figure 3-10. This is an example of four heat exchangers on a vehicle with air conditioning and a turbo charged engine.

Most vehicles have some form of coolant temperature sensor system. Some of the systems used to indicate engine temperature are as follows: 1) Electronic Gauge 2) Indicator light 3) Electric Gauge 4) Digital Gauge. All perform the same function to indicate engine temperature and warn of overheating. Some vehicles have a coolant level indicator in the expansion tank.

Most vehicles have a translucent expansion tank with indicator level marks which allows for a visual level check.

If the coolant level indicator light is on, check the coolant level. If the coolant temperature senor indicates excessively high temperature, shut the engine down and check the coolant level. If the engine overheats, it will be damaged.

SECTION 4

Induction Systems

Air that enters an engine through the intake manifold must be clean and at the correct temperature for maximum fuel vaporization. This function is performed by the air cleaner assembly. Gasoline and diesel engines both have air cleaners with paper filters. On carburated engines, the air cleaner usually sits on top of the carburator. Refer to figure 2-1. On fuel injected engines, the air cleaner is located at the air injecton intake. Some engines have air cleaners located away from the engine and connected to it by ducting. Refer to figure 4-2.

Intake Manifold

All automotive engines have an intake manifold. An intake manifold is a casting or a set of pipes, usually called 'runners' one for each cylinder, that carries the air/fuel mixture from below the throttle valve to the intake port of the cylinder head on engines with carburetors and carries air only on engines with ported fuel injection. On engines with a carburetor(s) or throttle body fuel injection, fuel mixes with intake air as it enters the intake manifold.
Intake manifold runners are designed to be as short and as smooth as possible.
There are numerous configurations used for intake manifolds. Below are a few examples:
I) V-type engines have the intake manifold between the two cylinder banks. 2)Intake and exhaust manifolds on opposite sides of the cylinder head (crossflow head). 3) Intake and exhaust manifolds on the same side of the cylinder head.
Intake manifolds have an inherent problem when it comes to delivering the same air fuel ratio to each cylinder. Unless fuel vaporizes completely, the air fuel mixture will contain droplets of fuel. Inertia stops the droplets from turning corners in the manifold. The droplets hit the sides of the manifold walls at corners where they collect and form puddles of liquid fuel.

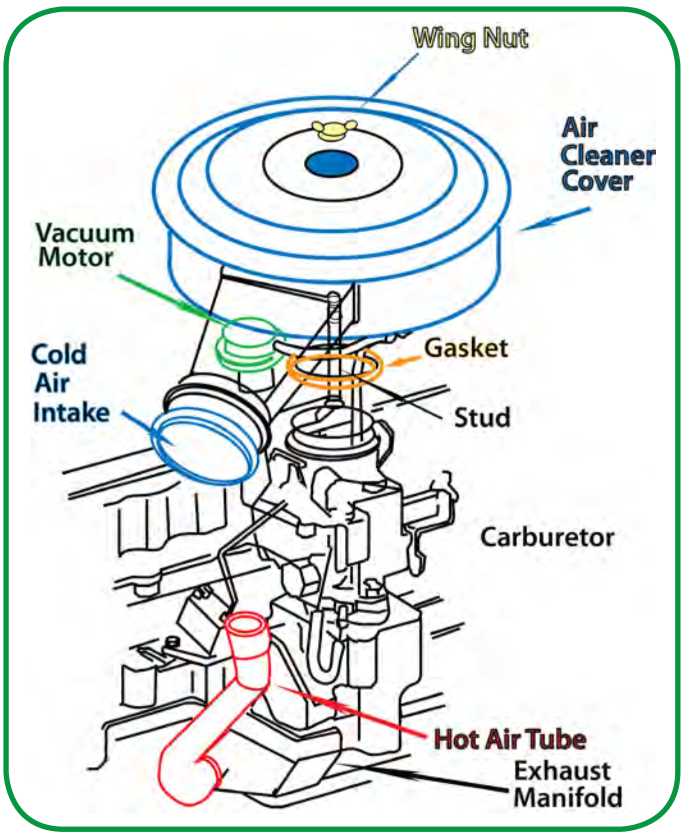


Figure 4-1. TAC Air Cleaner.

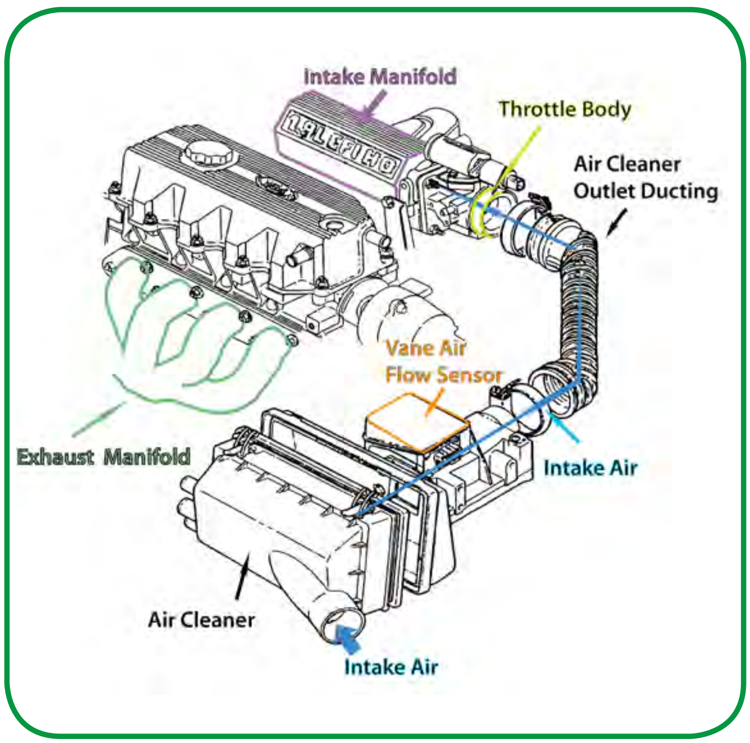


Figure 4-2. Remote Air Cleaner.

So-called fuel 'puddling' takes place mostly at the end of the intake manifold. When the air fuel mixture flows over the fuel puddle, it picks up more fuel vapor. This richens up the mixture flowing into some cylinders. The result is an uneven distribution of the air fuel mixture. It stands to reason that if some cylinders get more fuel (rich mixture) others will get less (lean mixture). The unequal fuel distribution of intake manifolds was a major reason for vehicle manufacturers installing fuel injection systems on engines.

Types of Vacuum

When a piston is on the intake stroke, vacuum is created in the intake manifold. There are various types of vacuum depending whether the engine is carburated or fuel injected or whether the vacuum is measured above or below the throttle valve.

Ported vacuum operates many components of emission control systems through TVVs or electric ported vacuum switches. Ported vacuum is only available off idle, and therefore it is for used for ignition advance. Refer to figure 4-3.

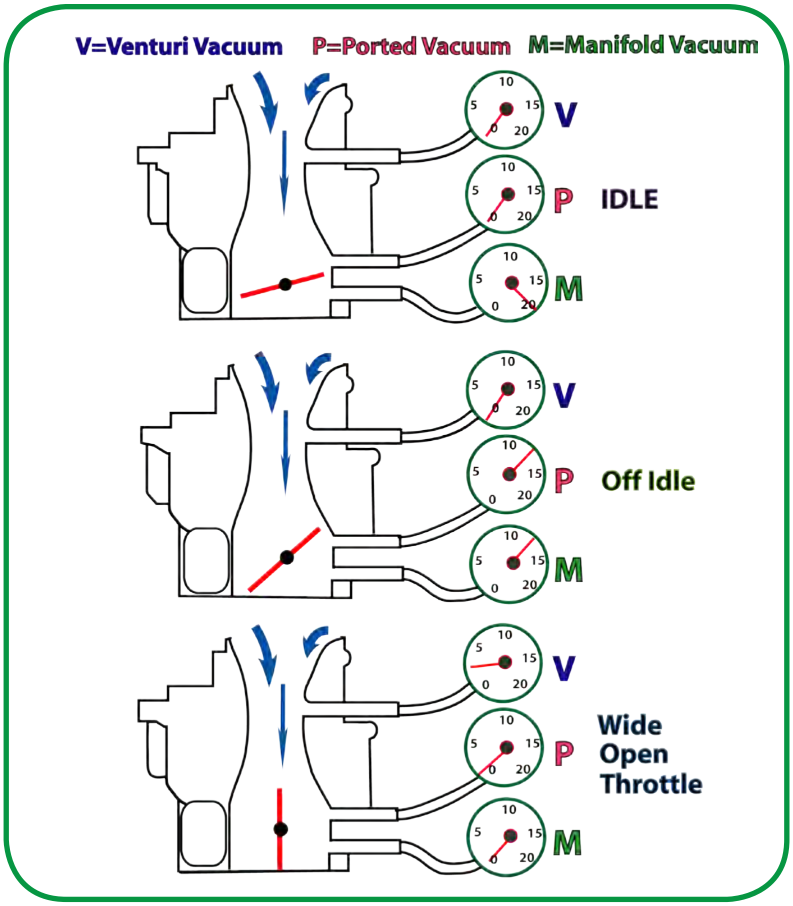


Fig. 4-3. Vacuum sources.
Venturi vacuum increases with engine RPM. Ported vacuum is only at off idle. Manifold vacuum is highest at idle and lowest at wide-open throttle.

Variable Intake System

A tuned intake manifold on a carburated engine is one that has been designed or modified to produce the highest pressure when the cylinder intake valve closes at the beginning of the compression stroke.

When the intake valve opens, the air fuel mixture is drawn into the cylinder. When the intake valve closes, the flow of mixture stops. However, the inertia of the air/fuel mixture keeps it moving. This results in the mixture being forced against the closed throttle valve. If the intake valve now opens, extra mixture is forced into the cylinder. The result is a surge in engine power from the ram effect of the mixture entering the cylinder. An intake manifold which has been tuned takes advantage of the ram effect and this increase in engine power is referred to as a tuned intake manifold.

Some engine manufacturers have improved performance by designing a variable induction system. Each cylinder has two runners: one long runner tuned for low speed and one long runner tuned for high speed. There is a PCM (Power Control Module) (computer controlled) throttle valve in each high speed runner that remains closed until the engine reaches 3500 to 4000 RPM (Revolutions per Minute). This improves engine performance.

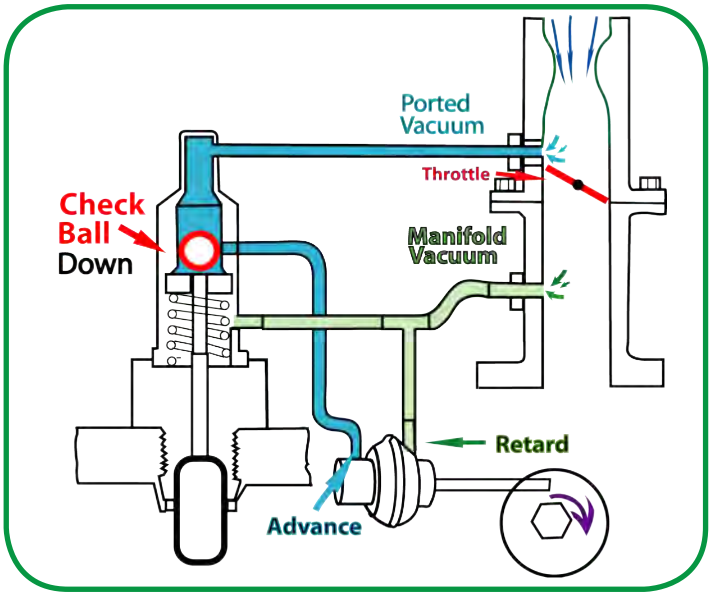


Fig. 4-4. This is an example of a thermal vacuum valve (TVV) under normal operating conditions.

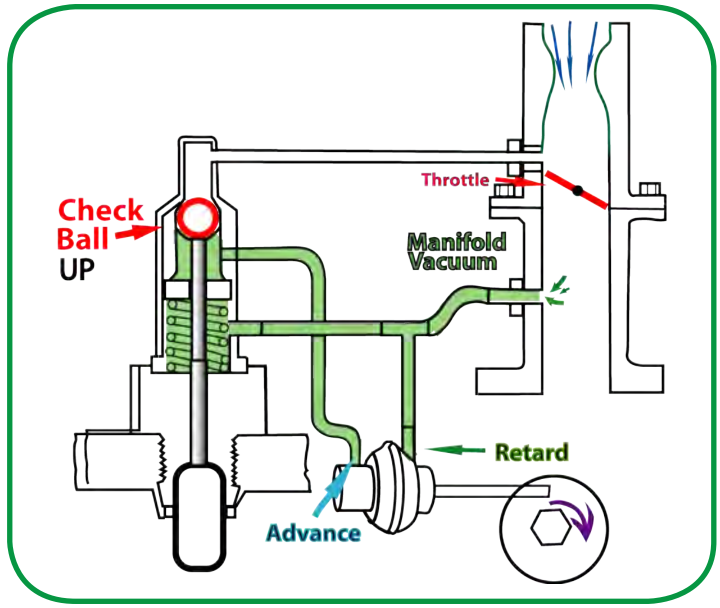


Fig. 4-5 is an example of a thermal vacuum valve (TVV) when the engine overheats.

Manifold vacuum controls many emission components including the TAC. Since manifold vacuum is available at idle, it is used for ignition retard. Thermal vacuum valves route manifold vacuum to the distributor vacuum advance under excessive coolant temperature conditions. Refer to figure 4-4 and figure 4-5 . Manifold vacuum is also used to operate EGR (Exhaust Gas Recirculation) valves. Refer to figure 4-6 and 4-7.

Venturi vacuum is used by EGR systems to provide EGR valve control signal. Venturi vacuum is too weak to open an EGR valve. However, signal strength is proportional to airflow, which means that the EGR system can apply vacuum to the EGR valve that is proportional to the venturi vacuum signal. Thus allowing EGR flow to be almost proportional to airflow.

Refer to the underhood emissions vacuum diagram when performing your visual inspection for correct vacuum hose routing. A thermal vacuum valve (TVV) is a valve that opens and closes as a function of coolant temperature.

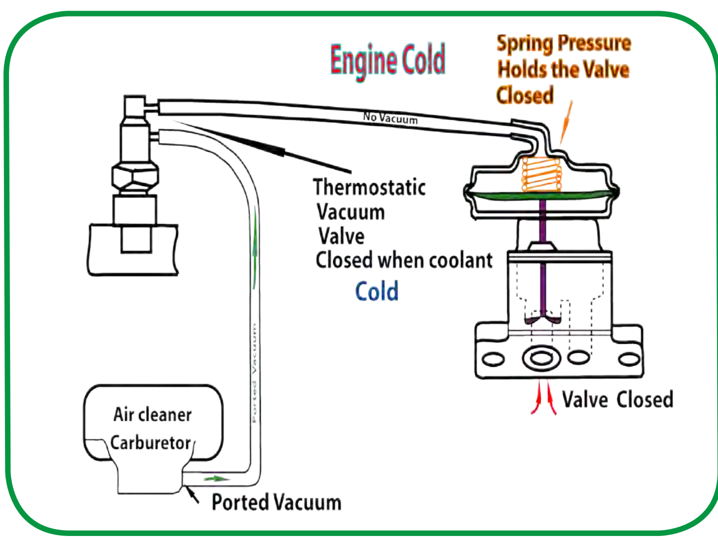


Fig. 4-6 is an example of a thermal vacuum valve (TVV) operating an EGR Valve. Engine cold, off idle. No vacuum to the EGR valve.

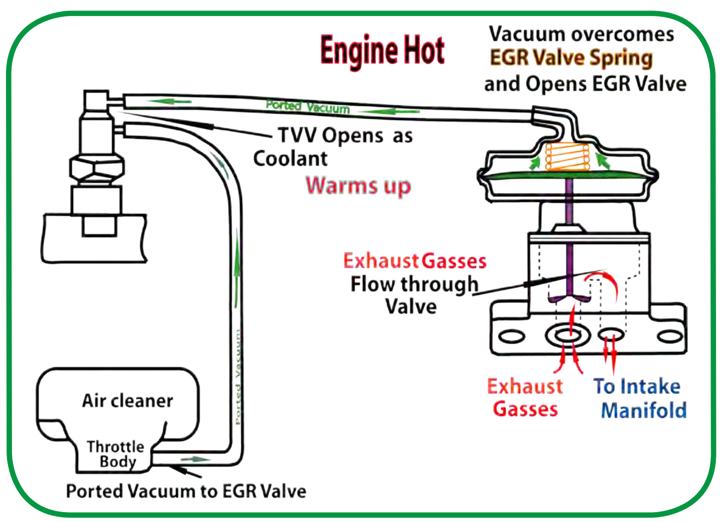


Fig. 4-7 is an example of a thermal vacuum valve (TVV) operating an EGR Valve. Engine hot,off idle. Ported vacuum is routed to the EGR valve.

Forced Induction

The purpose of forced induction (supercharging and turbocharging) is to increase the intake manifold pressure as well as the density and force a greater mass of air into the cylinders during their intake stroke.

Forced induction is the process of forcing more air fuel mixture into the cylinders that would normally enter by using a pump. The more air fuel mixture in the cylinders, the higher the pressure during combustion and resulting in higher power output. Increases in power using forced induction range from 30 to 60 percent more than a non-turbocharged (naturally aspirated) engine. Refer to figure 4-3 for pressures above and below the throttle valve.

Turbochargers and superchargers are the two devices used to force more air fuel mixture into the cylinders. They are also called 'blowers'. With a blower on an engine, there is now pressure in the manifold instead of vacuum. This is referred to as 'boost pressure'. The systems are designed so that boost pressure is available during normal engine operation and the associated power when needed.

Superchargers

There are two types of superchargers used on automobile engines.
Roots Supercharger
Spiral Supercharger
The Roots supercharger has tow rotors which turn inside a housing. Each rotor has two or three lobes driven from the crankshaft by a belt or chain and geared to turn two or three times as fast as the engine. Refer to figure 4-8 for an example of airflow through a Roots supercharger on a port fuel injected engine.

Roots Supercharger

Superchargers on carburetor or throttle body (TBI) equipped engines are usually found on the air intake side, and the air fuel mixture flows through the supercharger. On port fuel injected engines, only air flows through the supercharger. Refer to figure 4-2. The airflows through the air cleaner and passes the airflow/sensor, which signals the PCM how much air is entering the engine. The air then flows past the throttle valve into the supercharger; where it is compressed and routed to an intercooler that cools the air after it has been compressed and directs it to the intake manifold.
Intercoolers cool intake air to increase its density after it has been compressed. Hot air contains less O_2 for combustion. In addition, the cooler air entering the engine allows for higher compression without detonation. Detonation is engine knock as a result of fuel burning too quickly. Detonation is the result of two flame fronts in a cylinder causing an explosion resulting in a very rapid rise in pressure. The result is a rapping metallic sound called pinging. Pinging also called spark knock or detonation can cause severe engine damage because the high pressures created by detonation put excessive loads on the engine and in particular the piston bearings. Detonation has been known to cause burn holes in pistons.
A Roots supercharger is really a positive displacement air pump. This means that with each revolution of the rotor forces the same volume of air into the intake manifold regardless of speed.
Superchargers take power from the engine as to reduce this so called 'parasitic' loss of power. Some engine manufacturers of superchargers use a magnetic clutch controlled by the PCM, which engages and disengages the supercharger as a function of engine load requirements. Refer to figure 4-9. Other manufacturers use a boost control or bypass valve to reduce the power loss. At part throttle, the bypass valve routes some air back through the supercharger air intake, and this improves performance. The bypass valve can be controlled by vacuum throttle linkage. At idle, the bypass valve is wide open. At full throttle, the bypass valve is closed.

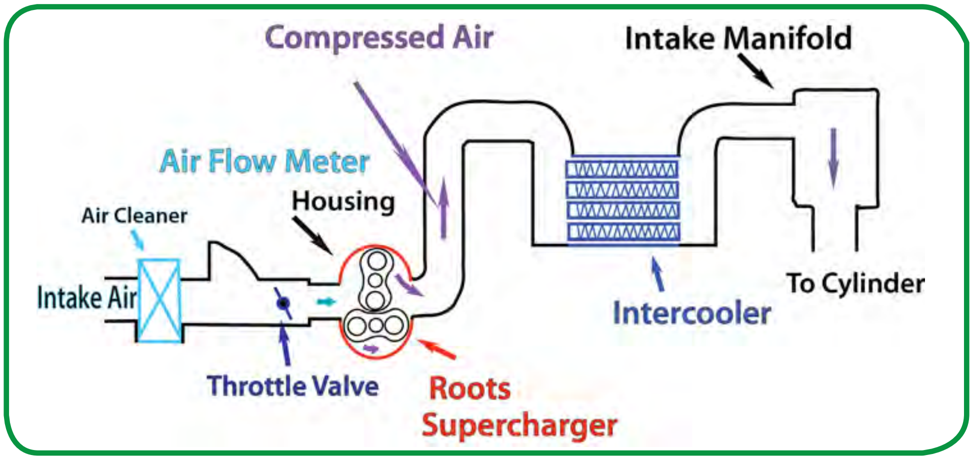


Figure 4-8. Airflow through a roots supercharger on a engine with ported fuel injection.

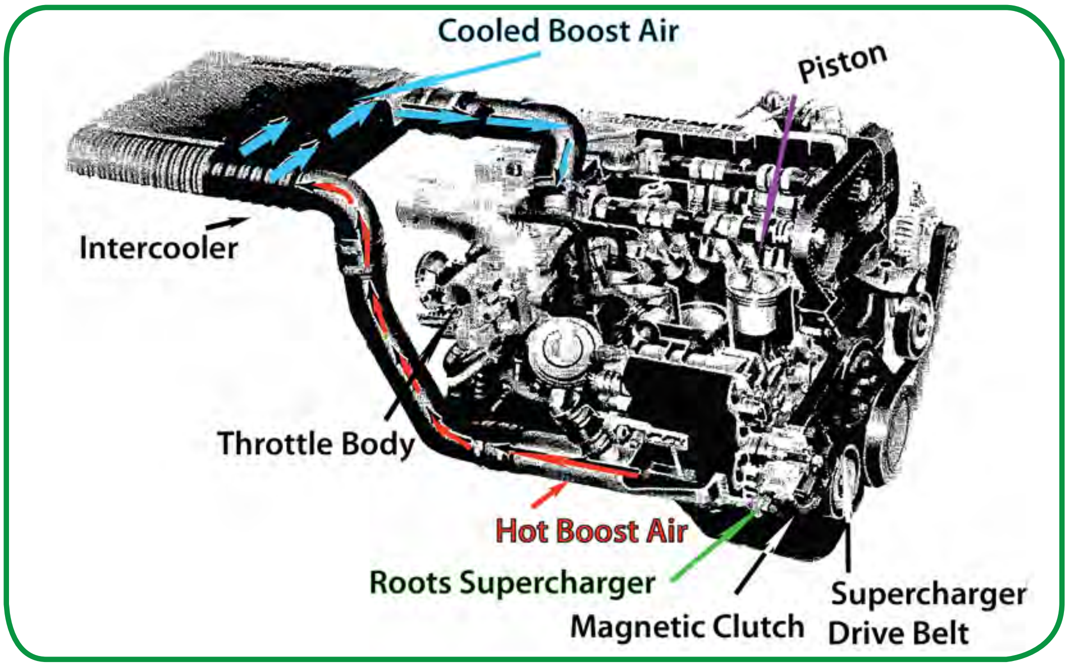


Figure 4-9. Roots supercharger with a magnetic clutch and intercooler.

Spiral Supercharger

Spiral superchargers also known as a scroll supercharger is another positive displacement pump. This type of supercharger can be found on Volkswagen engines. It is called the G-charger because the shape of the spirals are like the letter G. In the supercharger housing, a displacer moves eccentrically around inside the spirals to compress the intake air.

Centrifugal supercharger

A centrifugal supercharger is a variable displacement supercharger which draws air in through a central inlet and uses centrifugal force to move the air to the perimeter of the pump housing. This increases its pressure and then forces the compressed air through an outlet. Refer to figure 4-10. Since centrifugal force increases with speed, the volume of intake air of a centrifugal supercharger increases as speed increases, which results in more boost pressure as speed increases.

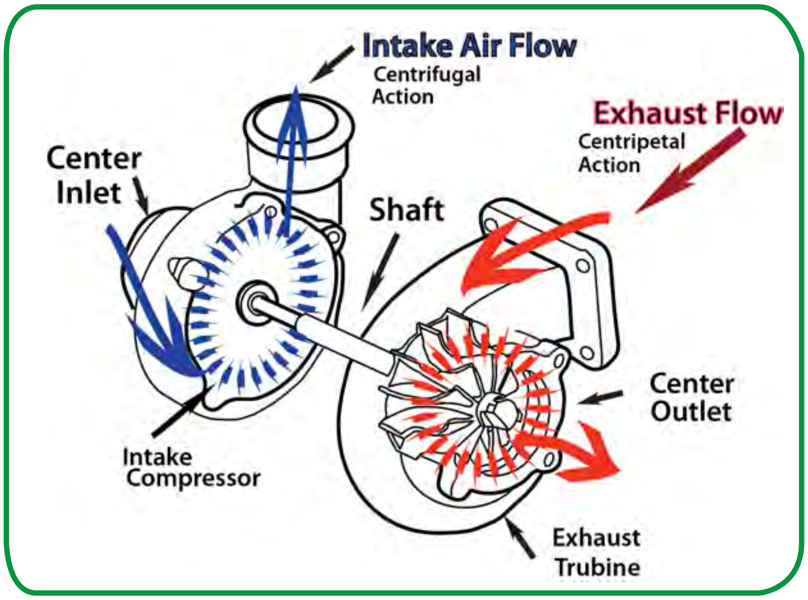


Figure 4-10. A centrifugal supercharger draws air through a central inlet and uses centrifugal force to accelerate the air. Thus increasing its pressure and forcing the compresses air through an outlet. Centrifugal superchargers are driven by exhaust gasses which apply centripetal force to a turbine, which is connected to the intake compressor by a shaft.

Turbochargers

A turbocharger is a centrifugal air pump whose purpose is to increase the intake manifold pressure as well as increase the density and force of a greater mass of air into the cylinders during the intake stroke. Refer to figure 4-11.

A turbocharger is driven by exhaust gas. Figure 4-12 shows the exhaust gas and air flow through a turbocharger. A turbine and compressor are mounted on either end of a shaft. When the engine is running, the exhaust gasses flow though the turbine. The turbine turns the compressor at the other end of the shaft. When the compressor spins, it sucks in air, compresses it and forces it into the intake manifold. To prevent over boost and limit boost pressure, turbochargers have a wastegate which is operated pneumatically by the PCM. Refer to figure 4-12, or Refer to figure 4-13.

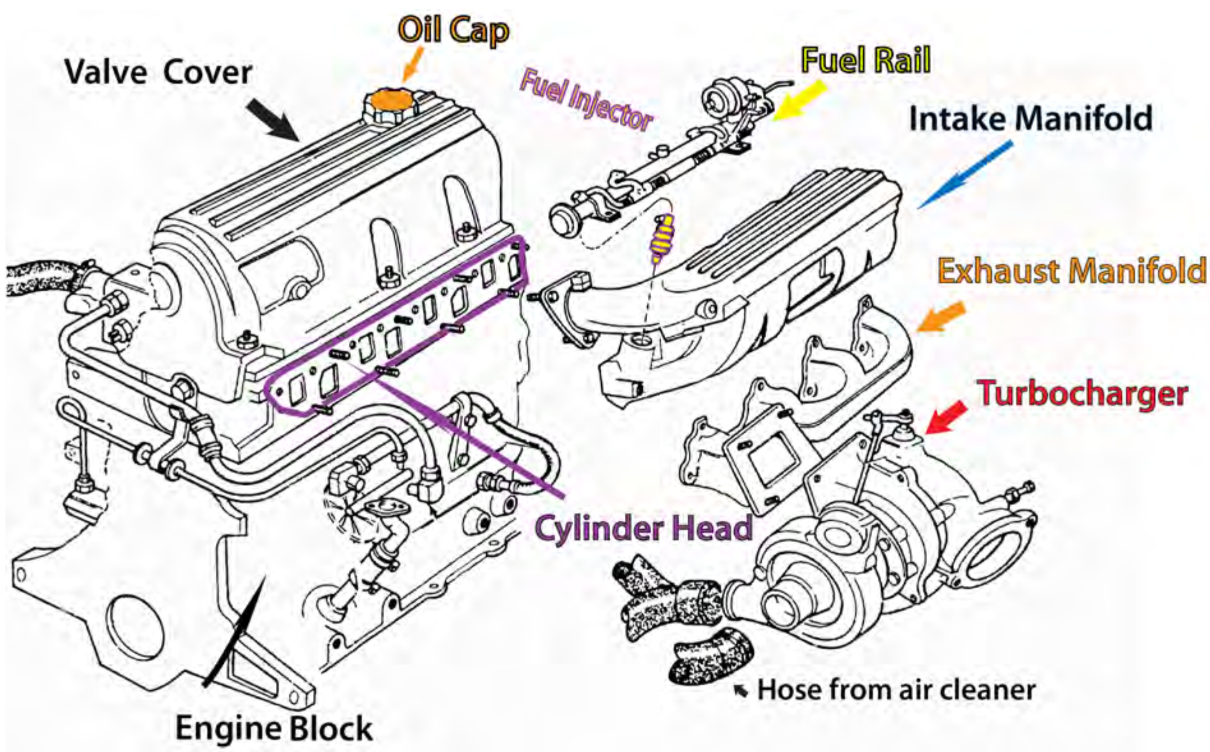


Figure 4-11 . Location of a turbocharger on an engine.

Refer to figure 4-12. To control the boost pressure and prevent overboost, an exhaust waste gate is incorporated in the system. This is an example of a pneumatically operated wastegate. Refer to figure 4-13 for an example of a westgate controlled by the PCM.

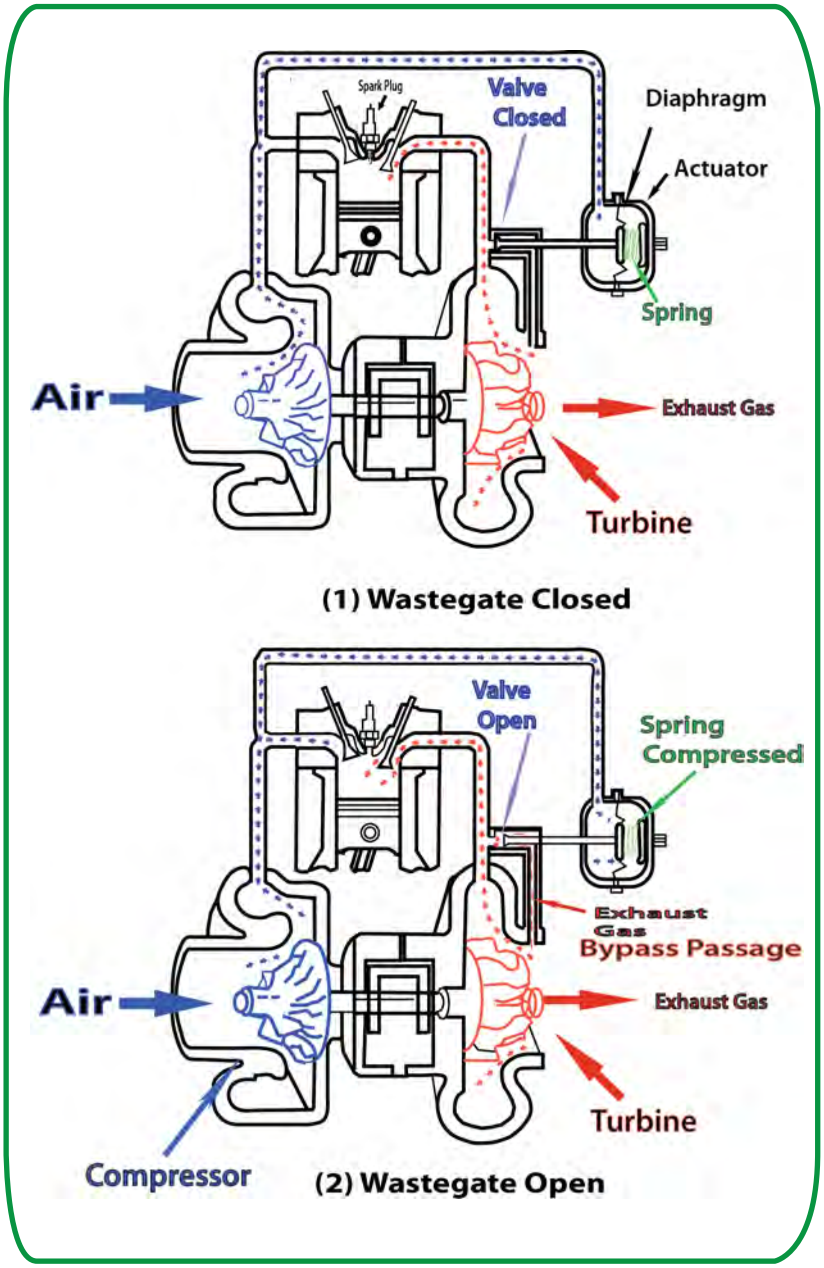


Figure 4-12. This is an example of a wastegate which limits boost pressure pneumatically.

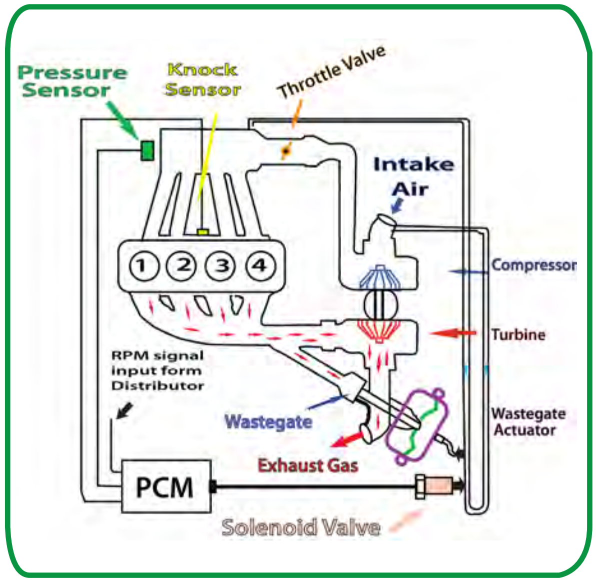


Figure 4-13. This is an example of a wastegate controlled by the PCM, which limits boost pressure pneumatically.

A pneumatic wastegate system is worked by air. Refer to figure 4-12. When the boost pressure exceeds spring force, the valve opens and exhaust gasses exit by the bypass passage. This prevents boost pressure from increasing and limits the pressure. PCM controlled wastegates have a pressure sensor in the intake manifold. When the sensor signals the PCM that the pressure is too high, the PCM actuates a solenoid (electric switch) which opens the exhaust bypass passage there by reducing boost pressure and preventing over boost.

When air is compressed, it becomes hot. The hot air expands and becomes less dense; as a result, the air contains less O_2 for combustion. To cool the compressed air and increase its density, most turbocharged systems have an intercooler. The intercooler is usually an air to air heat transfer device. Hot air flows through the internal passages of the intercooler much like the coolant in a radiator. Cooler outside air flows through the intercooler fins and cools the hot compressed air inside the intercooler.

As with superchargers, turbochargers can cause detonation. To prevent this many systems have a knock sensor. A knock sensor is a sensor designed to vibrate at approximately the same frequency as engine knock. This signals the PCM to retard the timing.

Turbocharger Lag

When an engine accelerates, there are one or two seconds before the exhaust flow develops enough energy to accelerate the turbine due to the inertia of the exhaust gas. This is called 'turbo lag'. Engine manufactures have come up with various solutions to solve this problem. One of the solutions is to use lighter parts. Smaller, lighter parts reduce turbo lag. Another solution is to vary the angle at which the exhaust gas strikes the turbine blades. No wastegate is needed to control boost pressure when so called "variable geometry turbochargers" are installed on an engine. Both boost and turbine speed are controlled by moving vanes.
The use of two small turbines instead of one is another method used to control boost pressure. These are called twin-turbo or bi-turbo engines.
The shaft of a turbocharger rotates so fast that the bearings have their own oil supply to keep the bearings lubricated and cool. Some turbocharger systems use coolant flowing through the bearing housing to cool the bearings in additon to lubricating oil.

Diesel Turbochargers

A diesel engine runs with an unthrottled air intake. The fuel injection pump of a diesel engine is calibrated and governed to inject the correct amount of fuel taking into account the engine load, speed and intake air volume. A diesel turbocharger is mounted on the inlet of the intake manifold. The turbocharger compresses the intake air and increases its density. The fuel injection pump of a turbo diesel engine has a manifold pressure compensator, which varies the amount of fuel injected as a function of intake air pressure. The manifold pressure compensator is a pressure operated diaphragm that moves a governor linkage. The compensator regulates fuel metering by responding to changes in manifold pressure by the combined effect of turbo boost pressure and atmosphere pressure. Turbo boost pressure changes independently of atmospheric pressure. Atmospheric pressure decreases as altitude increases and increases as altitude decreases.

SECTION 5

Exhaust System

When the mixture is burnt in the cylinder, the exhaust gasses exit through the exhaust valve and enter the exhaust manifold on to the catalytic convertor to the muffler and exit the exhaust system by the tail pipe. Refer to figure 5-1.

The function of the exhaust system is to:

1. Route poisonous exhaust gasses to the rear of the vehicle.
2. Suppress exhaust noise (Muffler Resonator). Refer to figure 5-2.
3. Regulate engine temperature by warming the air entering the engine and there by the air fuel mixture of a cold engine for quicker warm up and less exhaust gas pollution. The most common system is the TAC (Thermostatic Air Cleaner) System which routes hot air from the exhaust manifold into cold engines.
4. Convert poisonous gasses to non poisonous gasses using a (CAT) Catalytic Converter which converts HC and CO to O_2 and CO_2, and a (TWC) Three Way Catalyst which additionally reduces NO_x.

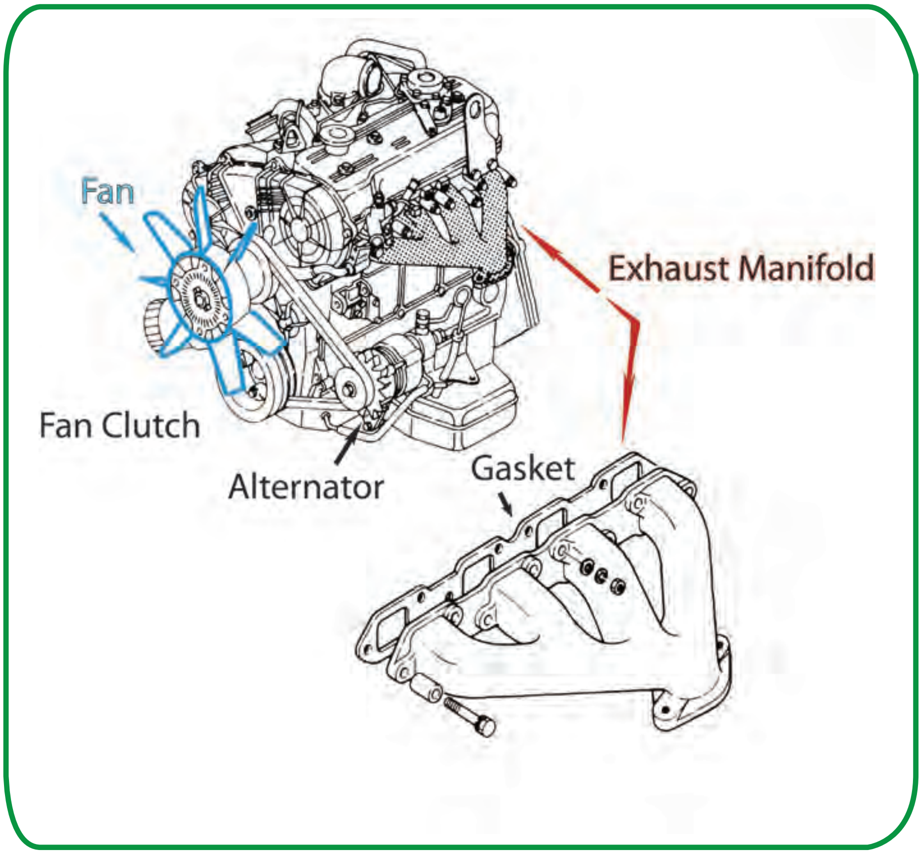


Figure 5-1. The left side exhaust manifold of a V-8 engine which has two exhaust manifolds.

Some engines use a single exhaust system with one or two mufflers. Others use a dual exhaust system with two or four mufflers. The two small mufflers are called resonators. Resonators cancel out sound frequency waves and are designed to work best in the frequency range where the engine makes the most noise.

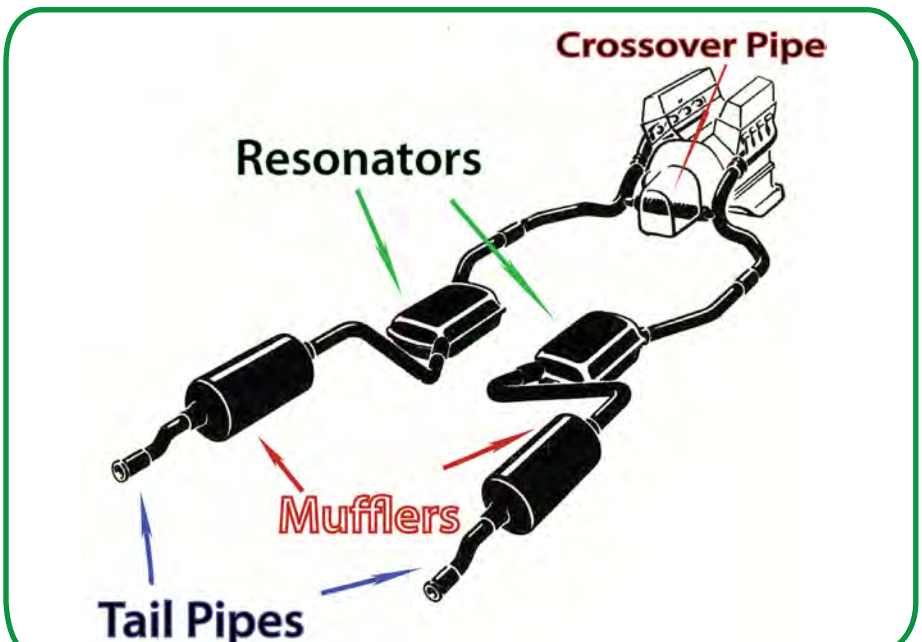


Figure 5-2. This is an example of a dual exhaust system using a crossover pipe, two resonators, and two mufflers.

The function of a muffler is to reduce noise while developing the least amount of a specified exhaust back pressure.

Mufflers have two basic designs:

1. Mufflers with several baffled chambers to suppress sound. Refer to figure 5-3.
2. Glass Pack and Steel Pack mufflers have a straight through design. The exhaust goes through a perforated pipe surrounded by glass, wool or metal shavings. Refer to figure 5-4.

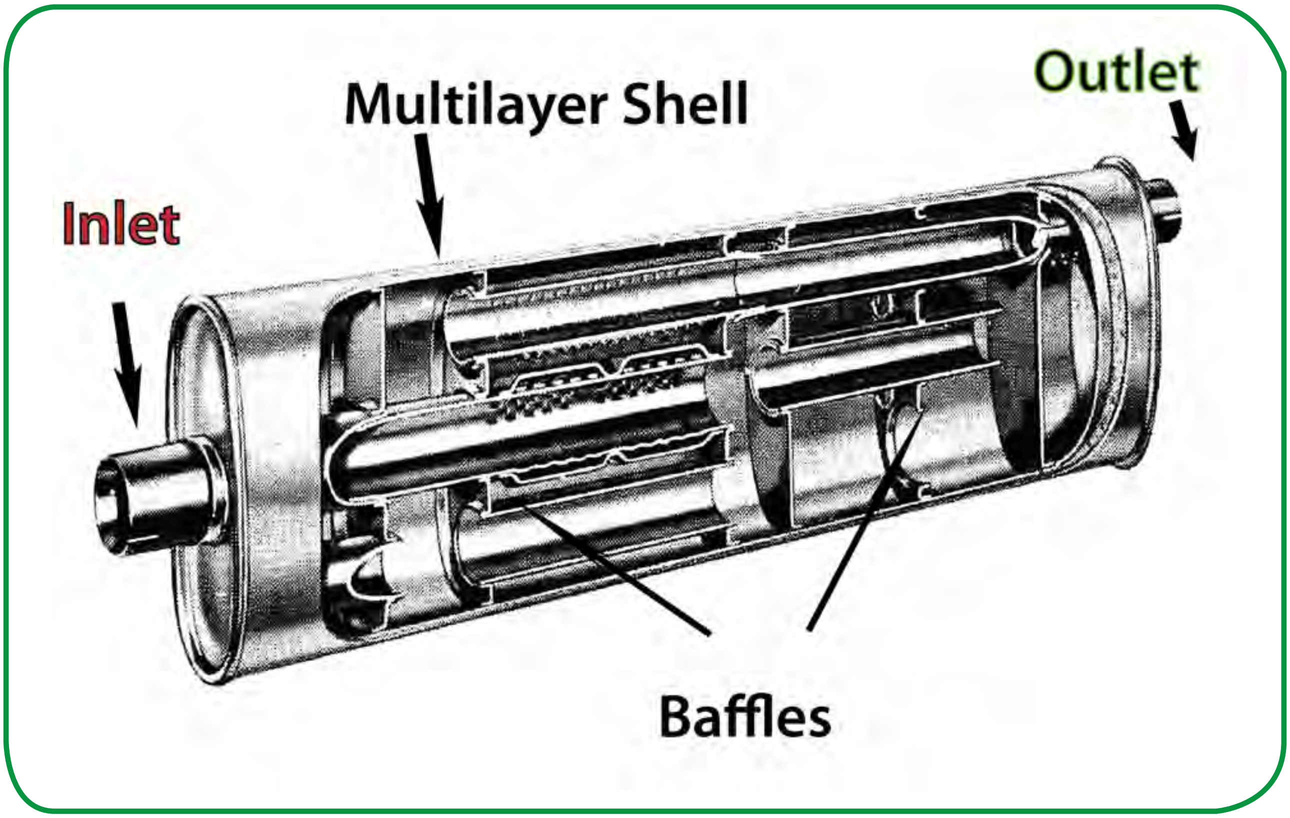


Figure 5-3. A muffler using baffles.

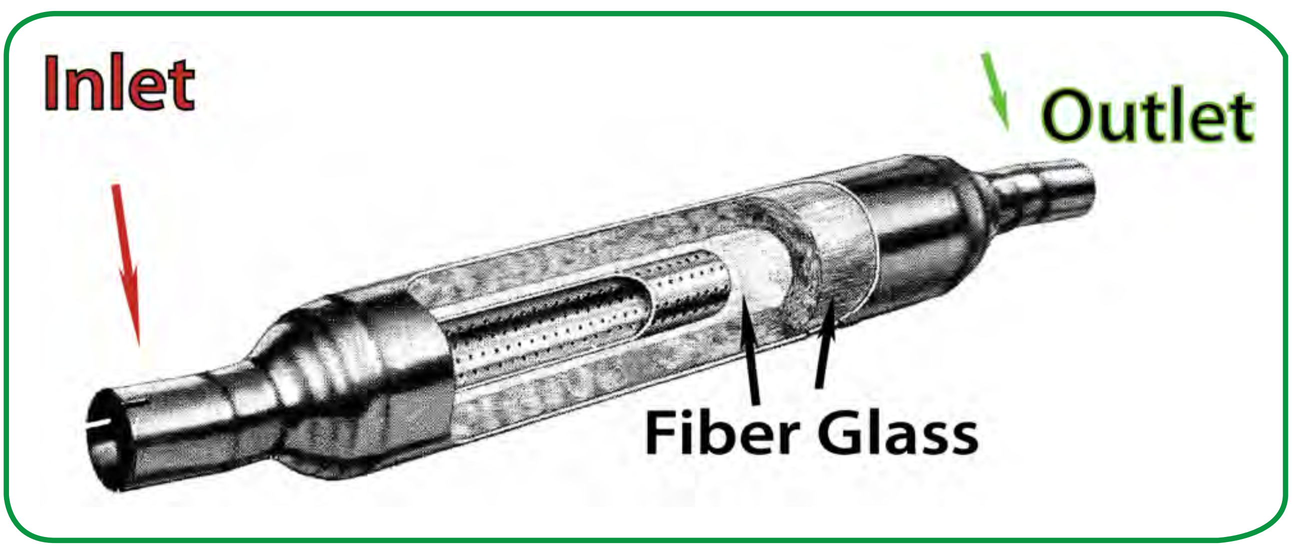


Figure 5-4. An example of a "straight-through"muffler . Heavy fiber glass packing is used around a perforated tube.

There are basically three exhaust system configurations.

1) Inline: One exhaust manifold connected to a single catalytic converter, muffler and system of exhaust pipes.

2) Single V-configuration: The engine has two exhaust manifolds. One is attached to each cylinder head. These engines usually have a crossover or a Y-pipe behind the engine that connects the exhaust gasses from each manifold.

3) Dual V-configuration: The engine has separate exhaust manifolds, catalytic converters, mufflers and pipes for each cylinder head.

Refer to figure 5-5.

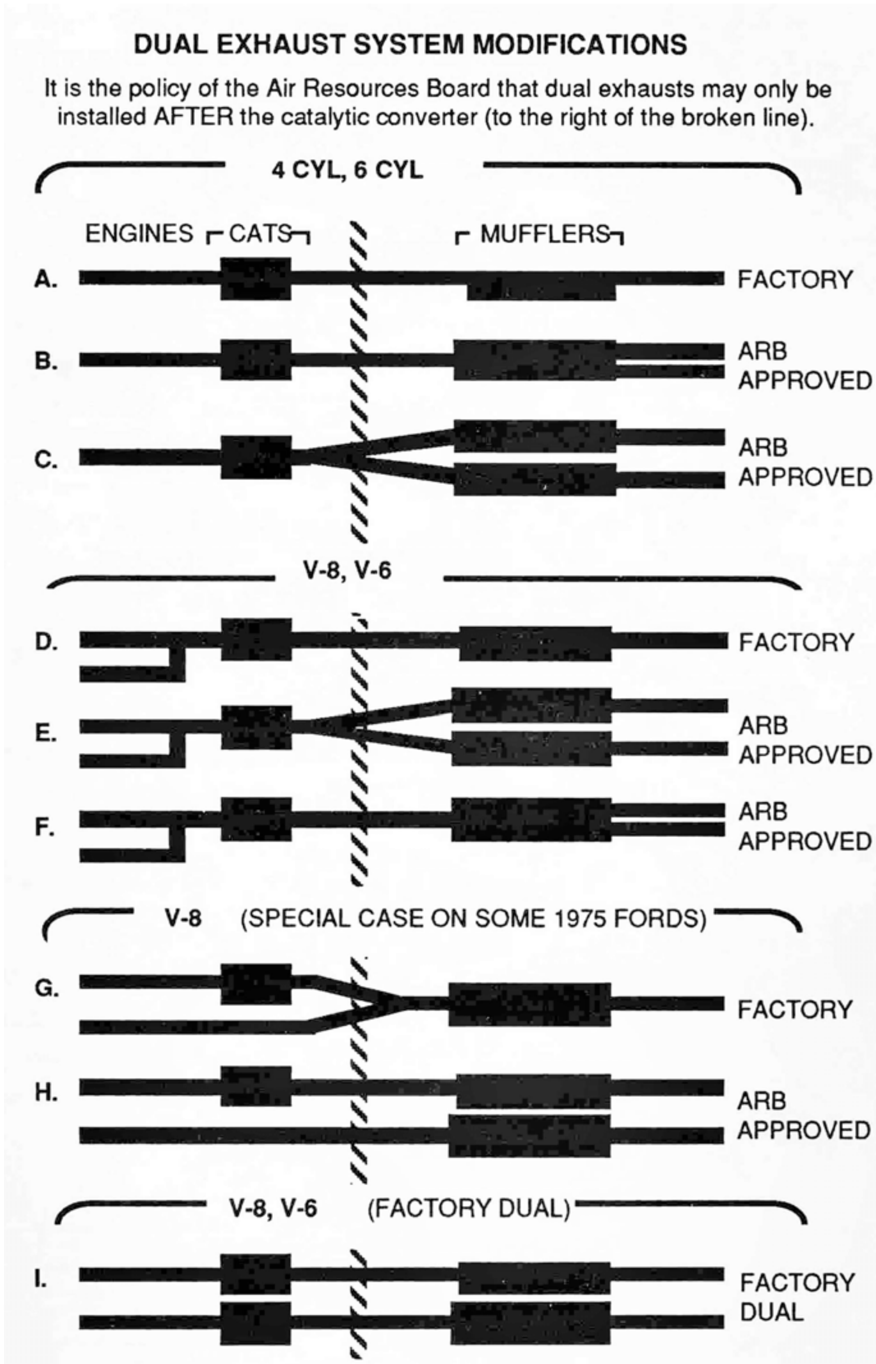


Figure 5-5. Dual exhaust system modifications.

A Catalytic Converter (CAT) is easily identifiable from mufflers and resonators because they have heat shields. Refer to figure 5-6 for an example of the location of a CAT and its heat shields.

Refer to figure 5-7 for an example of exhaust headers. Exhaust headers reduce backpressure and increase exhaust flow. They may be an illegal modification depending on the vehicle.

Note: Through the Air Injection Tube, which goes into the catalytic converter, air is routed into the middle of the Three Way Catalytic Converter (TWC) in order to help reduce HC and CO by adding O_2. Refer to figure 4-8 for a cut away view of a catalytic converter, and refer to figure 5-9 for a photo of a catalytic converter.

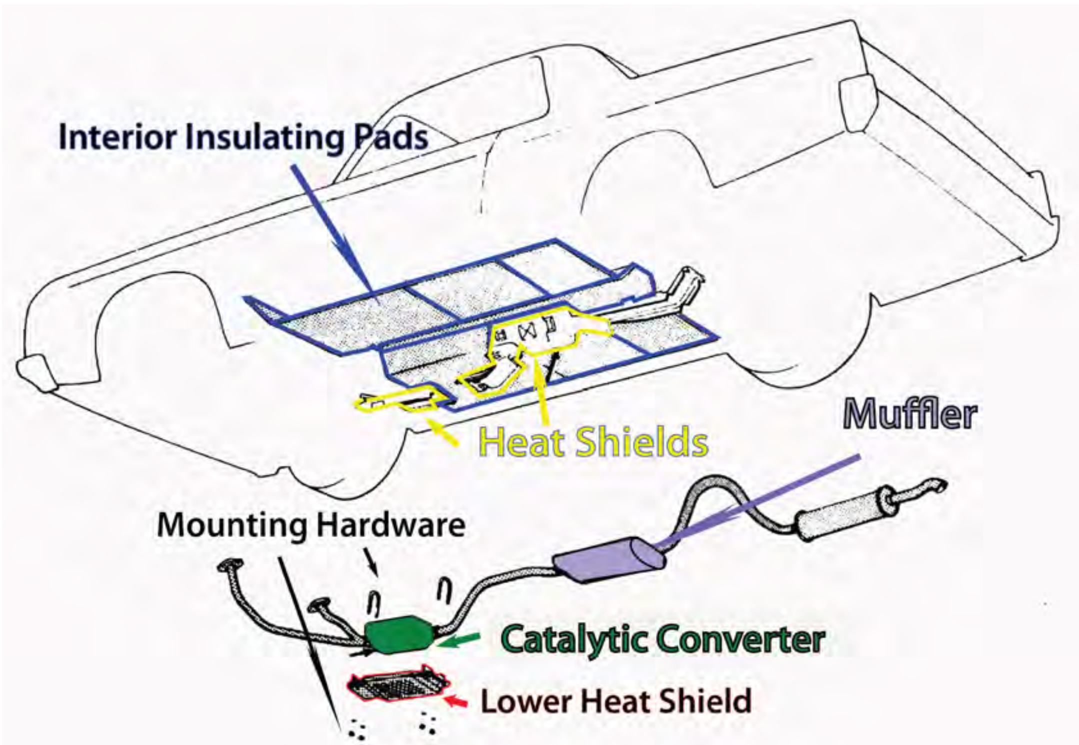
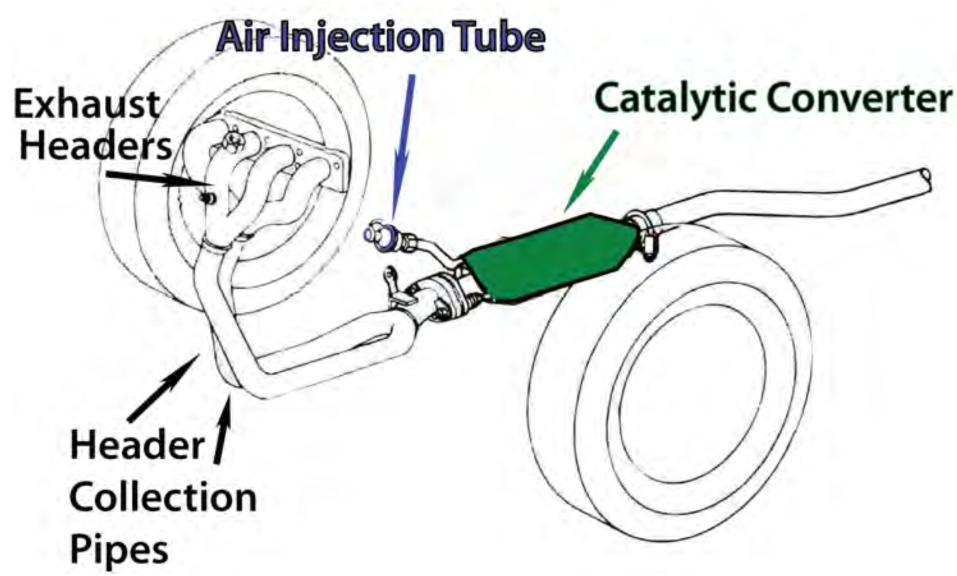


Figure 5-6. This is an example of the location of a CAT and its heat shields.

Figure 5-7. This is an example of exhaust headers. Exhaust headers reduce back pressure and increase exhaust flow.



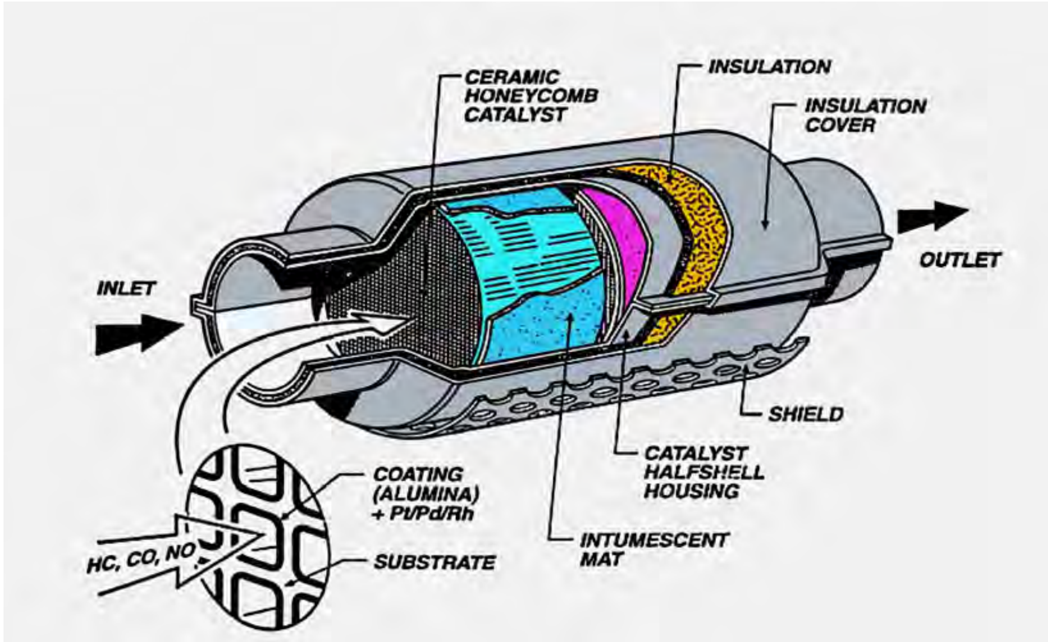


Figure 5-8. Cut away diagram of a catalytic converter.

Figure 5-9. Photo of a catalytic converter.

The entire exhaust system is held in place and together by clamps, brackets and welds.

SECTION 6

Electrical Circuits & Ohm's Law

Electrical Circuits

Electricity is essential to the smooth operation of an automobile. Whether it is an electric light bulb or a fuel injector, the correct voltage, current, and resistance is essential for correct operation of the device in a circuit.
All electrical circuits consist of:

1) A resistor
A resistor can be a light bulb, horn, solenoid, fuel injector, or any other electrical component.

2) A source of voltage
The voltage source can be a battery or an alternator /generator.

3) A conductor
The conductor is usually a copper or aluminum wire. A conductor is a material through which electricity flows easily with little resistance. Positive conductors are covered with insulation. An insulator is a material through which electricity flows with difficulty. Good insulating material is called dielectric.
Current flow from positive to negative is used in this book as it is used in the auto industry. Refer to figure 6-1

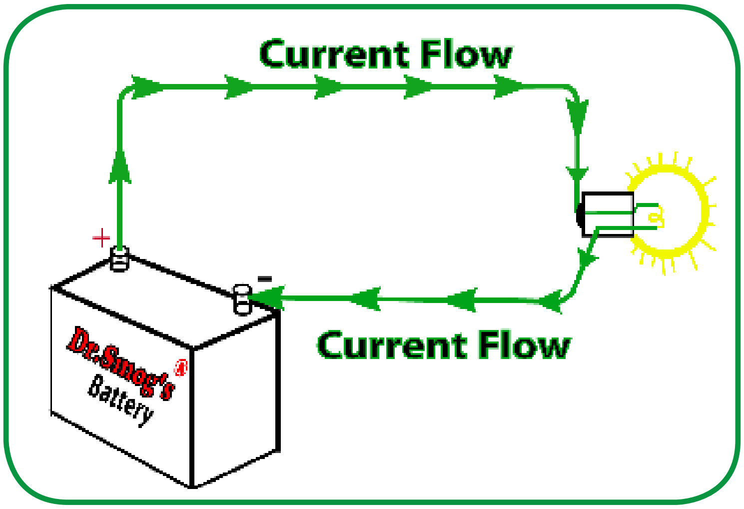


Fig.6-1 Current flows from positive to negative.

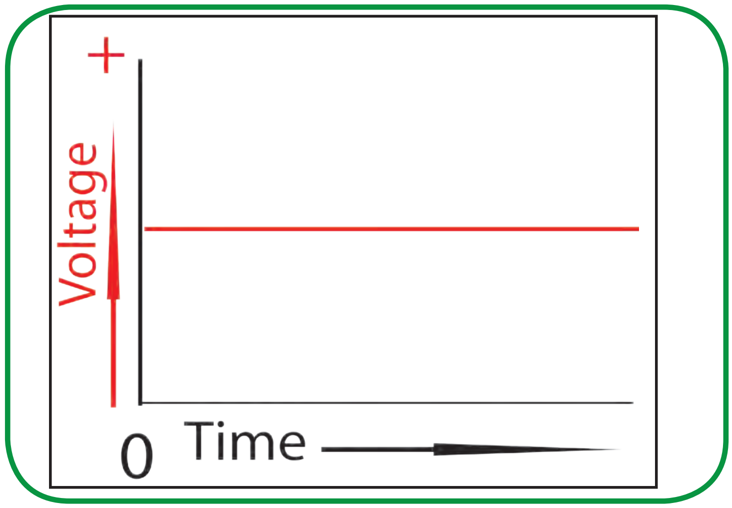


Fig.6-2 Direct Current (DC) flows in one direction.

Types of electricity

There are two types of electricity. Static electricity is an electric charge at rest (there is no electron flow), and dynamic electricity is when electrons flow. There are two types of current flow, AC and DC. An automobile battery produces a DC current (refer to figure 2-2), and an automobile alternator produces AC current. However, this AC current is rectified to DC for use by the automobile electrical system. Household electricity is AC. Refer to figure 6-3.

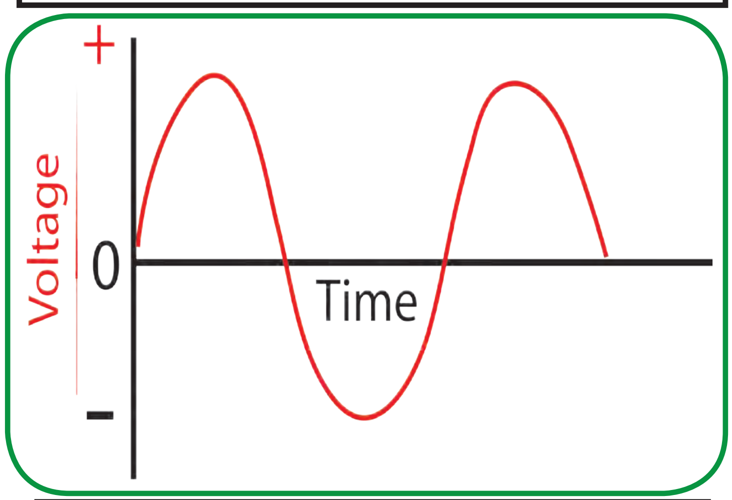


Fig.6 -3 AC current flows from positive to negative and back again.

Current

Current is defined as a flow of electrons through a conductor. Like when water flows in a pipe and there is a difference in pressure at the ends of the pipe, an electric current flows in a conductor because of a difference in electrical pressure at the ends of the conductor. In an electrical circuit, a large number of electrons at one point will cause a current to flow to another point where there are a smaller number of electrons, if the two points are connected by a conductor. The unit of measure for current in electricity is the ampere, and the flow of electricity through a circuit is called current.

Voltage

When electron level is higher at one point than another point, there is a difference of potential between the points. When the points are connected by a conductor, electrons flow from the point of high potential to the point of low potential. An analogy is when an automobile tire is inflated; there exists a difference of potential (pressure) between the inside of the tire and the outside. When the valve is opened, the air rushes out. The earth is considered to be electrically neutral, it has no charge. This means that if a positively charged object is connected to the earth, electrons flow from the earth to the object, and if a negatively charged object is connected, the electrons flow from the object to the earth.

The force that causes electrons to flow through a conductor is called electromotive force (EMP or electron moving force). The unit of measure is the volt. When there is a potential difference of electrical pressure between two points it means that a field of force exists, which tends to move electrons from one point to another. If the points are connected by a conductor (wire), electrons will flow as long as the potential difference exists. Potential difference and EMF is measured in volts, so the term voltage is used. For example, an automobile storage battery is 12.0 volts. This means that there is a potential difference of 12 volts between the terminals.

Resistance

Resistance is the property of a conductor to restrict the flow of electric current, and exists in every circuit. Resistance is like ***electrical friction*** because it affects the flow of electricity in a manner similar to the effect of friction of mechanical objects. For example, if the interior of a water pipe is very rough because of rust, a smaller amount of water will flow through the pipe at a given pressure than if the pipe were clean and smooth. The same is true for electrical current. If strands of wire are broken or if there is corrosion at a connector the flow of electrons is stopped completely or meets resistance and less current flows.

The unit of measure for resistance in electricity is the ohm. The symbol for ohms is the Greek letter **omega (Ω)**.

Sources of Voltage

Voltage is required whenever electrons are to be moved. Some types of energy must be converted into a form able to move electrons along a conductor. A source of voltage has a greater potential of electrons at one point than another. This potential is created when electrons are freed from their atoms by :

a) Chemical Action

An automobile storage battery converts chemical energy directly into electricity. A battery is made up of two electrodes and an electrolyte solution. Chemical action within a cell causes the electrolyte to react to the two electrodes. The result is that electrons are transferred from one electrode to another. This produces a positive and negative charge at the electrode terminals of the cell.

The lead acid storage battery is the main source of electrical energy in a vehicle, when the engine is not running or being started. It is called a storage battery because it stores chemicals that cause the reaction needed to produce voltage at its terminals. An automobile storage battery has six cells of 2.13 volts each connected in series, which results in a voltage of 12.78 volts. The cells can be recharged by sending current into the battery in the reverse direction.

b) Friction
EMF/Voltage generated by friction is called static electricity. Electrons rubbed on one material remains on the surface of another material. The material that gains the electrons is said to be positively charged. A spark occurs when the charged material comes close to an uncharged or grounded material. Automotive components such as the PCM can be damaged by the charge from static electricity.

c) Heat
Energy from heat can free electrons from the junction of two different metals and result in the production of a small voltage. Some automobile temperature sensors operate on this principal.

d) Light
Light energy can free electrons from material with photoelectric properties. Applications on automobiles include optical distributors, which use a disk with slots to let light from LEDs alternatively block and strike photodiodes. This switching on and off creates an AC voltage. Sensors for headlights are another application light energy.

e) Magnetic Action.
When a conductor is moved through a magnetic field, a voltage is produced in the conductor. This is called electromagnetic induction and is used by an automobile charging system's alternator to generate voltage and current. The alternator is the main source of voltage, when the engine is running.

f) Pressure
A small voltage can be produced when certain types of crystals are put under pressure. When voltage is produced by pressure, it is called a piezoelectric effect. Automotive applications include MAP and knock sensors.

Ohm's Law

Ohm's law is a mathematical expression of the relationship between voltage (E), current (I), and resistance (R).

$I=\frac{E}{R}$ $\quad$ $\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$

$E=I \times R$ $\quad$ $\text{Volts} = \text{Amperes} \times \text{Ohms}$

$R=\frac{E}{I}$ $\quad$ $\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$

Electrical Circuits

There are three types of electrical circuits commonly used in automobiles.

1) Series circuits
2) Parallel circuits
3) Series-parallel circuits

However, they all require the same basic components.

a) A power source that is either a battery or generator/alternator, which is a source of voltage.
b) Conductors, which are the wires and printed circuits, provide a path for the current to flow.
d) Loads that change electrical energy into another form of energy to perform work. Control devices such as relays and switches turn the current flow on and off and other protection devices. Circuit breakers, fuses, and fusible links interrupt current flow, if it becomes high enough to damage conductors or components.

1) Series Circuit

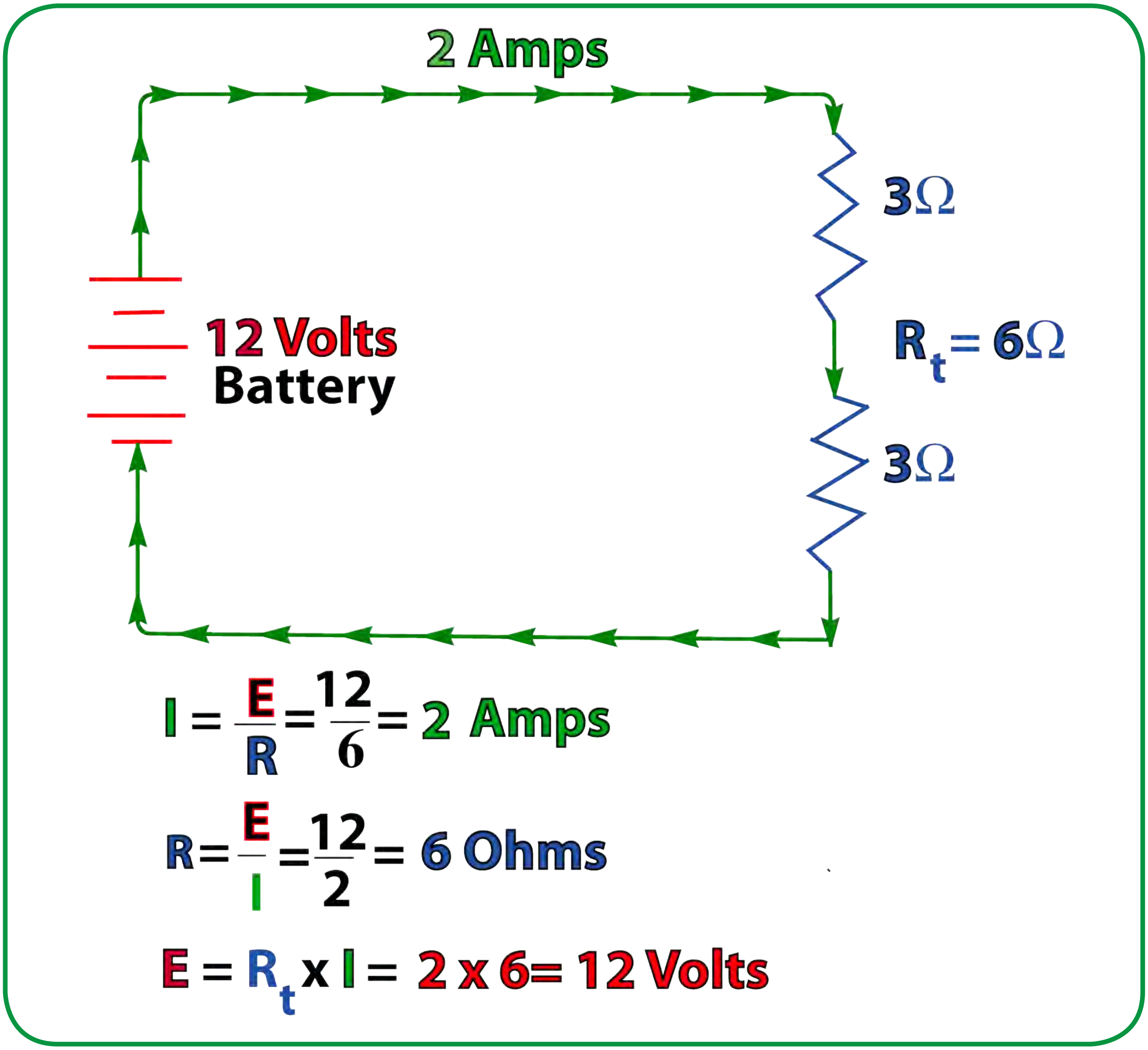


Fig. 6-4. Series Circuit.

A series circuit is one in which current flows through the circuit in one continual path. Current which flows through one resistor flows through the other resistors in the circuit.

a) Current is constant in a series circuit, so current through each resistor is the same.
b) Voltage drop across each resistor will be different, if the resistance values are different.
c) The sum of the voltage drops equals the source voltage.
d) The total resistance is equal to the sum of the individual resistors/components. Refer to figure 6-4.

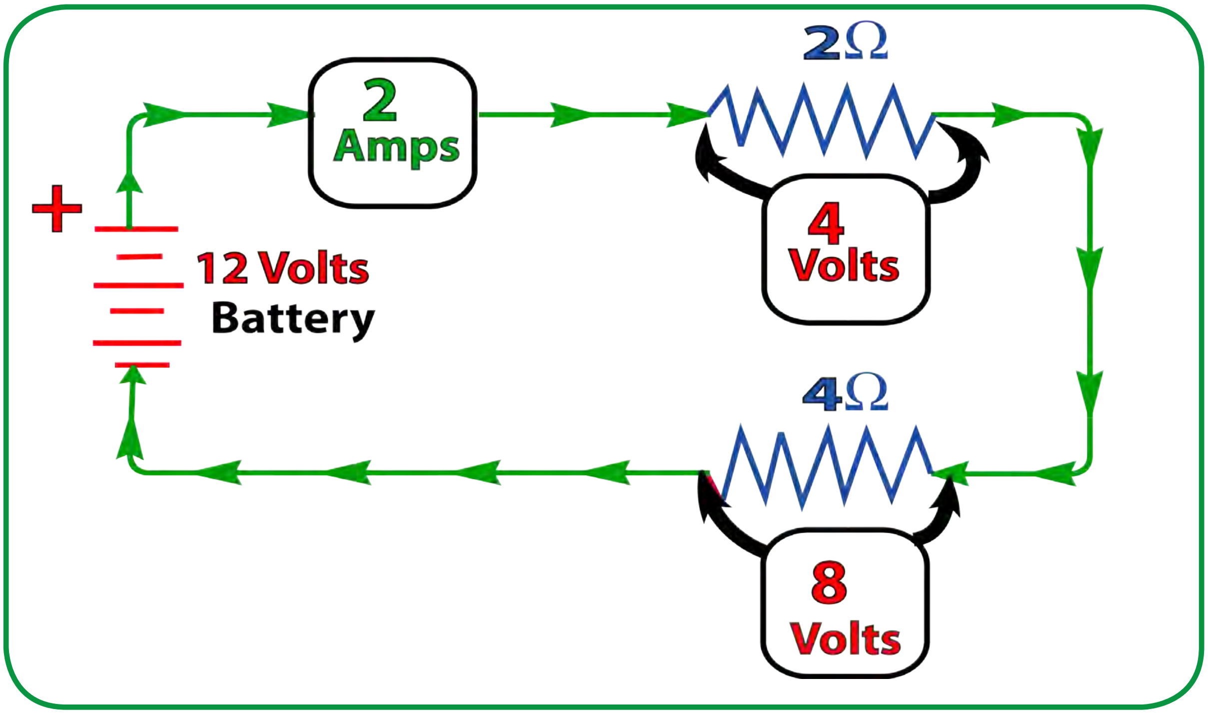


Fig. 6-5. Series Circuit.

Refer to figure 6-5.

The series circuit consists of a 2-ohm resistor and a 4-ohm resistor in series to a 12-volt battery. In a series circuit, all current that flows through one resistor also flows though the other resistors (amps are constant in a series circuit), and the total circuit resistance is equal to the sum of the individual resistors. Ohm's Law can be used to find the total resistance and then find the total amps.

$R_t = R1 + R2$

In this circuit:

$R_1 =$ 2 ohms

$R_2 =$ 4 ohms

$R_t =$ 4 ohms + 2 ohms

$R_t =$6 ohms

E=12 volts

<u>Since:</u>

$I = \frac{E}{R}$ $\quad Amps = \frac{Volts}{Ohms} = \frac{12}{6} = 2$

When you apply Ohm's law to the 2 ohm resistor, you can find the **voltage drop** across the resistor. Voltage drop may be defined as the voltage required to overcome the resistance. This could be the resistance in a connector, diode, relay, switch, transistor, wire, or any component in an electrical circuit, for example, the MIL (malfunction indicator light bulb). Applying Ohm's law to figure 6-5:

E= I x R	**E=I x R**	
E= 2 x 2	**E=2 x 4**	E_t**=12 Volts.**
E=4 volts	**E=8 volts**	

Since total voltage in a series circuit is equal the sum of the individual voltages,

If you place an ammeter in this circuit (ammeters are always placed in series in any circuit), it will read 2 amps. If you use a voltmeter across the resistors in this circuit (**to read voltage drop across a resistor always place the meter in parallel**), it will read 4 volts and 8 volts.

2) Parallel circuits

In parallel circuit:

a) There is more than one path for the current to flow.
b) The current through each resistor will be different, if the resistance is different.
c) The sum of the separate currents equals the total current in the circuit.
d) The sum of the voltage drop equals the source voltage.
e) The voltage across each resistor is the same.
f) Total resistance in a parallel circuit is less than the lowest individual resistance.

Refer to figure 6-6. There is a six-ohm resistor and a three ohm resistor connected to a 12 volt battery.
The resistors are in parallel with each other.
The current through each resistor (called a branch of the circuit) can be determined by Ohm's law.

$I_1 = ?$
$R_1 = 6$ ohms
E= 12 volts

$I_1 = \frac{E}{R}$ Amps = $\frac{\text{Volts}}{\text{Ohms}}$ $\frac{12}{6}$ = 2 amps

$I_2 = ?$
$R_2 = 3$ ohms
E = 12 volts

$I_2 = \frac{E}{R}$ Amps = $\frac{\text{Volts}}{\text{Ohms}}$ $\frac{12}{3}$ = 4 amps

$I_t = I_1 + I_2$ $I_t = 2+4$ $I_t = 6$ amps

The equivalent resistance of the entire circuit: $R_t = \frac{E}{I} = \frac{12}{6} = 2$ ohms

The total value of any two resistors in parallel: (R_t) $= \frac{R_1 x R_2}{R_1 + R_2} = \frac{6 \times 3}{6+3} = 2\Omega$

Refer to figure 6-6. There is a six-ohm resistor and a three-ohm resistor connected to a12-volt battery.

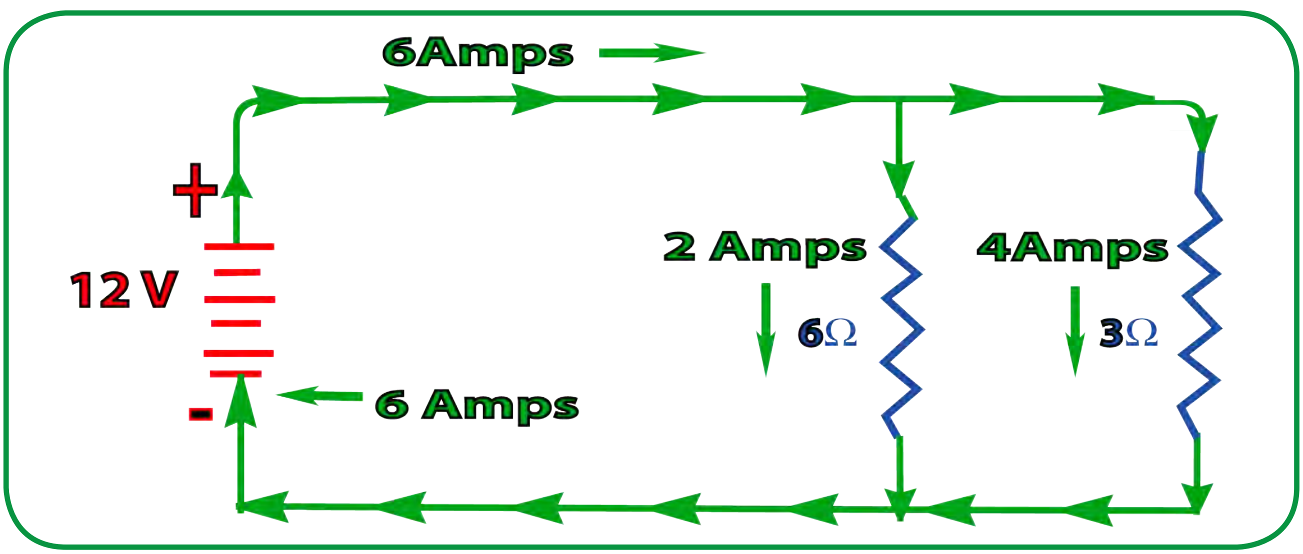


Fig. 6-6. Parallel Circuit. Two resistors.

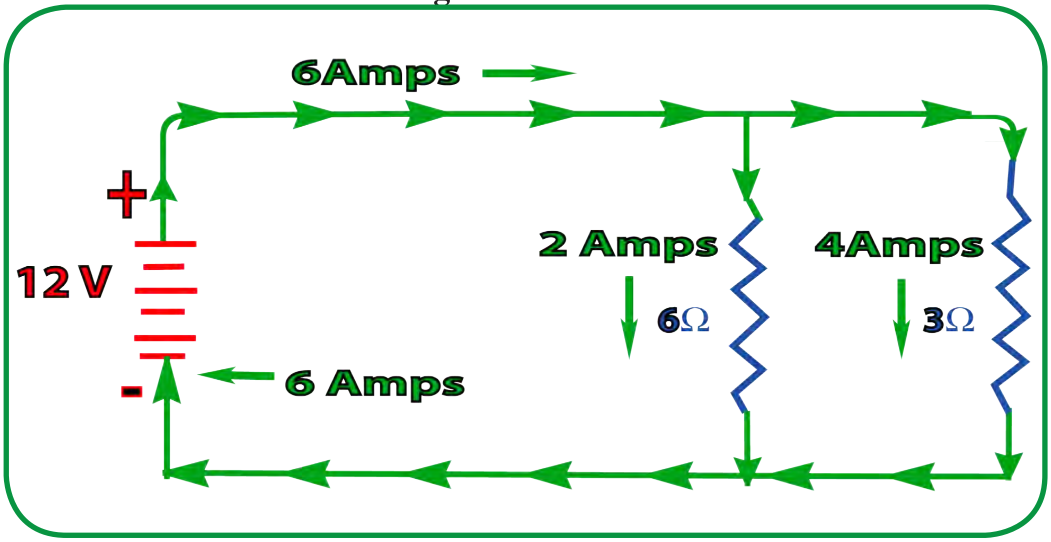


Fig. 6-7. Parallel Equivalent Circuit.

Refer to figure 6-8. This circuit has four resistors in parallel.
The branch currents are:

$I_1 = \frac{E}{R}\ \frac{12v}{6\Omega} = 2$ amps $\quad I_2 = \frac{E}{R}\ \frac{12}{3\Omega} = 4$ amps $\quad I_3 = \frac{E}{R}\ \frac{12}{4\Omega} = 3$ amps $\quad I_4 = \frac{E}{R}\ \frac{12}{4\Omega} = 3$ amps

$I_t = I_1 + I_2 + I_3 + I_4 \quad I_t = 2 + 4 + 3 + 36 \quad \boxed{I_t = 12 \text{ amps}}$

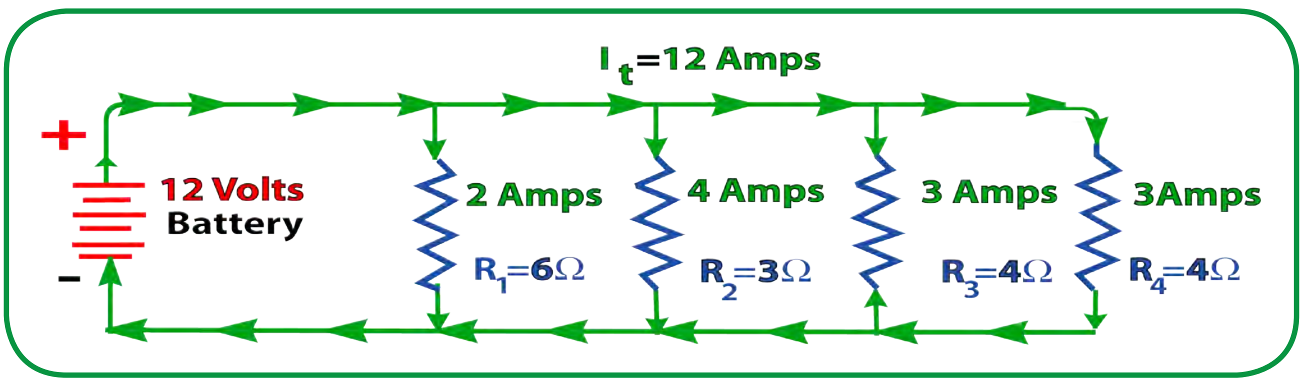


Fig. 6-8. Parallel Circuit with four resistors.

The equivalent resistance of the entire circuit =1Ω

The total value of any two resistors in parallel (R_t) is:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_t = \frac{E}{I} = \frac{12}{12} = 1\ \Omega$$

The resistance is worked out as follows:

$$R_5 = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{6 \times 3}{6 + 3} = 2\ \Omega$$

$$R_t = \frac{R_5 \times R_6}{R_5 + R_6} = \frac{2 \times 2}{2 + 2} = 1\Omega$$

$$R_6 = \frac{R_3 \times R_4}{R_3 + R_4} = \frac{4 \times 4}{4 + 4} = 2\ \Omega$$

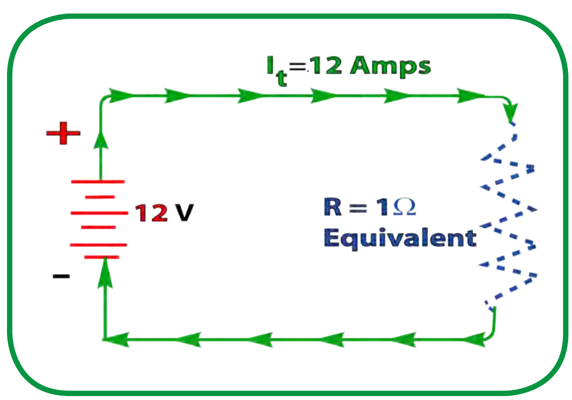


Fig. 6-9. Parallel Circuit four resistor equivalent.

3) Series Parallel circuits

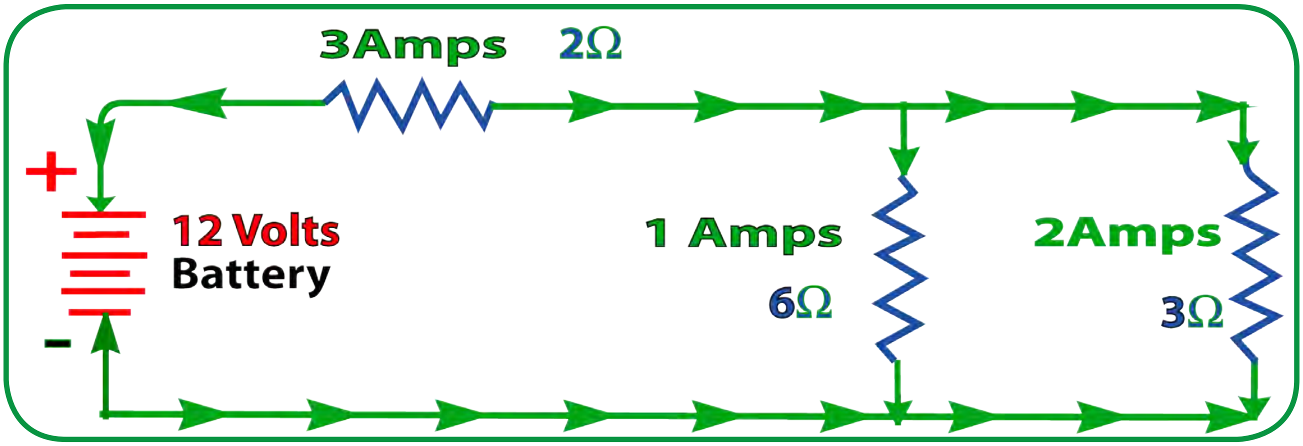


Fig. 6-10. Series Parallel Circuit.

Refer to figure 6-10. This is a series parallel circuit. The six and three ohm resistors are in parallel with each other, and both are in series with the two ohm resistor. The total current in this circuit is equal to the total voltage divided by the total resistance. The six-ohm resistor and the three-ohm resistor are equivalent to a two-ohm resistor.

$$R = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{6 \times 3}{6 + 3} = 2\ \Omega$$

This equivalent two-ohm resistor added to the other 2-ohm resistor ($2\Omega + 2\Omega = 4\Omega$).
Refer to figure 6-11. This is the equivalent circuit.

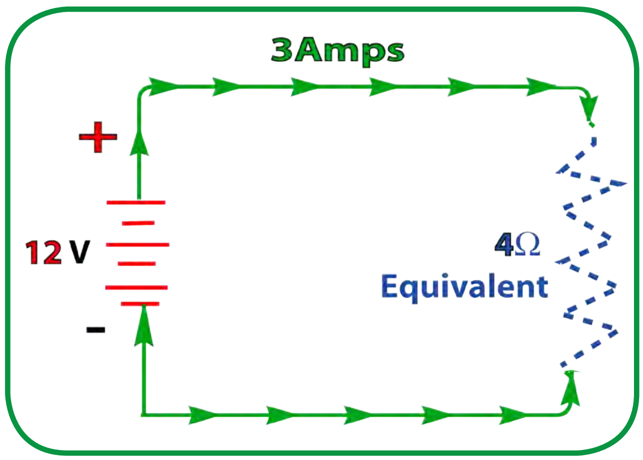


Fig. 6-11. Series Parallel Equivalent Circuit.

$$I_t = \frac{E}{R} = \frac{12}{4} = 3 \text{ amps}$$

There are three amps flowing through the 2 ohm resistor that is closest to the battery. The voltage drop across this resistor is:

$E = I \times R$

$E = 3 \times 2$

$E = 6$ volts

This leaves six volts across the six and three ohm resistor.
The current through the 6 ohm resistor is:

$$I = \frac{E}{R} = \frac{6}{6} = 1 \text{ amps}$$

The current across the 3 ohm resistor is:

$$I = \frac{E}{R} = \frac{6}{3} = 2 \text{ amps}$$

The total current must be equal to the sum of the two currents.
Therefore, the total current is: $I_t = (1+2) = 3$ amps

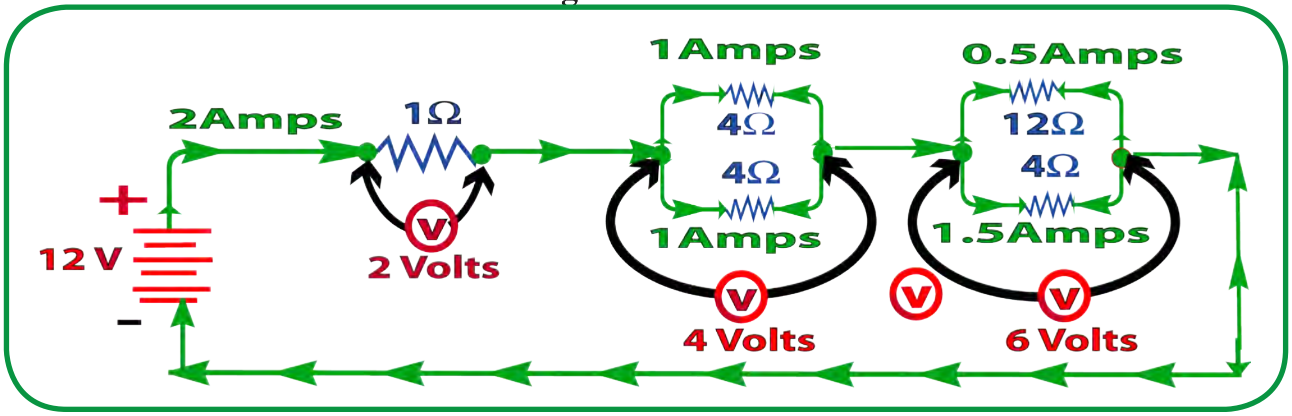


Fig. 6-12. Series Parallel Circuit.

Refer to figure 1-12. The equivalent circuit resistance is calculated as follows:

$$R = \frac{R_1 x R_2}{R_1 + R_2} = \frac{12 \times 4}{12 + 4} = \frac{48}{16} = 3\ \Omega$$

$$R = \frac{R_1 x R_2}{R_1 + R_2} = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\ \Omega$$

Add these two-ohm values to the **Ω** resistor $R_t = (3\ \Omega + 2\ \Omega + 1\ \Omega)$

$R_{t|} = 6\Omega$.

Refer to figure 6-13 for the equivalent circuit.

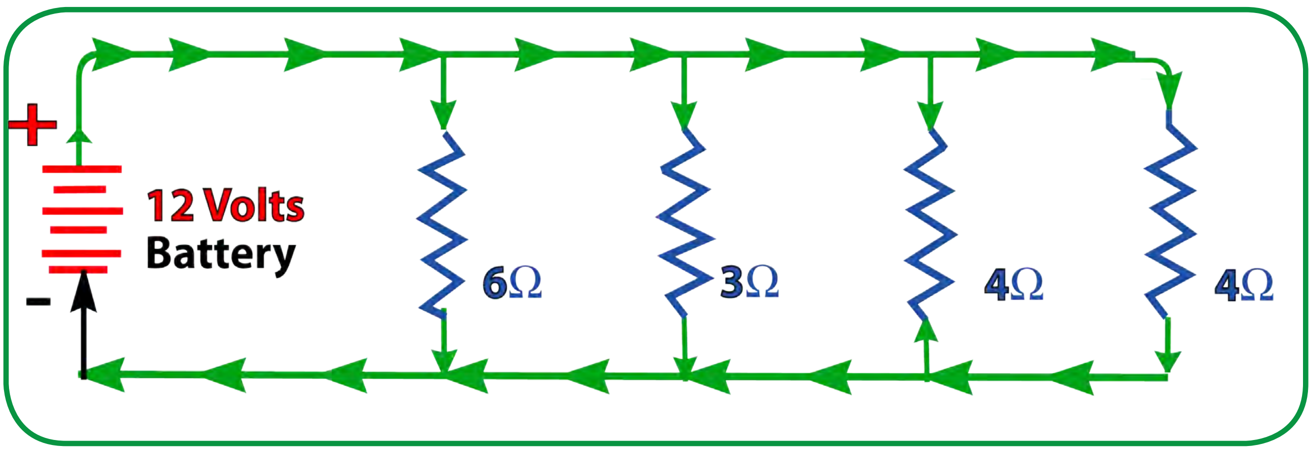


Fig. 6-13. Series Parallel Equivalent Circuit.

The total current is :

$$I_t = \frac{E}{R} = \frac{12}{6} = 2 \text{ amps}$$

The voltage drop across each resistor in the equivalent circuit is shown and calculated as follows:

E=IxR	E=IxR	E=I x R	
E=2x3	E=2x2	E=2 x 1	E_t= 12 volts
E=6 volts	E=4 volts	E=2 volts	

A six-volt drop across the equivalent 3 ohm resistor means here is a 6 volt drop across the 12 ohm and 4 ohm resistor in the actual circuit. The branch currents are:

$$I = \frac{E}{R} = \frac{6}{12} = 0.5 \text{ amps} \qquad I = \frac{E}{R} = \frac{6}{4} = 1.5 \text{ amps}$$

In the same way, the branch currents flows through each of the 4 ohm resistors: $I = \frac{E}{R} = \frac{4}{4} = 1$ amp

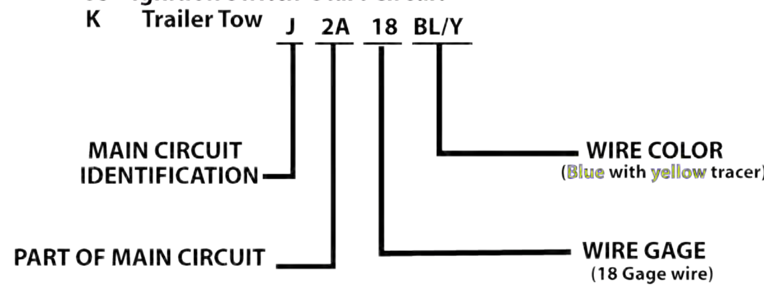
Refer to figure 6-14 for an example of a wiring identification diagram.

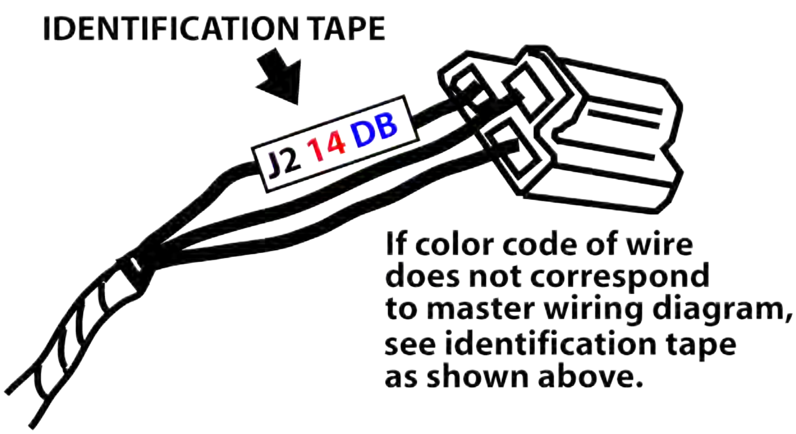
WIRING COLOR CODE CHART

COLOR CODE	COLOR	STANDARD TRACER COLOR	COLOR CODE	COLOR	STANDARD TRACER COLOR
BK	BLACK	WH	PK	PINK	BK or WH
BR	BROWN	WH	RD	RED	WH
DB	DARK BLUE	WH	TN	TAN	BK
DG	DARK GREEN	WH	VT	VIOLET	WH
GY	GRAY	BK	WT	WHITE	BK
LB	LIGHT BLUE	BK	YL	YELLOW	BK
LG	LIGHT GREEN	BK	*	WITH TRACER	
OR	ORANGE	BK			

CIRCUIT IDENTIFICATION CODES

A1 Battery Circuit to Ammeter
A2 Battery Circuit to Ammeter
B Back Up Light Circuit
C Air Conditioning and Heater
D Emergency Stop Light and Turn Signal Circuit
E Instrument Panel Cluster, Switches
F Radio Speakers and Power Seats Circuits G
G Gages and Warning Light Circuits
H Horn Circuit
J Ignition System Run Circuit
J1 Ignition Switch Feed Circuit
J3 Ignition Switch Start Circuit
K Trailer Tow





METRIC SIZE	AWG GAUGE
.22	24
.35	22
.5	20
.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13.0	6
19.0	4
32.0	2

Fig. 6-14. Circuit and wire code identification information charts.

How to use a Voltmeter

Automotive circuits are called ground return systems because the metal frame and body are used as a return path to complete the circuit. On the groundside, current flows through insulated wires and various loads. Voltmeters are used to measure the electromagnetic force (EMF) that is voltage.

Refer to figure 6 -15.

Voltmeters are used for:

1) Measuring source voltage in a circuit (no load voltage)
2) Measuring voltage at any point in a circuit
3) Measuring differential voltage between two points.
4) Measuring voltage drop across connectors, relays solenoids, switches, terminals, or other loads.
5) To check continuity.

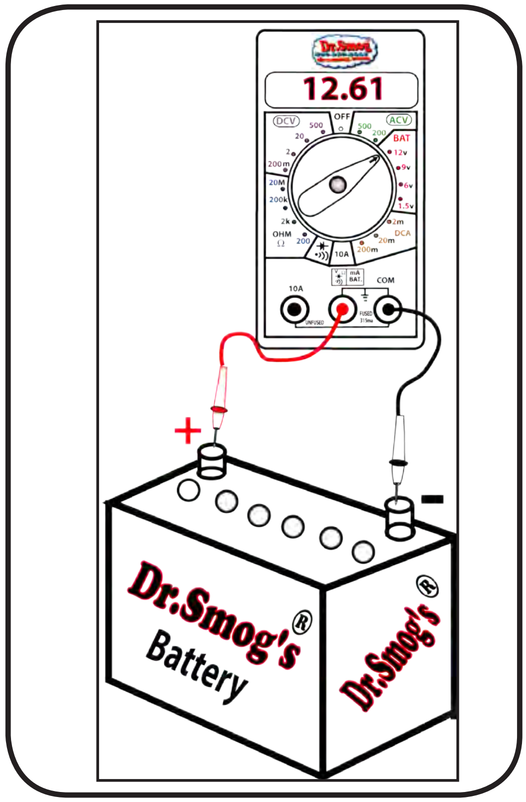


Fig. 6-15. Measuring the battery's state of charge (open circuit voltage) with no load by applied using a DVOM. Voltage <12 volts is a discharged battery.

Voltmeters are normally connected in parallel with the circuit or load, except when checking continuity when a voltmeter is connected in series. Refer to figures 6-16 and 6-17.

If your voltmeter shows normal system voltage, the circuit is complete between the test point and ground. If your DVOM shows no voltage, the circuit is open (no continuity) between the test points and ground. An over-range indicator is a feature on some DVOMs. Over-range is indicated by an OL or a 1 to the far left of the screen. Meters must be connected in the correct polarity to avoid damage. DVOMs will show a minus sign, if the polarity is incorrect. It is best to maintain correct polarity, when using a voltmeter.

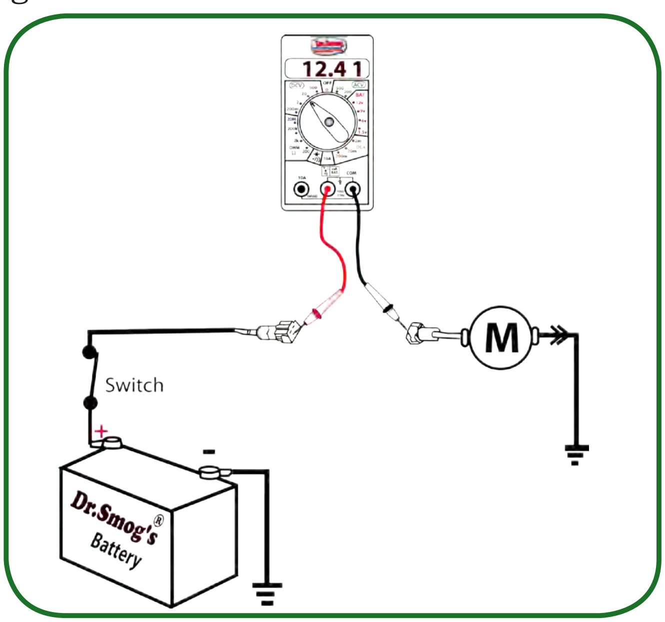


Fig. 6-16. DVOM measuring voltage in a series. Warning unexpected high current can damage meter.

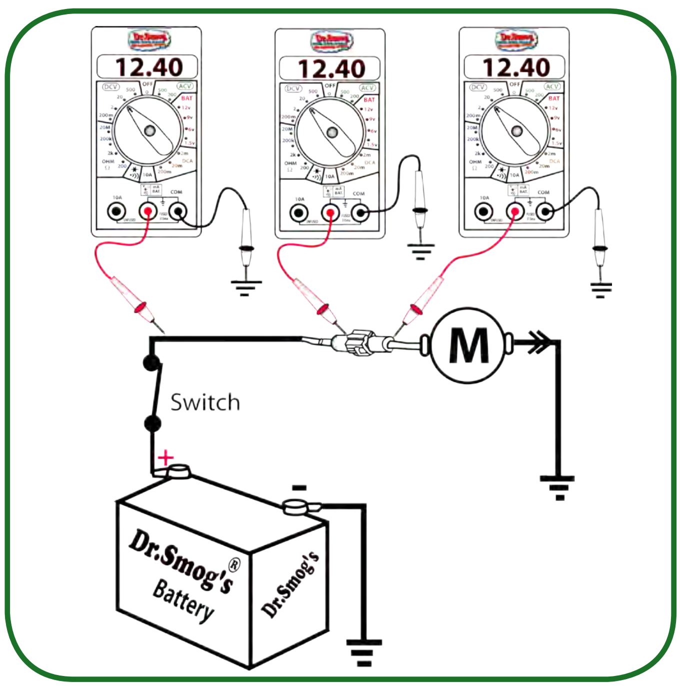


Fig. 6-17. DVOM measuring voltage in parallel.

SECTION 7

Ignition Systems

The function of the ignition system is to deliver the correct level of voltage at the electrodes of the spark plugs so that the gap between the electrodes is arced (jumped). Voltage in the region of 20,000 volts and up is required to create a spark for complete combustion.

There are many design configurations used by manufacturers, but all have a primary and secondary electrical circuits. The primary circuit uses battery voltage to control the events required to provide the system with the high voltage at the correct time. The secondary circuit increases 12 volt battery voltage to up to 50,000 volts and distributes it to each cylinder through the specially designed, thickly insulated spark plug wires. Refer to figure 7-1 for an example of an ignition circuit.

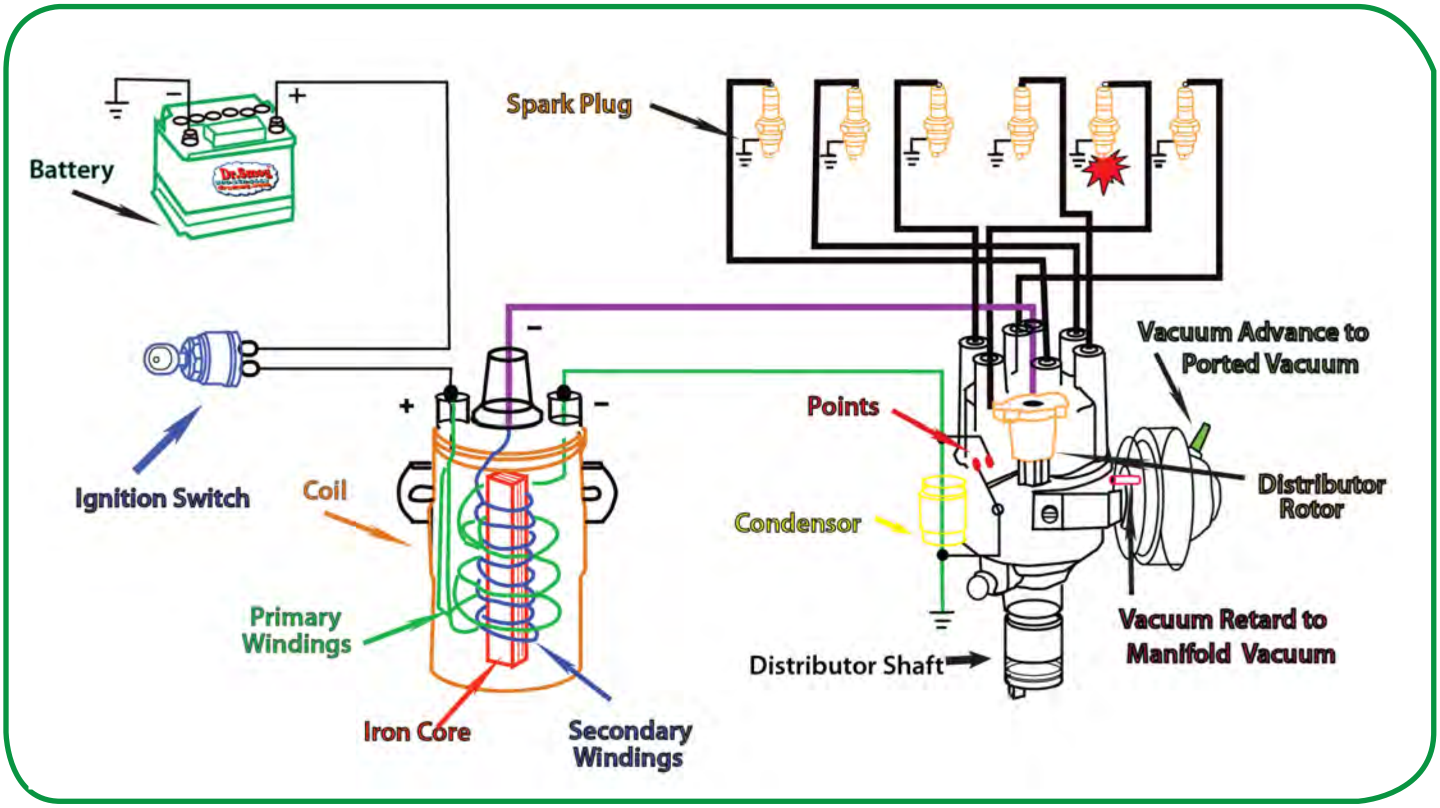


Figure 7-1. Ignition system low voltage primary and high voltage secondary circuits.

Battery voltage is supplied to the positive side of the coil from the battery or alternator. An alternator is an electrical device attached to the engine and driven by a belt that produces electricity.

The negative side of the coil is connected to the system's switching device. The primary circuit's on and off switching device may be mechanical or electronic. The switching device completes the circuit by grounding it based on signals it receives from the triggering device.

Coil

The primary circuit inside the coil consists of a few hundred turns of thick wire, and the secondary windings have thousands of turns of thin wire. When the ignition switch is on (closed), current flows through the primary windings. This produces a magnetic field around the primary windings.

When the primary circuit is opened, current stops flowing and the magnetic field collapses. As the magnetic field collapses, it moves towards the center of the coil because the soft iron core in the center of the coil attracts magnetism. In doing so, it cuts across the thousands of turns of the secondary coil windings. This induces (produces) a voltage in each turn of wire. The thousand of turns added up to produce the high voltage necessary to jump the spark plug gap.
The high voltage current from the coil secondary windings is delivered to the distributor cap and rotor; where it is distributed to the spark plugs in the firing order. Voltage enters the distributor cap through a central terminal, goes through the rotor, crosses the air gap from the rotor tip to a terminal in the distributor cap and then flows out of the distributor through a highly insulated wire to a spark plug.
Distributor caps and rotors are usually made of plastic. The rotor is attached to the top of the distributor shaft and rotates with the shaft to distribute high voltage to the terminals in the cap. Refer to figure 7-2 for four examples of types of primary circuit triggers that are used to switch the ignition primary circuit current on and off and induce a high voltage in the secondary circuit.
A distributor consists of a rotating arm or rotor inside a distributor cap, which sits on top of a distributor shaft. The distributor shaft is driven by a gear on the camshaft. This keeps the firing order in time with the opening and closing of the cylinder head valves. When the camshaft turns, so does the distributor. The distributor shaft usually drives the oil pump.

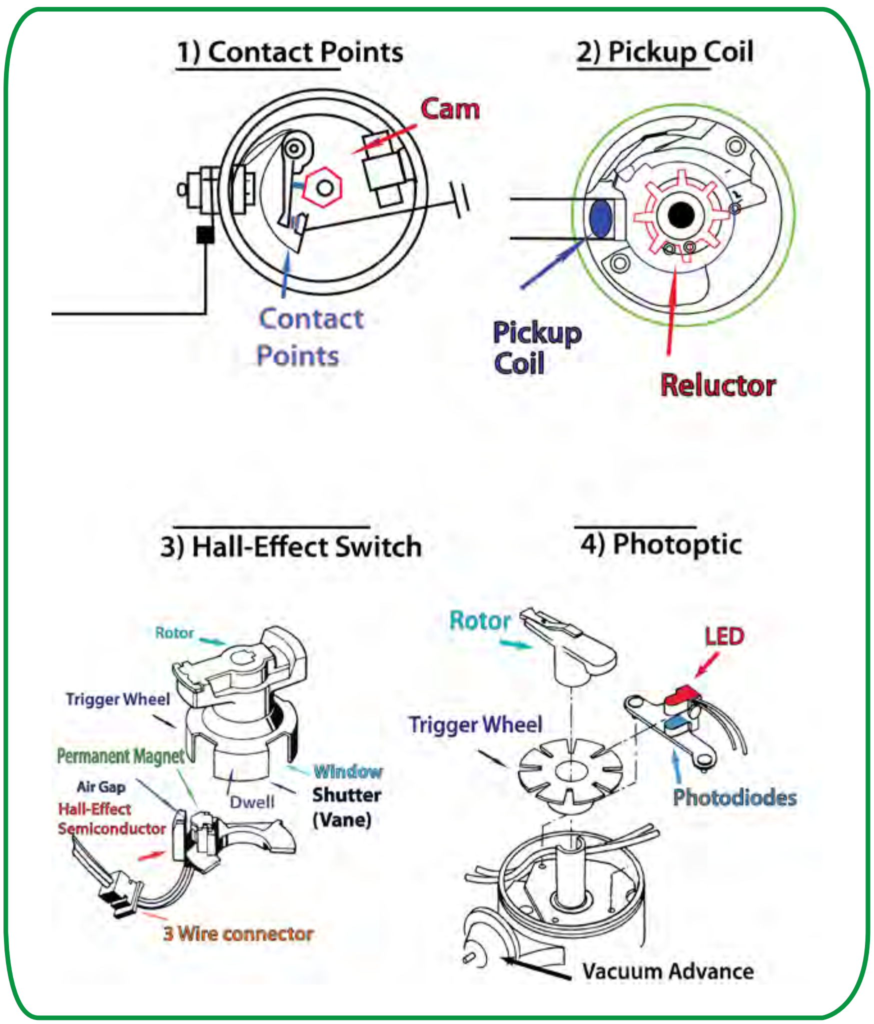


Figure 7-2. This is an example of four types of primary circuit triggers used to turn the ignition primary circuit current on and off.

Contact point distributors open the circuit mechanically by opening and closing a pair of contact points. The length of time the points are closed is referred to as the dwell angle and expressed as the number of degrees of distributor rotation. The points are operated by a breaker cam on top of the distributor shaft. Electronic systems use primary triggers to switch the primary circuit on and off. The reluctor in the electronic distributor performs the same function as the points only magnetically. Refer to figure 7-3 for examples of primary circuit triggers. The ignition systems triggering device monitors the position of the camshaft or crankshaft and sends a signal to the switching device at the correct time for ignition of the air fuel mixture to produce a compromise between maximum power and minimum polluting emissions.

1) Contact Points Primary Circuit Trigger

Contact points act as a mechanical switch which are opened and closed by a breaker cam on top of the distributor shaft.

2) Pickup Coil Primary Circuit Trigger

A stationary pick up coil is attached to the distributor, and a rotating reluctor is attached at the top of the distributor shaft. The reluctor has the same number of teeth as the engine has cylinders. The pickup coil assembly is a small permanent magnet and pickup coil. The pickup coil generates an AC current.

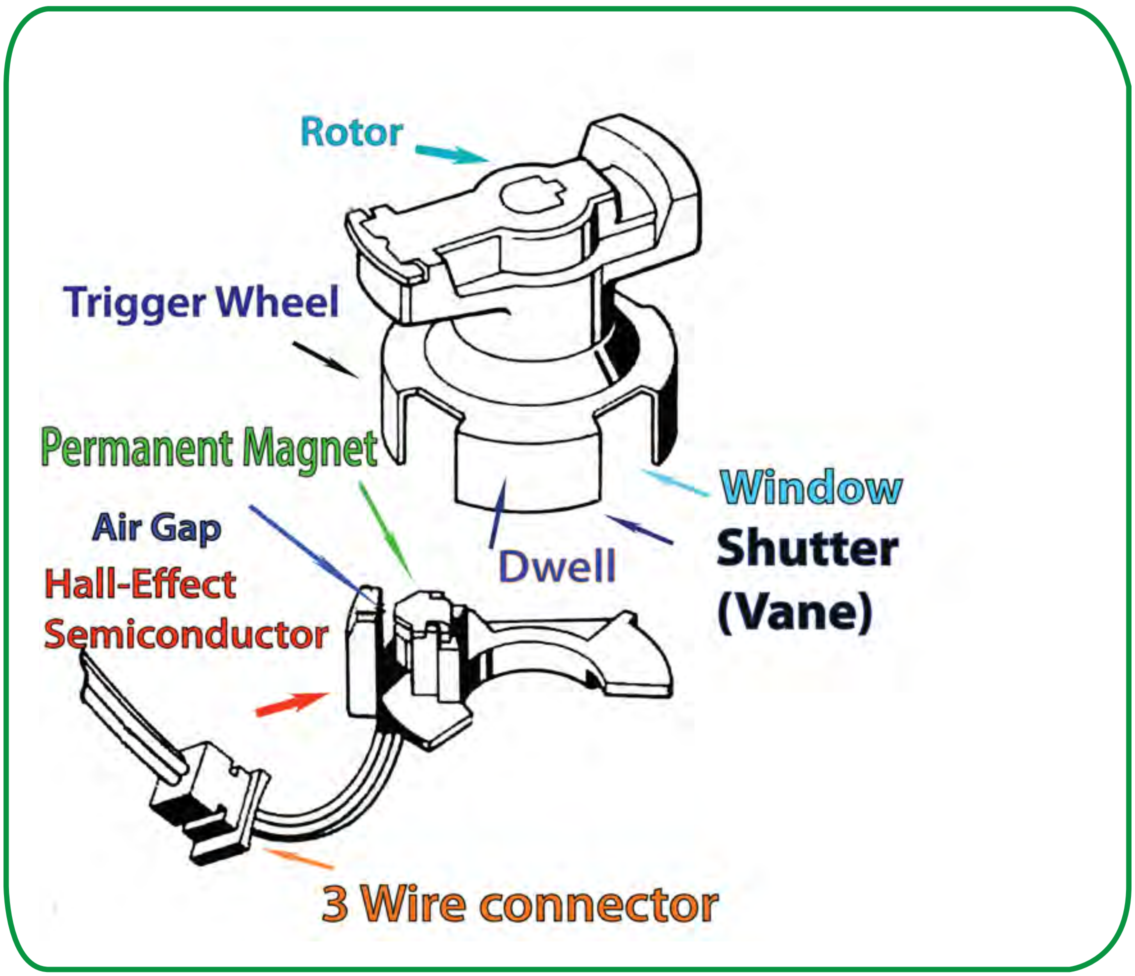


Figure 7-3. This is an example of a Hall effect switch

As a reluctor tooth comes closer to the pole piece, voltage increases. When the tooth and the pole piece are aligned, voltage drops to zero. As a tooth moves away from a pole piece, the magnetic field reverses, and voltage increases with the opposite polarity.
The current stops flowing in the primary circuit because when the reluctor aligns with the pole piece, the rate of change of flux (flow) density is zero. This means voltage and current flow are zero.

3) Hall-Effect

A Hall-effect switch has a rotating trigger wheel and a stationary sensing unit. The Hall effect is the ability to generate a low voltage in a semiconductor by passing current through it in one direction and applying a magnetic field at right angles to its surface. Hall-effect switches in distributors are made up of a Hall element, a permanent magnet and a shutter wheel that consists of alternating vanes and windows which pass between the Hall semiconductor and the permanent magnet. When the shutters enter the gap between the permanent magnet and the Hall effect semiconductor, it causes the Hall output voltage to change. This voltage signal is sent to the Ignition Module (IM) or Engine Control Unit (ECU) which controls the primary circuit switching on and off. Refer to figure 7-3.

4) Photoptic Distributor

A photoptic distributor uses a beam of light to control the primary circuit. Optical means that the system uses light. A photoptic diode is a diode which uses the presence of absence of light to switch a circuit on or off. Two LEDs (light emitting diodes) are on one side of the slotted trigger wheel, and two LED are on the other. The trigger wheel rotates with the distributor shaft. When the trigger wheel slot moves under the LED, the light fall on the photodiodes. When the trigger wheel moves and blocks the light, the photodiode switches off. This on and off voltage signals the ECU engine speed and crankshaft position. The ECU uses this information to control ignition timing. Refer to figure 7-4.

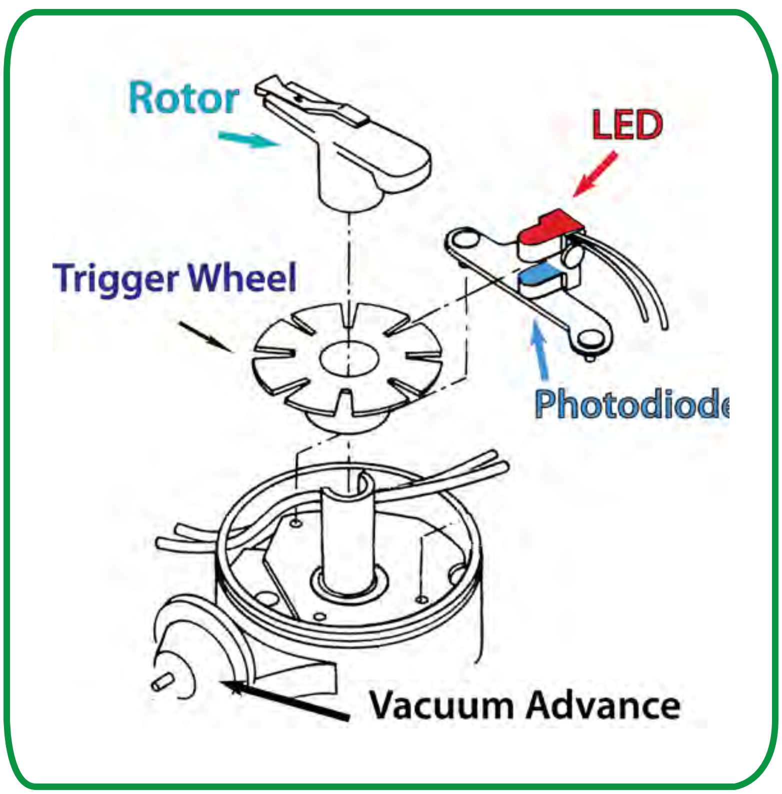


Figure 7-4.Example of a photoptic distributor

Ignition cables/spark plug cables/wires

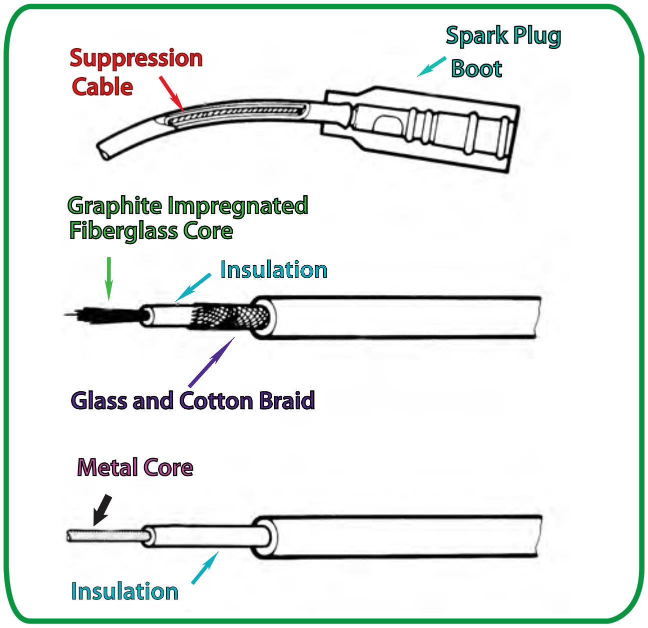


Figure 7-5. Types of spark plug wire. High resistance non-metallic spark plug wires are the most common wires used.

Spark plugs

The spark plug is where the high voltage electricity of the coil distributed by the distributor has to jump a gap to ground.
The completeness of the combustion depends on the intensity of the spark voltage. If the gap between electrodes is too wide, if there is dirt between them or if the electrodes are oil or carbon fowled, the spark will be weak, and combustion will not be complete. Refer to figure 7-7.
Spark plugs have a resistor built into the central electrode that reduces Radio Frequency Interference caused by the ignition system. Spark plugs come in various heat ranges. If the wrong heat range is used; for example, too cold a spark plug rating, sooty deposits will accumulate on the electrodes. The result is the same as if the air fuel mixture was too rich. If a spark plug is too hot, it burns the electrodes and can widened the electrode gap to the point that the spark cannot jump the gap. The result is a misfire. This increases the exhaust emissions of HC and CO.

Spark plug wires are highly insulated, so they can transfer the high voltage to the spark plugs and not short to ground before reaching the spark plugs.
Since the high voltage discharge from the coil causes radio frequency interference with radio and TV reception the cables are designed with high resistance to reduce this interference. Refer to figure 7-5. There are insulation boots on the ends of spark plug and coil cables to prevent the high voltage in the wire shorting to ground.
The boots also protect against water and corrosion. An electrical short to ground is the result of electricity completing the circuit prematurely at the incorrect location. Refer to figure 7-6.

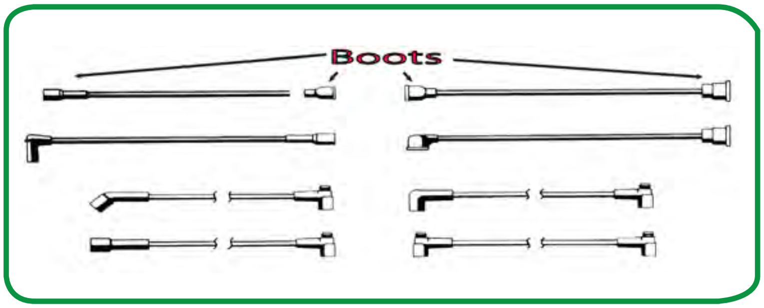


Figure 7-6. Boots at the ends of spark plug and coil wires protect against shorts and corrosion.

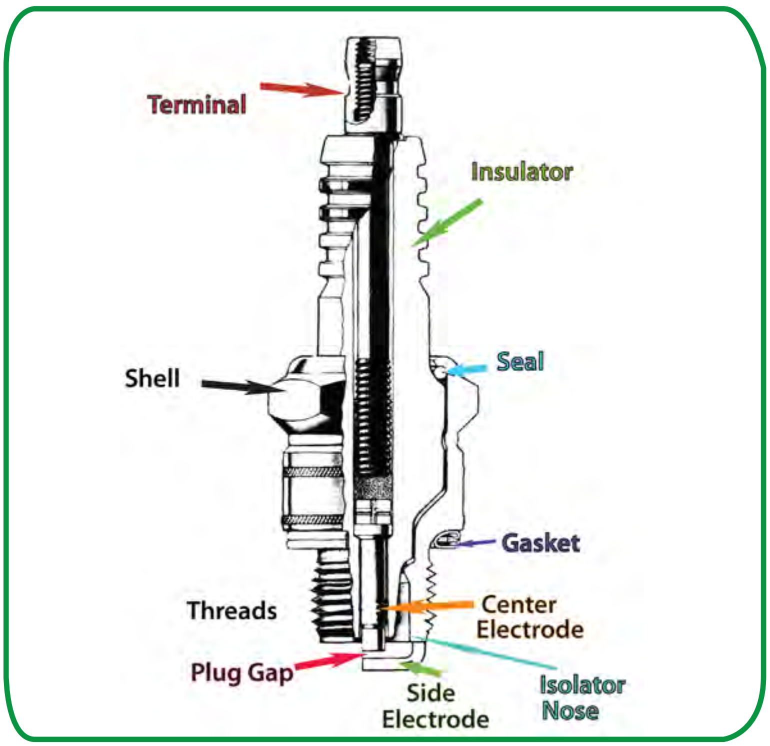
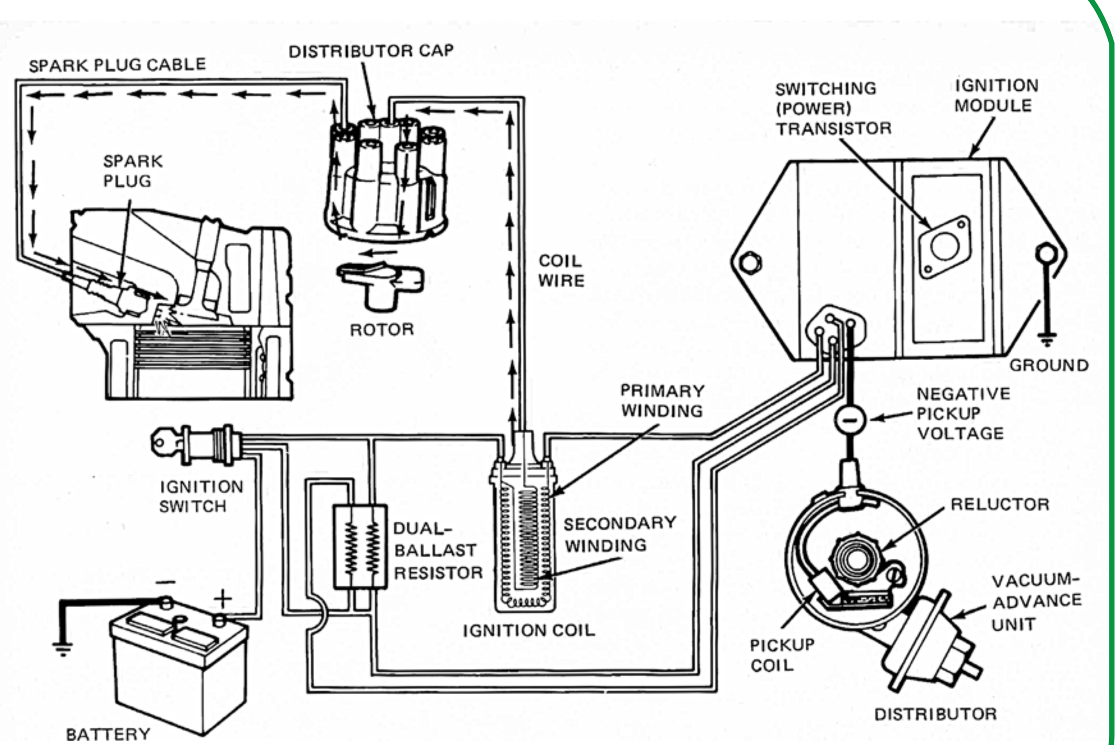


Figure 7-7. Spark Plug.

Since an automotive engine runs at different speeds and loads, the ignition system must change when the ignition spark occurs in order to have the correct spark advance timing for operating conditions. Spark advance is the positon in degrees that a piston is at Before Top Dead Center (BTDC). Spark retard is the position in degrees that a piston is at After Top Dead Center (ATDC).
Spark advance is accomplished by using centrifugal and vacuum devices or electronically. When the engine is idling ignition occurs just before the piston reaches Top Dead Center (TDC). As engine speed increases, the ignition spark must occur earlier so that igniton produces maximum pressure just as the piston passes TDC. For better power, fuel economy and lower emissions the spark must occur earlier as engine speed increases. Older engines use centrifugal devices and or vacuum advances.
Most modern engines use electronic ignition systems so that they can meet or exceed Environmental Protection Agency (EPA) regulations. Electronic Ignition systems have primary and secondary circuits just like conventional systems. The main difference between between the sysems is the primary circuit switching mechanism. Refer to figure 7-3 that shows various types of primary circuit triggers which switch the primary circuit on and off. The primary circuit trigger signals the ignition module or Power Control Module (PCM) when to open the circuit. Refer to figure 7-8.

Figure 7-8. An example of a distributor type electronic ignition system.



The primary circuit triggers may use magnetism, a Hall Effect Switch or a light beam to signal the ignition module to open the primary circuit.
Secondary circuits of electronic ignition systems are basically the same as conventional systems except they can produce secondary voltage as high as 50,00 volts. This allows for wider spark plug gaps that allow the use of leaner air fuel ratios, and hence better fuel economy.

Distributorless Ignition Systems (DIS)

Distributorless Ignition System (DIS) have electronic spark advance controls but do not have a separate distributor. Refer to figure 7-9. A Crankshaft Position Sensor (CKP) signals crankshaft speed, and a Camshaft Position Sensor (CMP) signals piston position to an ignition module. Refer to figure 7-10. The Ignition Module (IM) or Electronic Control Module (ECM) uses this information to deliver a spark at the correct time.

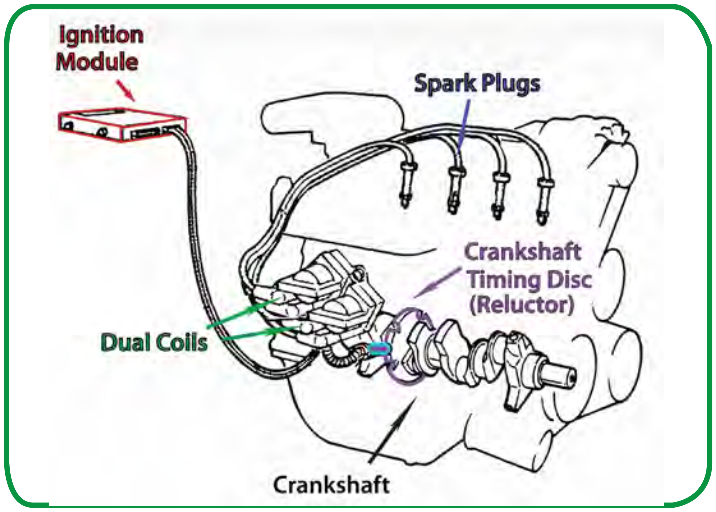


Figure 7-9.Distributorless ignition system using a magnetic crankshaft position sensor (CKP).

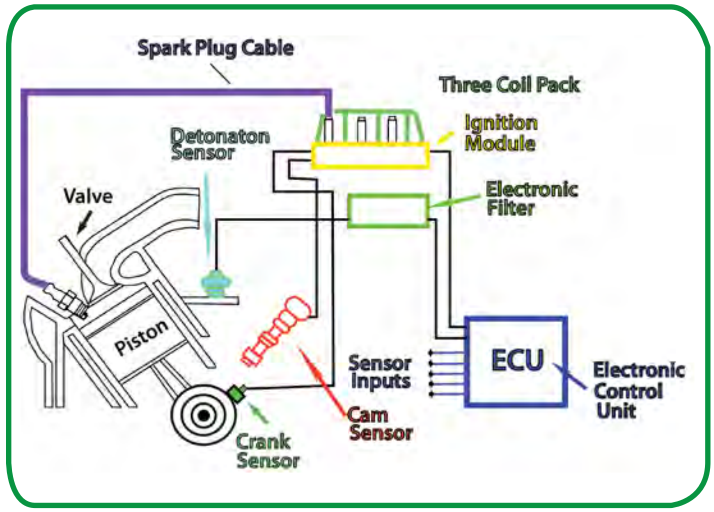


Figure 7-10. Distributorless igniton system using crankshaft (CKP) and camshaft (CMP) positon sensors

Distributorless Direct Ignition

Some engines have direct ignition systems, which do not require spark plug cables. A secondary conductor replaces the spark plug wires. This eliminates secondary voltage loss by the use of wires, and there are no cables to wear out or maintain.

Inductive and Capacitor Discharge Ignition Systems

All the ignition systems described so far are called inductive ignition systems because they store the primary energy in the coil or inductor. There are also capacitor discharge ignition systems, which store primary energy in a capacitor or condenser. In this system, the capacitor produces a high voltage surge when a transistor (an electronic on and off switch) closes. Some capacitor discharge systems use a coil and capacitor for each cylinder.

SECTION 8
Carburetors

Carburetors mix air and fuel to produce a combustible mixture. How rich or lean a mixture needs to be depends on the operating condition of the engine. Each condition has it's own fuel ratio requirements.

When air enters a carburetor, it passes through a venturi. When air passes through the narrow passage of a venturi, it speeds up because of the large volume of air trying to pass though the narrow venturi. The results are:

1) A pressure drop
2) A temperature drop

Refer to figure 8-1.

The main discharge nozzle port is located in the **venturi** where the low pressure causes the fuel to flow out of the nozzle because of the pressure differential between the **venturi** and the atmospheric pressure in the float bowl.

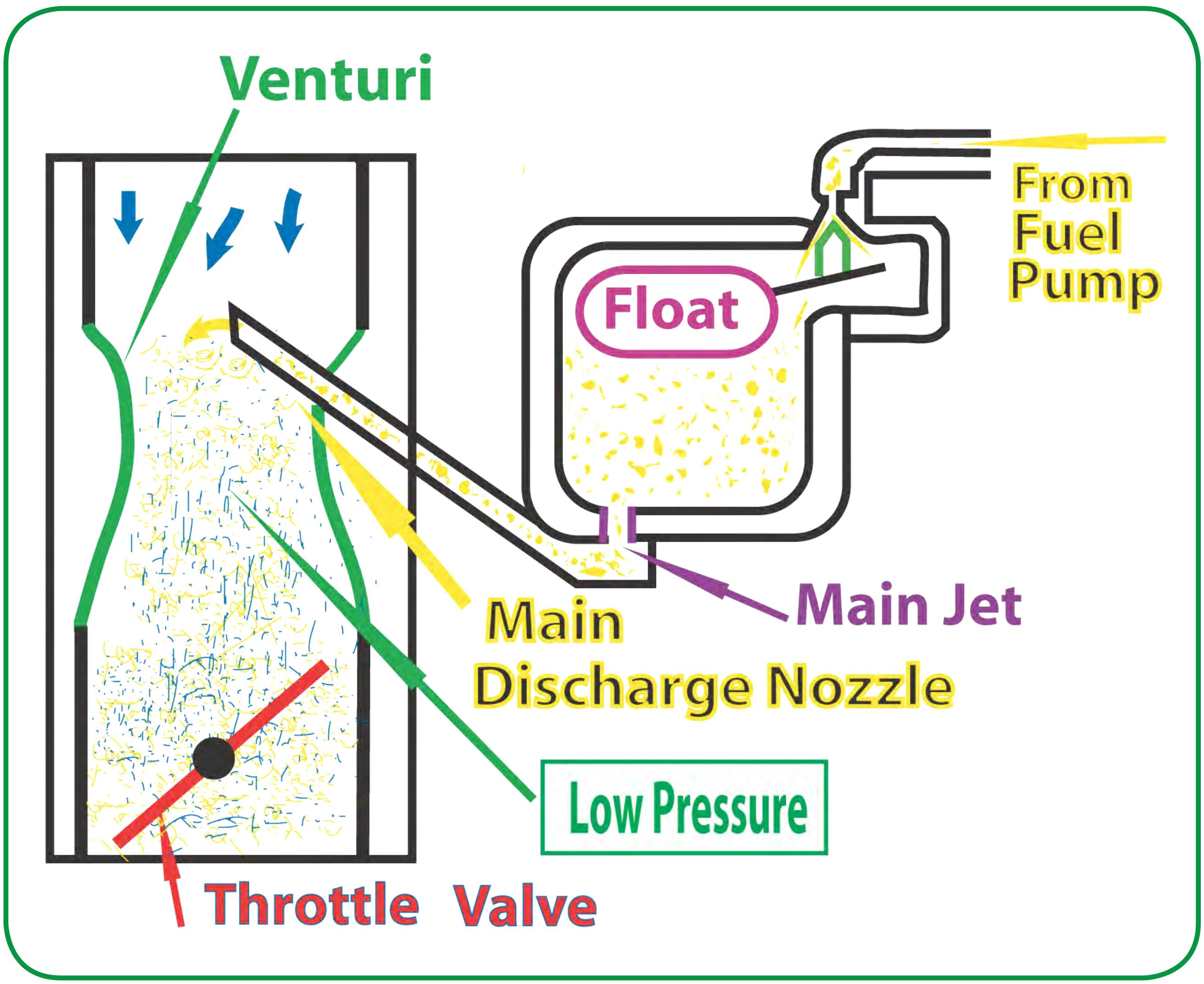


Fig. 8-1. Basic carburetor operations.

1) Float circuit

Fuel to the carburetor comes through the **fuel inlet valve** of the float circuit. Refer to figure 8-2.

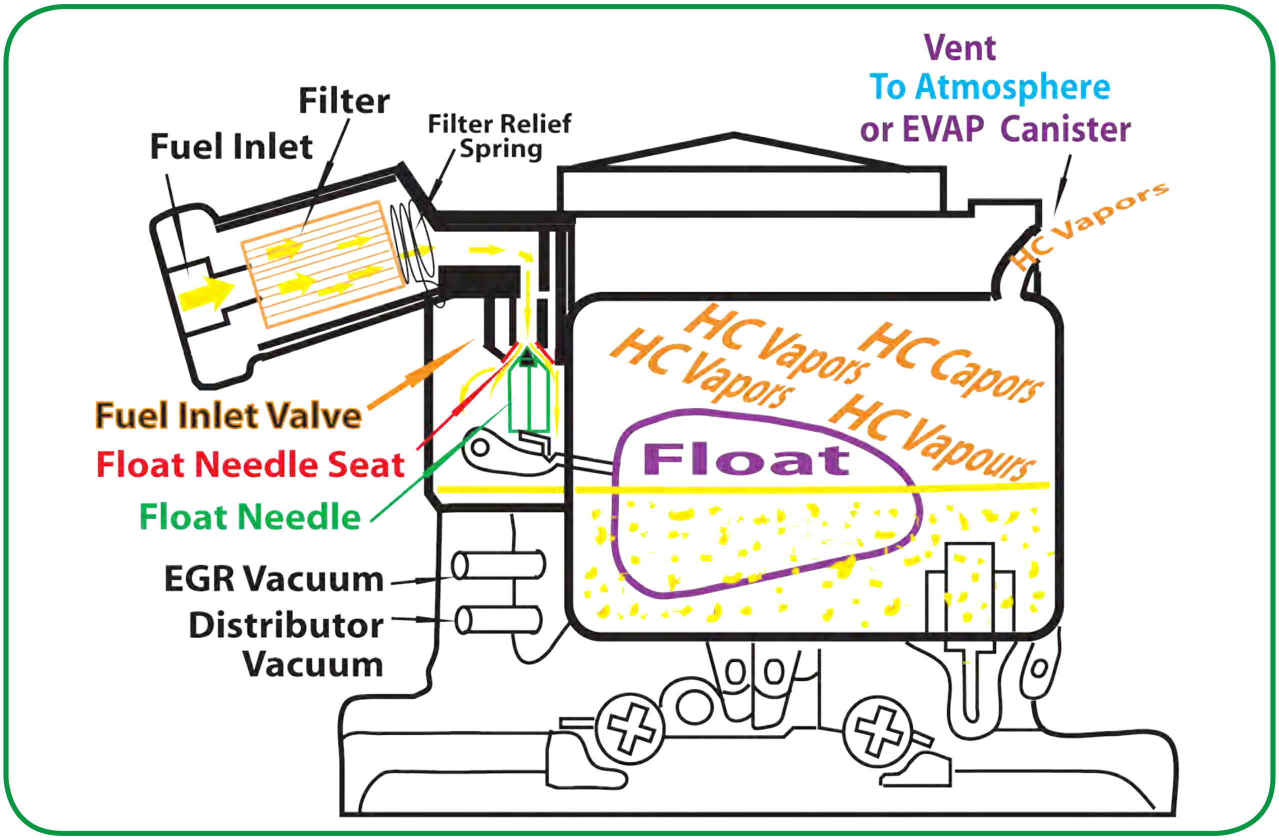


Figure 8-2 Carburetor Float Circuit

The **fuel inlet valve** is operated by a float and lever assembly. When the fuel in the float bowl drops, so does the **float**. This causes the **float needle** to come off the **float needle seat** and allows fuel from the fuel pump to enter the float bowl under pressure from the fuel pump. As the bowl starts to full up, the **float** rises and the **float needle** closes the **fuel inlet valve**. The fuel inlet valve opens and closes continually at different rates depending on how much fuel is being used by the engine.

Float bowl level is critical:
a) Too **high** of a float bowl level will result in a **rich** mixture.
b) Too **low** of a float bowl level will result in a **lean** mixture.
All carburetors have vents to prevent the build up of pressure due to engine heat. The pressure would otherwise cause percolation of the fuel and engine flooding. Originally carburetor bowls were vented to the atmosphere. Now they are vented to the EVAP canister.

2) Idle circuit

An idle circuit is necessary because there is not enough air flowing through the carburetor to draw fuel through the main discharge nozzle to keep the engine running when the throttle is closed. There is high vacuum below the **throttle valve**, and this together with atmospheric pressure on the fuel in the float bowl results in fuel being drawn through the **idle port.** Refer to figure 8-3. Vacuum will draw fuel from the float bowl up through the calibrated **low speed jet**. As the fuel is being drawn through the **economizer**, vacuum is also drawing air at the **bypass** and **air bleed** openings. The fuel that is mixed with this air goes down through the economizer, which further meters and mixes it even more. The fuel and air proportions are controlled by the size of the **air bleed, by pass**, and **low speed jet** opening. The mixture goes through a passage to the idle port where it is drawn out by the vacuum below the throttle. The amount of fuel that can be drawn into the engine is determined by the **idle mixture screw**. The idle mixture is an adjustable needle valve that controls the amount of gasoline in the idle air/fuel mixture. Turning the screw **clockwise leans the mixture**, and turning the screw **counterclockwise richens** the mixture.

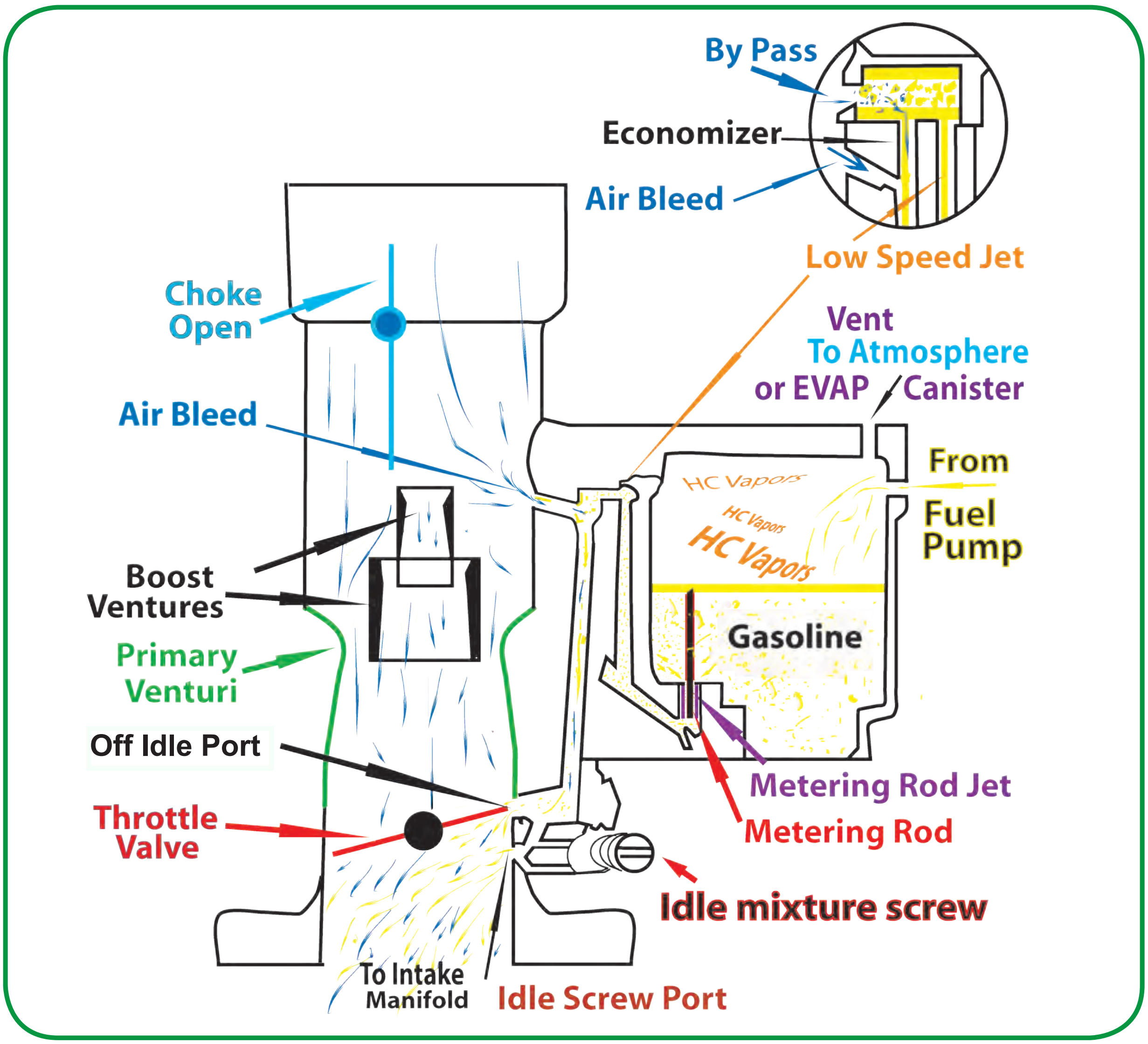


Figure 8-3 Carburetor idle circuits

3) Main Metering Circuit

Air that goes in through the air horn must pass through the **venturi**. The air speed increases, pressure drops, and temperature drops (this is the reason for having a TAC system). Refer to figure 8-4. Since the **main discharge nozzle** is located in the venturi the low pressure around it causes fuel to flow through the nozzle because of the pressure differential between the **venturi**, and the atmospheric pressure in the fuel bowl. As the throttle valve opens, vacuum at the idle port becomes so low that it stops supplying fuel.

The main metering system controls fuel flow through the **Main Discharge Nozzle**

The **main metering jet** controls the nozzle output. The main jet is large enough to supply fuel under full load. For part throttle a calibrated **main metering rod** is inserted into the jet. The rod is graduated in various diameters. This provides fuel metering for various throttle openings. When the accelerator pedal is pressed slightly, the thick part of the metering rod is in the jet. When the accelerator is depressed further, the rod comes out of the jet and a small diameter part of the metering red is in the jet allowing more fuel to flow. In this way, the main jet and metering rod can deliver the correct amount of fuel to the main discharge nozzle depending on engine operating conditions. The main metering rod may be lifted by either a vacuum operated piston or an actuating rod.

Fuel to the carburetor comes through the **fuel inlet valve** of the float circuit. Refer to figure 8-2.

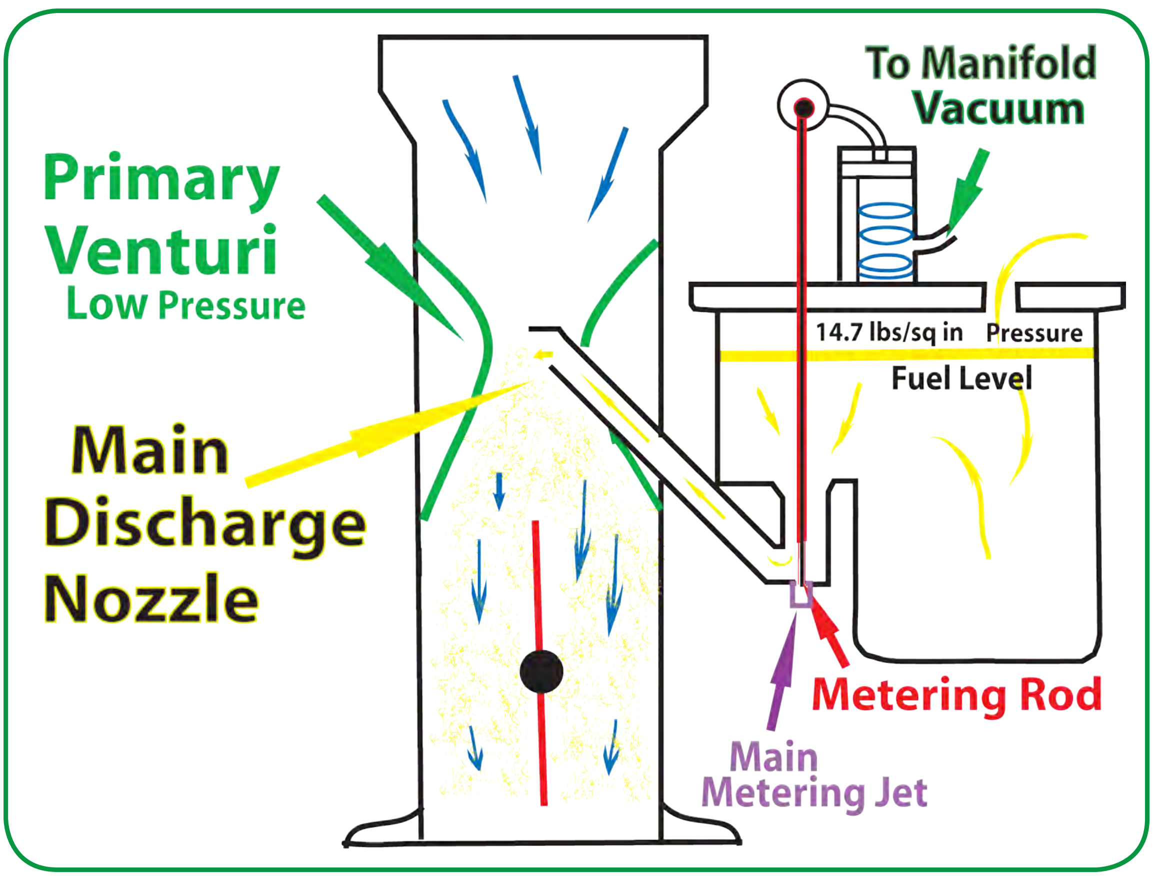


Fig. 8-4. Carburetor Metering Rod.

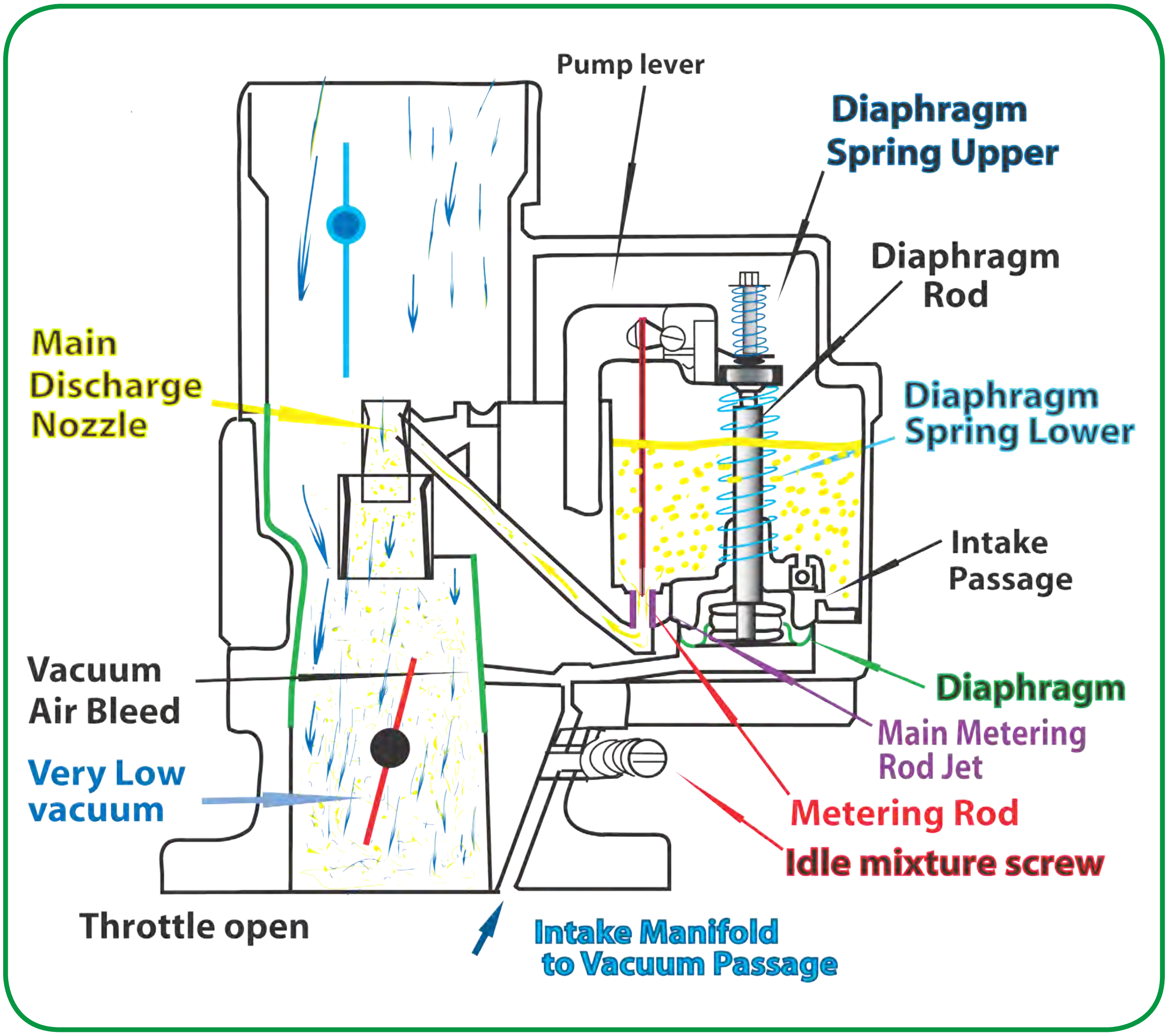


Fig. 8-5. Main Metering Circuit.

4) Power circuit

Normal cruise speed requires an air/fuel ratio of approximately 16 parts of air to 1 part of fuel, but for higher speeds at full throttle, an air fuel ratio of 12 parts of fuel to 1 part of air is necessary. To provide the extra fuel for high speed full power operation, a power circuit is incorporated into the carburetor. Refer to figure 8-6.

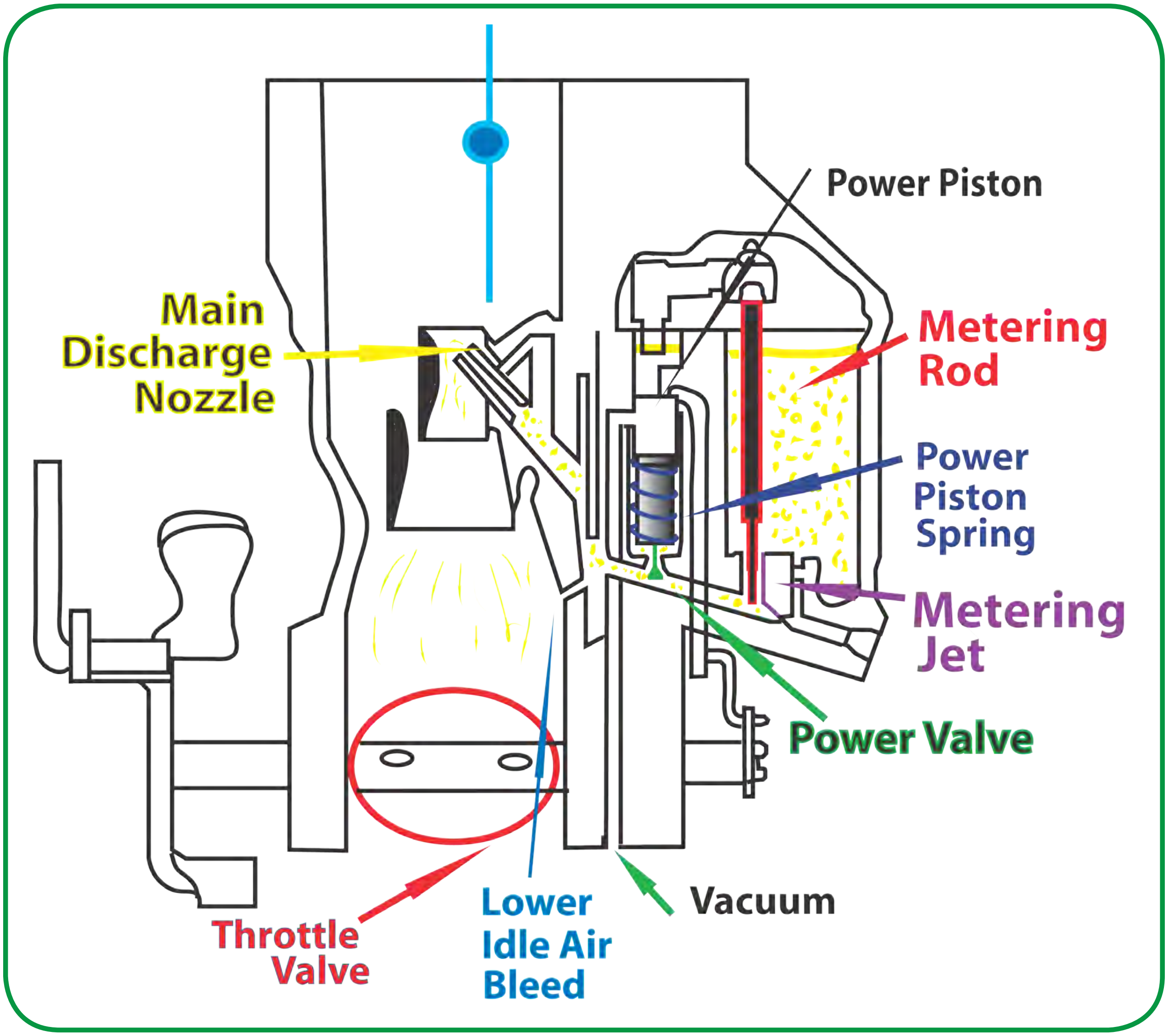


Fig.8-6. Power Circuit.

The power circuit consists of a **power piston, power piston Spring**, and **power valve**. The power valve controls a fuel passage that by passes the main metering jet from the bowl to the main discharge nozzle. Refer to figure 2-9. The power piston is held closed by manifold vacuum. When there is a demand for power and the throttle valve is open wide, manifold vacuum decreases, and a spring forces the power piston down opening the channel thus increasing the flow of fuel to the main discharge nozzle. The power valve is located at the bottom of the float bowl and is covered with fuel at all times. Refer to figure 2-8 and figure 2-9.

5) Accelerator circuit

The rapid opening of the throttle during acceleration allows a rush of extra air to be drawn into the engine, which is not mixed with the fuel because fuel is heavier than air and is harder to set in motion. This results in a sudden demand for fuel when transferring from the idle circuit to the main metering circuit. The extra fuel required for a smooth transition is provided by the accelerator pump circuit. Refer to figures 8-7 and 8-8.

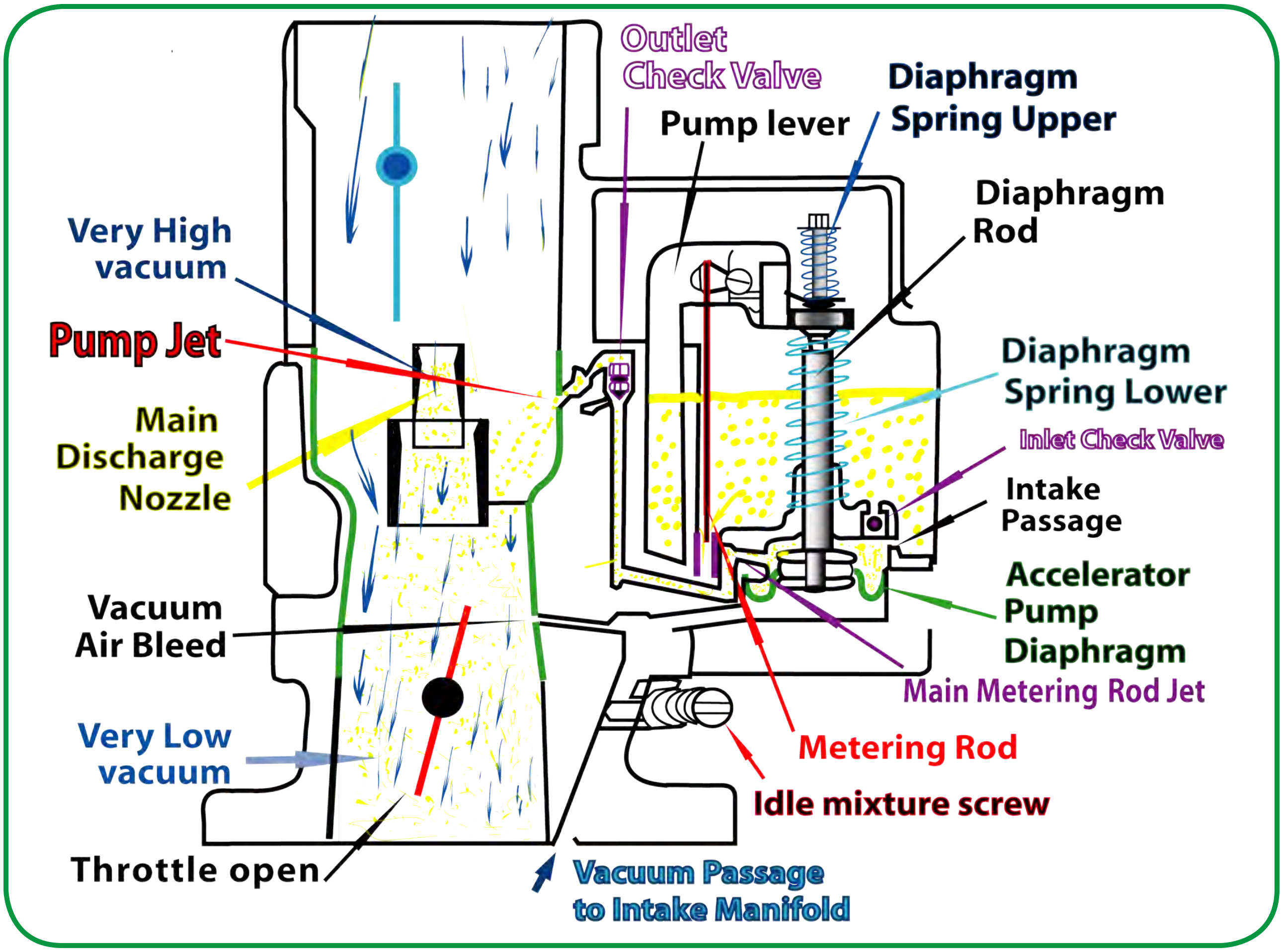


Fig. 8-7. Accelerator Pump Circuit.

The pump plunger is operated by a pump lever, which is linked to the throttle. When the throttle is opened, the lever pushes the pump plunger down, which forces fuel out through the **pump jet**. If the pump jet were not a part of the carburetor, the engine would have a "flat spot" on acceleration resulting in a momentary slow down and hesitation upon acceleration. When the throttle is opened suddenly the fuel from the **accelerator pump** may not discharge immediately, which would result in a hesitation. To prevent this, most accelerator pumps are fitted with a calibrated **diaphragm spring**, which applies pressure to the pump, so that the pump starts discharging fuel immediately and maintains fuel pressure all of the time the throttle is held open until the plunger is all the way down. This allows the accelerator pump system to discharge fuel for several seconds until the main system can take over for smooth acceleration. Some carburetors use the main discharge nozzle to supply fuel from the accelerator pump. Refer to figure 8-9.

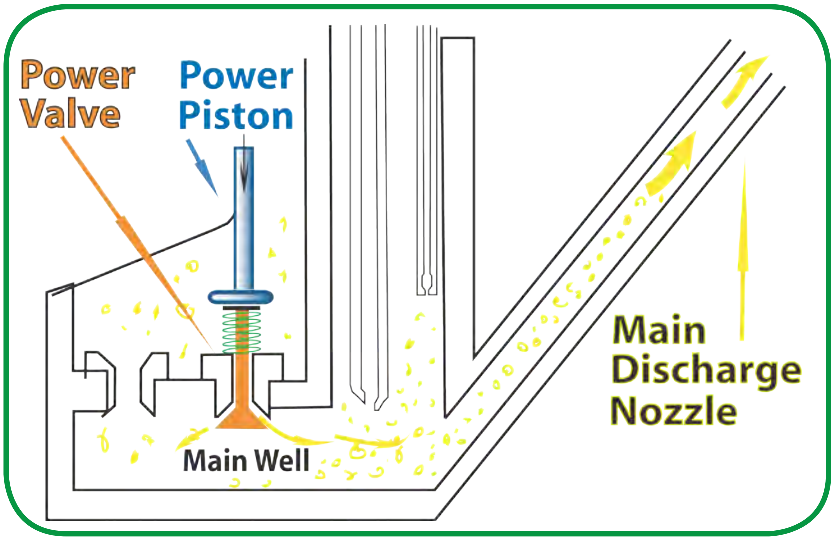


Fig. 8-8. The power valve.

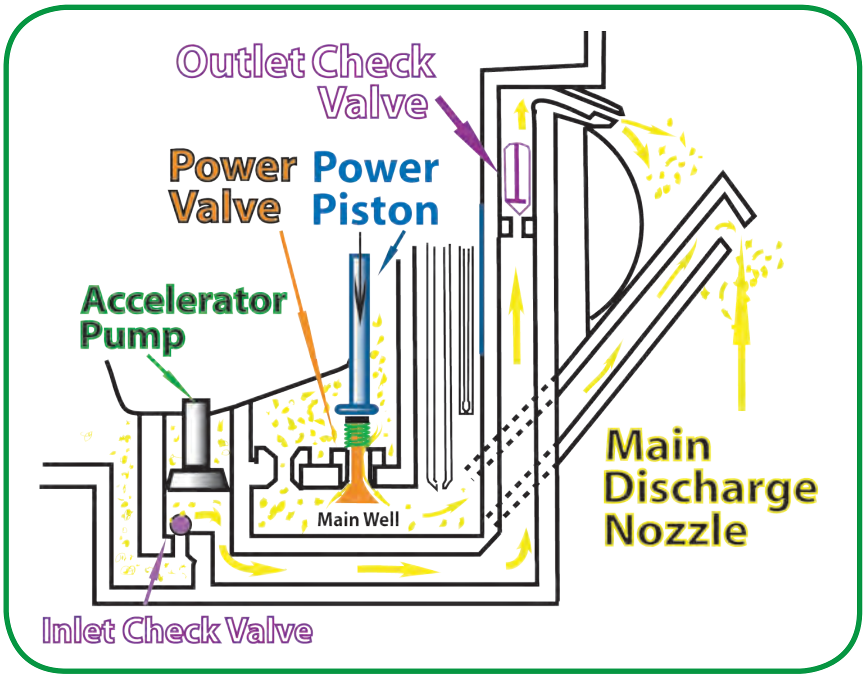


Fig. 8-9. The accelerator pump and power valve.

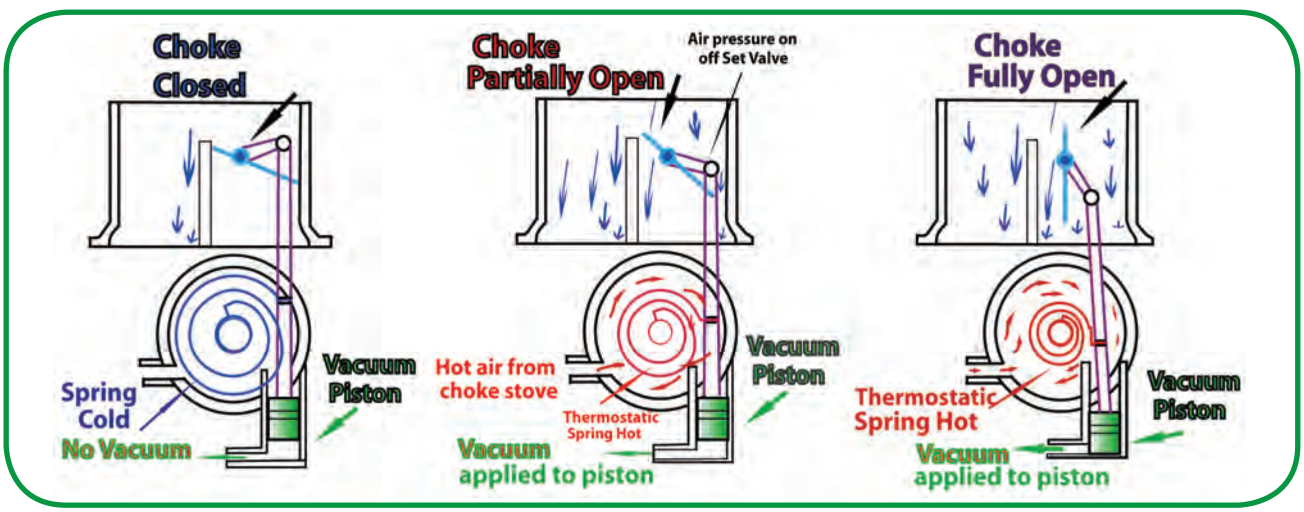


Fig. 8-10. The choke circuit.

6) Choke circuit

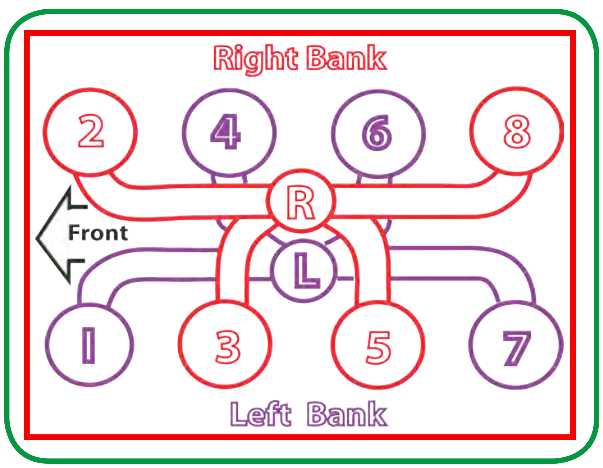
A cold engine requires a rich mixture to start. Carburetors use a choke for this function. The **choke** is a valve mounted on top of the air horn that allows only a small amount of air to pass when it is closed. The result is that almost pure gasoline is drawn from the main discharge nozzle by venturi vacuum. Refer to figure 8-10. When the engine starts, the vacuum pulls on the **vacuum piston** in an attempt to open the valve against the pull of the **thermostatic spring**. Hot air from a heat stove on the exhaust manifold is routed to the **thermostatic spring**. As the engine warms up, the hot air heats up the **thermostatic spring**. As the spring becomes hotter, it releases tension on the choke valve allowing it to start to open. When the engine is fully warmed up, the spring tension is so weak that the **vacuum piston** and incoming air keep the choke open. Most chokes are off set, so that when the engine starts, the incoming air will push more on the long side to partially open the valve. There are many other choke configurations.

For example, some chokes use an electrically heated coil to speed up the opening of the choke thermostatic spring, another passes engine coolant around the choke housing, and another places the thermostatic coil in the exhaust crossover area of the intake manifold. All chokes perform the same function; that is to richen the mixture for starting. If the choke remains on after the engine warms up, the result will be high CO emissions.

Two Barrel Carburetors

Carburetors can be one barrel, two barrel or four barrel; the reason for having a four barrel carburetor is that it can mix large quantities of air and fuel in the correct air fuel ratios. With a large one-barrel carburetor this would be impossible due to poor venturi action. A two barrel carburetor is in fact just the same as two single barrel carburetors joined together. They use a common air horn, and common main body, and a common throttle. They have two idling circuits, and two power circuits. The throttle valves are fastened to the same shaft, so that they move together. Refer to figure 8-11.

Fig. 8-11. How a two barrel carburetor supplies fuel to the engine cylinders



Four Barrel Carburetors

A four-barrel carburetor (quadrajet) has four barrels and four main nozzles. One pair of barrels makes up the primary side (small barrels) and the other the secondary side (large barrels). On V-8 engines, one primary and one secondary barrel supplies fuel to one group of cylinders, and the other primary and secondary barrels supply fuel to the remaining group of cylinders.

The primary side takes care of most operating conditions, and the secondary comes into operation for acceleration or full power, supplying additional amounts of fuel and air, and increasing volumetric efficiency. The secondary barrels are controlled either by mechanical linkage between the primary and secondary throttle shafts or a vacuum operated diaphragm. The vacuum comes from one of the primary venturis. Venturi vacuum increases as the speed of the air through the venturi increases. When the vacuum reaches a predetermined level, the diaphragm is activated to open the secondary throttle to supply the required air/fuel mixture.

Idle Compensator

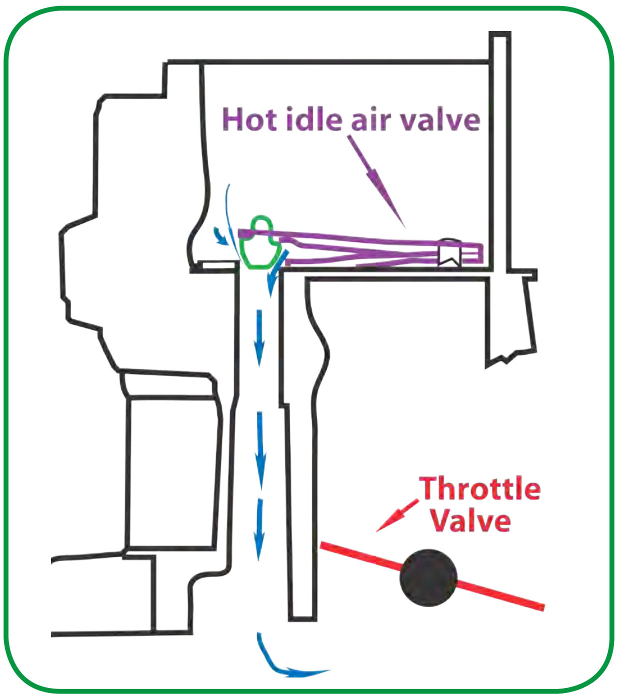


Fig. 8-12. **Hot idle air valve.**
Heat causes a bimetallic strip to open the air valve. This leans the mixture at idle.

To prevent stalling when idling in very hot weather, some carburetors use a thermostatically controlled air valve. When the carburetor becomes hot, a bimetallic strip opens a **hot idle air valve**, which allows extra air to enter the intake manifold below the throttle valve. The extra air compensates for the overly rich idle mixture due to heat-produced vapors entering the carburetor. Refer to figure 8-12.

Idle speed-up control for air conditioning

When the air conditioning is switched on, the increased load on the engine can cause idle problems. To compensate for the increased load, a solenoid on the carburetor is activated. The solenoid opens an air valve, which permits airflow below the throttle plate. Another configuration uses a vacuum diaphragm to control idle up speed, when the air conditioning is switched on. The idle speed up control also provides for better cooling.

Carburetor Modifications

To maintain the correct air fuel ratio and prevent a sudden rich fuel mixture on deceleration, carburetors may be equipped with an auxiliary air valve or a throttle position sensor. An auxiliary air valve admits fresh air along with a metered amount of fuel. A throttle position holds the throttle open slightly on deceleration and prevents the throttle valve from closing too quickly. Closing to quickly would increase manifold vacuum thereby drawing in large quantities of fuel into the intake manifold, which would not be burnt but instead would come out of the exhaust as high HC emissions.

Warming the Fuel Charge

Thermostatic Air Cleaner (TAC)

Thermostatically controlled air cleaners use a vacuum diaphragm operated flapper valve in the air cleaner snorkel. This valve can direct warm air from the exhaust manifold heat store to warm the intake air charge, when the engine is cold, or under hood air, when the engine is at operating temperature. This aids fuel vaporization for quicker warm up times, lower HC and CO emissions during warm up, and helps prevent carburetor icing. Refer to Figure 8-13.

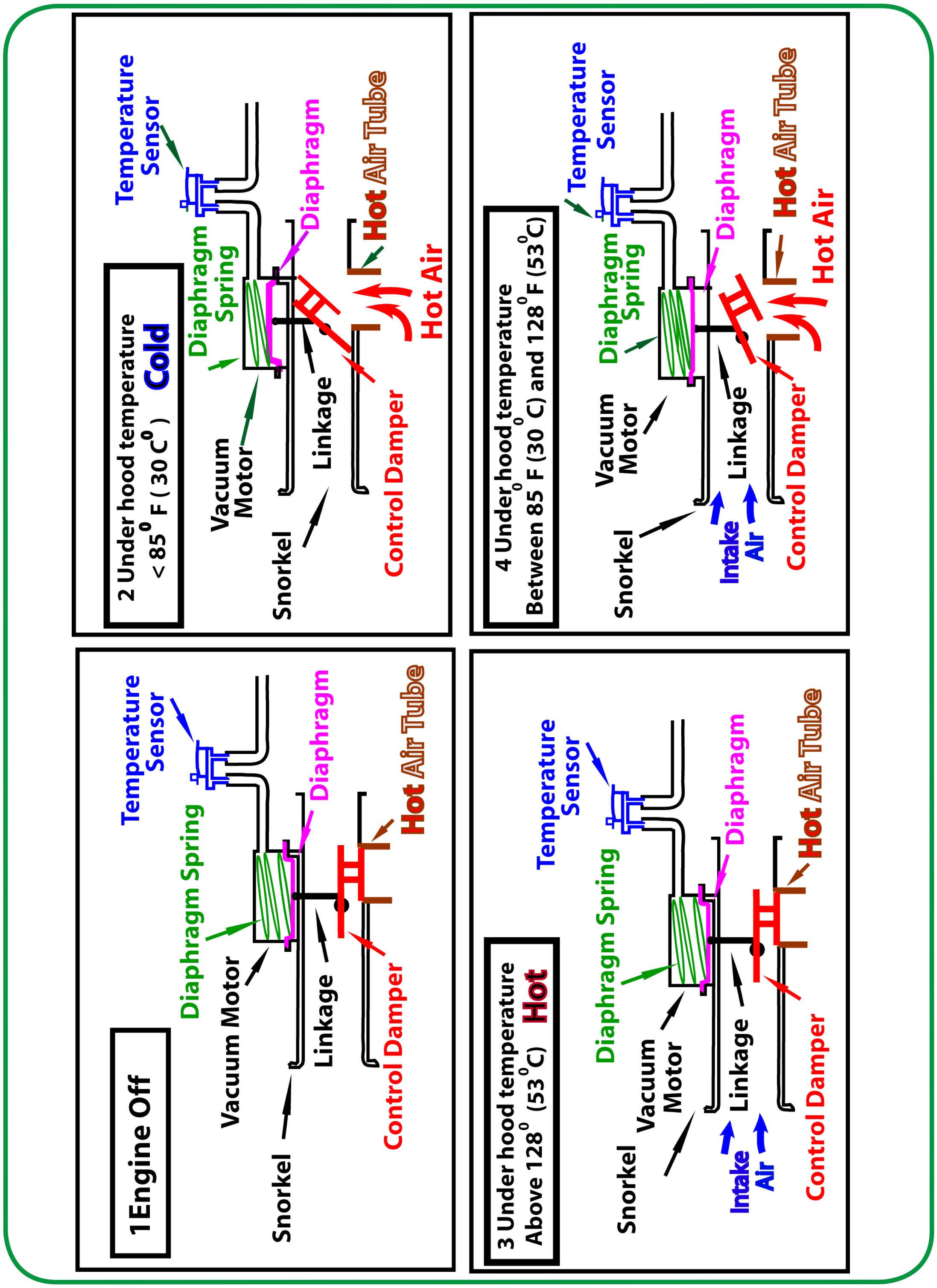


Fig. 8-13. TAC system operation.

Throttle return dashpot

On vehicles with automatic transmissions the drag put on the engine when it is suddenly returned to idle would stall the engine. A dashpot is arranged, so the throttle lever will strike it just before reaching the idle range. The dashpot diaphragm rod slowly collapses allowing the throttle to return to idle slowly. This prevents stalling. Refer to figure 8-14.

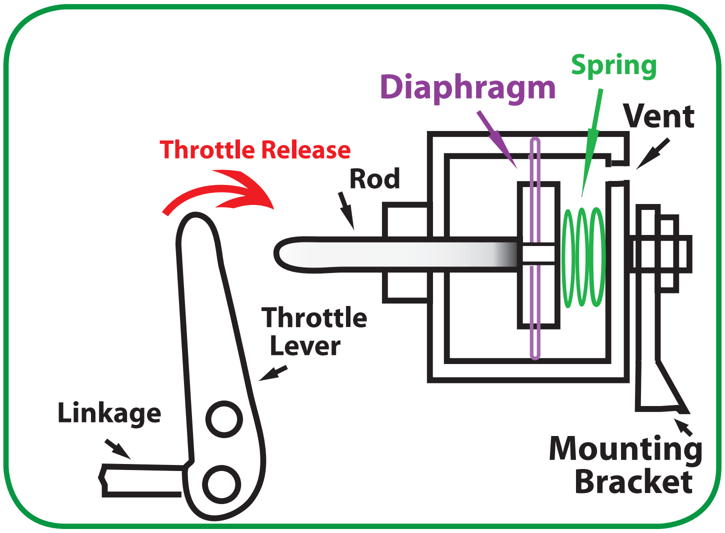


Fig. 8-14. A Dashpot prevents stalling when a carbureted engine returns to idle.

When the air fuel mixture enters the intake manifold, exhaust gasses are directed to the area where the carburetor is located. This warms the fuel charge and aids vaporization/atomization for quicker warm up times and lower HC and CO during warm up. In addition, cold driveability is improved. Exhaust gasses are controlled by manifold **heat control valves**. **Heat control valves** can be operated by a thermostatic spring or **coolant controlled vacuum switch**. Refer to figure 8-15 and figure 8-16.

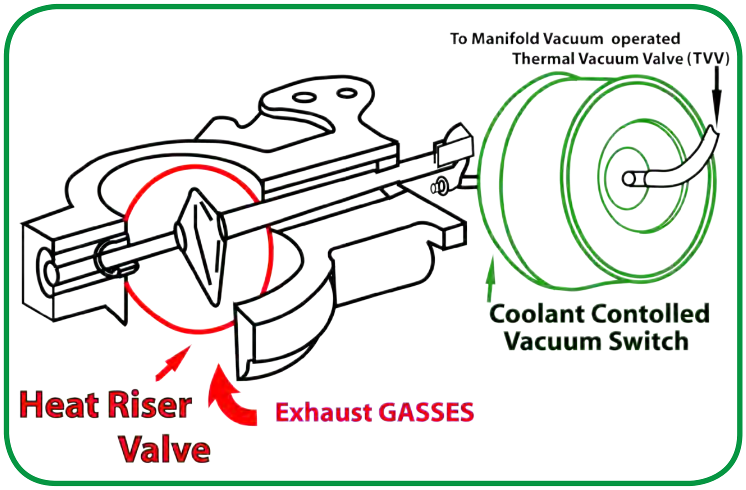
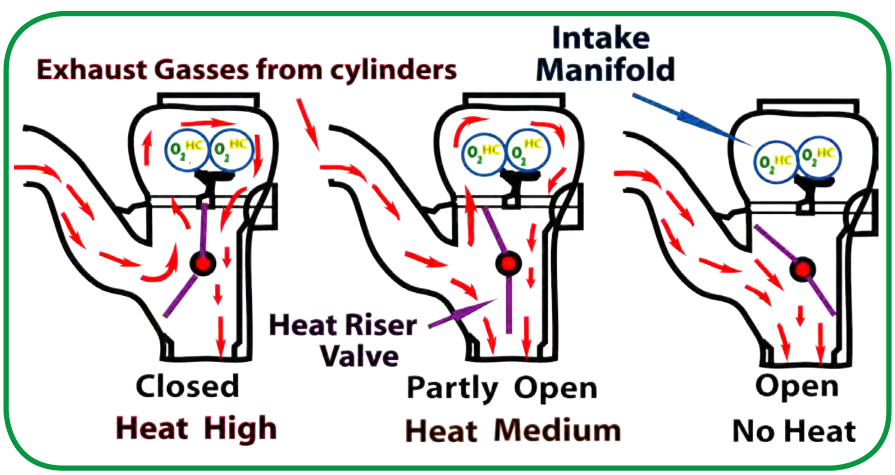


Fig. 8-15. Vacuum operated manifold heat control valve. When the engine is cold, vacuum is routed from a TVV to the control switch to close the valve. When the engine is hot, the TVV cuts off vacuum, and the valve opens. Some systems use a thermostatic spring to open the valve and a counterweight to close the valve.

Fig. 8-16 is an example of how a heat control valve operates. Exhaust gasses are routed around the intake manifold to warm and reduce condensation on the cold manifold walls. This helps fuel vaporization, and addition, cold driveability is improved.



V-8 Heat Crossover

Heat riser butterfly valves can stick closed due to wear, rust, or thermal vacuum valve TVV failure. Refer to figure 8-18. The continual heating of the intake manifold will cause the fuel in the carburetor bowl to boil resulting in a rich mixture and high CO. In addition, EGR metering on back-pressure transducer modulated systems will be affected due to increased backpressure. The manifold heat control valve on V-8 engines is located in the exhaust manifold on one bank. When the engine is cold, the valve is closed, and some of the hot exhaust gasses are routed up through the intake manifold and out the other side.

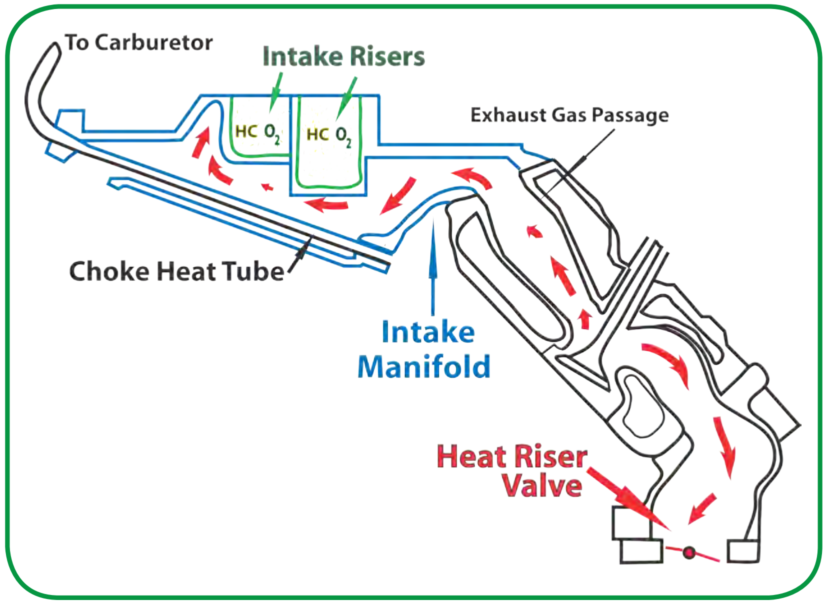


Fig. 28-17. V-8 heat crossover. The heat riser valve is closed, and exhaust gases are being routed up and around the intake manifold passages to warm the fuel charge to help vaporization of the fuel charge, shorten warm up times, improve driveability, and lower HC and CO emissions during warm up.

Thermal Vacuum Valves (TVV)

When the engine is hot, the valve is opened, and exhaust gases are routed out both exhaust manifolds. Some engines have engine coolant passages in the intake mansifold to prevent fuel from condensing on the cold walls or puddling in the floor of the manifold. All these systems are designed to warm the fuel charge for lower warm up emissions, quicker warm up times, and improved cold driveability.

The carburetor provides vacuum for TVVs, which supply vacuum to operate kickdown switches for automatic transmissions and overdrives, EGR valves, early fuel evaporation (EFE) heat riser controlled vacuum switches, distributor vacuum advance, vacuum solenoids, and many other emission control devices. Refer to figure 8-18. TVVs may have two to five ports. However, they operate the same way.

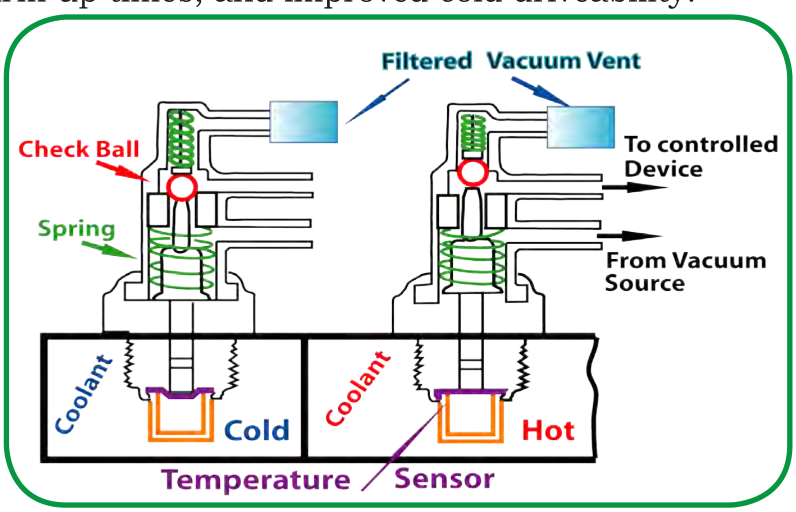


Fig.8-18. TVVs may have two to five ports. However, they operate the same way.

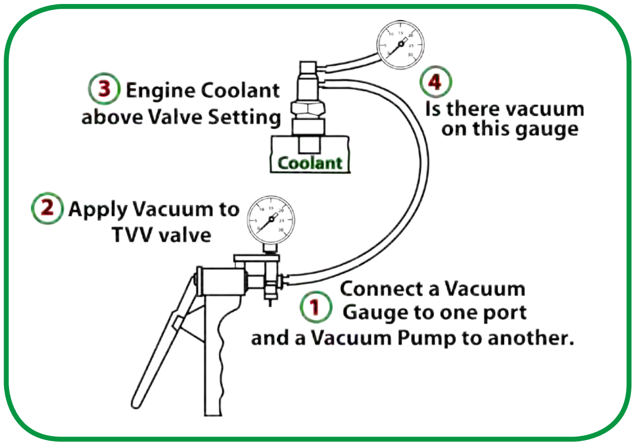


Fig. 8-19 is an example of a two port TVV. Test the operation of the switch at high and low temperature.

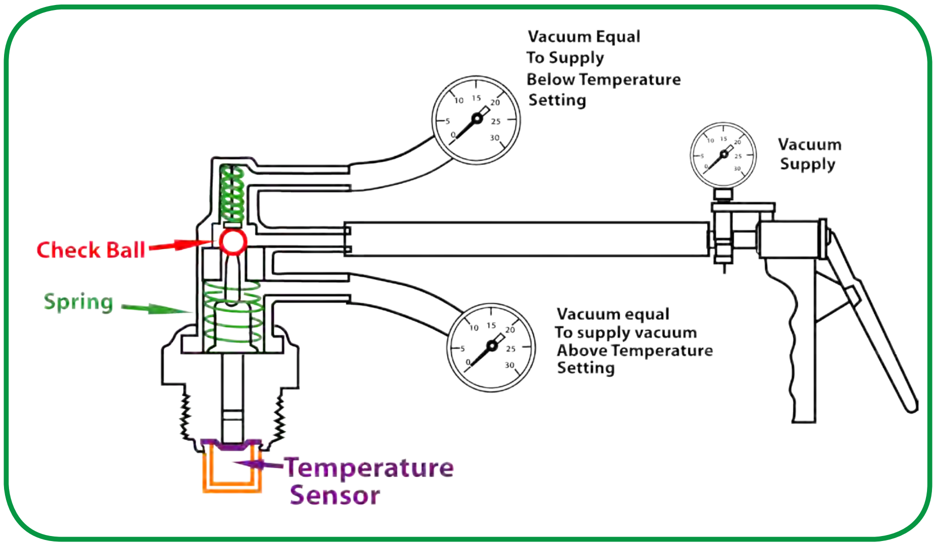
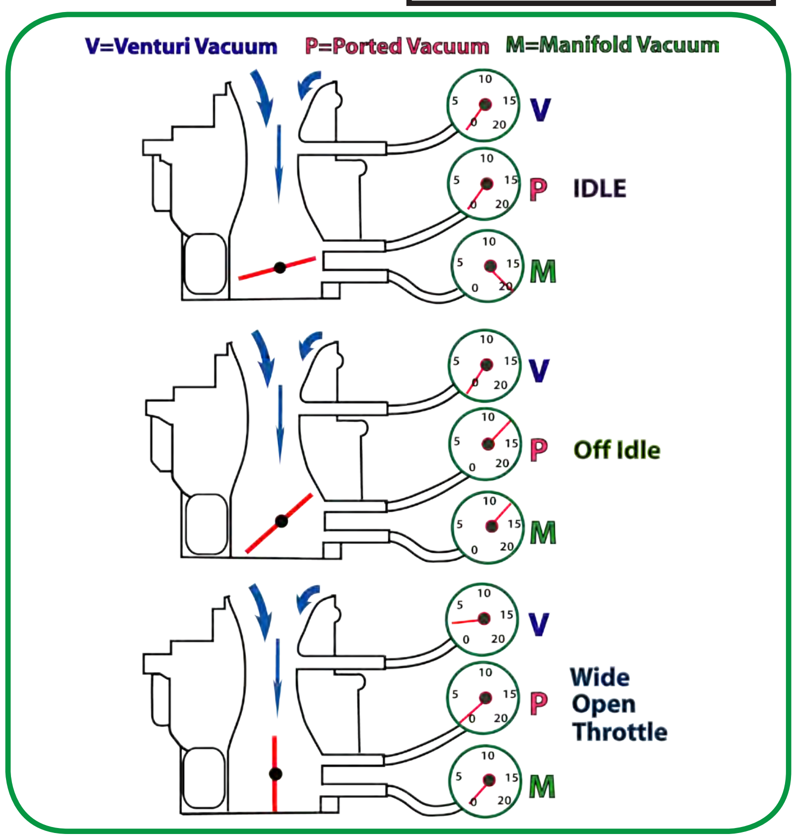


Fig. 8-20 is an example of a three port TVV. Test TVVs while is the engine cold, hot, and at normal operating temperature. Test air temperature valves with a heat gun. To test a TVV valve, you must know if it opens or closes a vacuum source at a high or low temperature. Refer to the maintenance and repair manual.

Types of Vacuum

Ported vacuum operates many components of emission control systems through a TVV or electric ported vacuum switch. **Ported vacuum** is only available off idle, and therefore is for used for ignition advance. Refer to figure 8-21.

Fig. 8-21. Vacuum sources. **Venturi vacuum** increases with engine RPM. **Ported vacuum** is only at idle. **Manifold vacuum** is highest at idle and lowest at wide-open throttle.



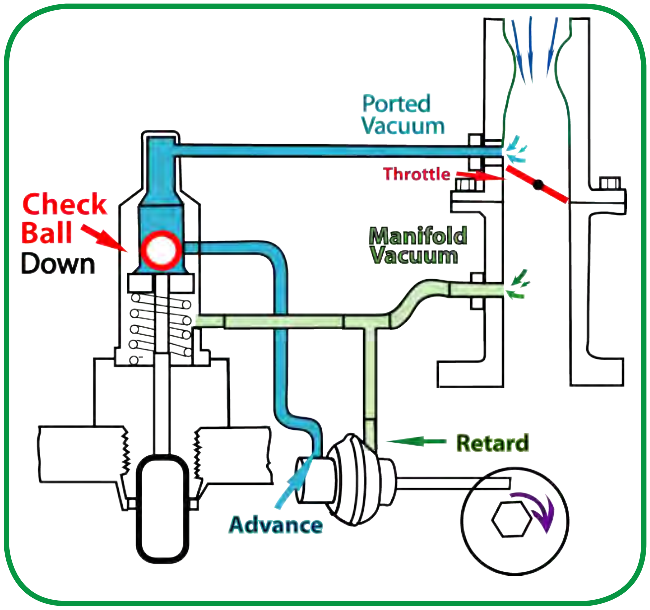


Fig.8-22 is an example of a thermal vacuum valve (TVV) under normal operating conditions.

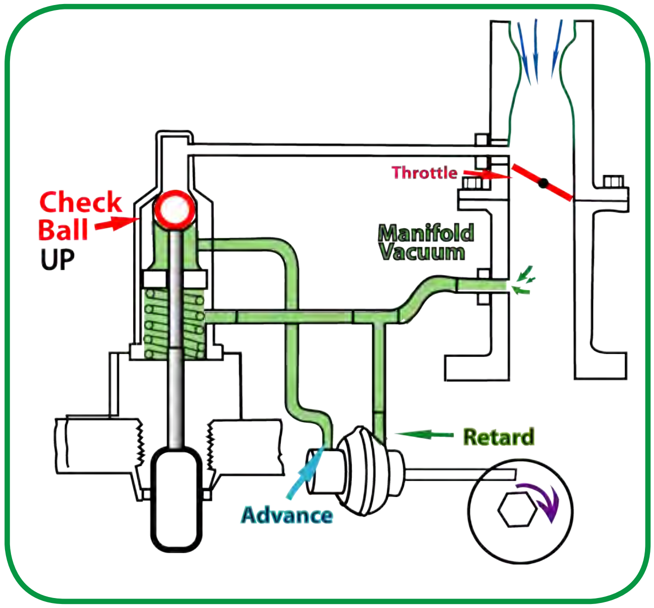


Fig. 8-23 is an example of a thermal vacuum valve (TVV) when the engine overheats.

Manifold vacuum controls many emission components including the TAC. Since manifold vacuum is available at idle, it is used for ignition retard. Thermal vacuum valves route manifold vacuum to the distributor vacuum advance under excessive coolant temperature conditions. Refer to figure 2-22 and figure 8-23. Manifold vacuum is also used to operate EGR valves. Refer to figure 2-24.

Venturi vacuum is used by EGR systems to provide an EGR valve control signal. Venturi vacuum is too weak to open an EGR valve. However, signal strength is proportional to airflow, which means that the EGR system can apply vacuum to the EGR valve that is proportional to the venturi vacuum signal. Thus allowing EGR flow to be almost proportional to airflow.

Refer to the underhood emissions vacuum diagram or vehicle reference information when performing your initial visual inspection for correct vacuum hose routing.

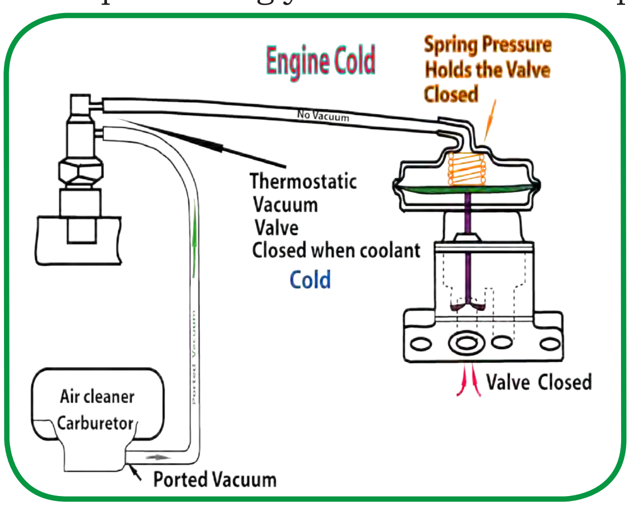


Fig. 8-24 is an xample of a thermal vacuum valve (TVV) operating an EGR Valve. Engine **cold**, off idle. No vacuum to the EGR valve.

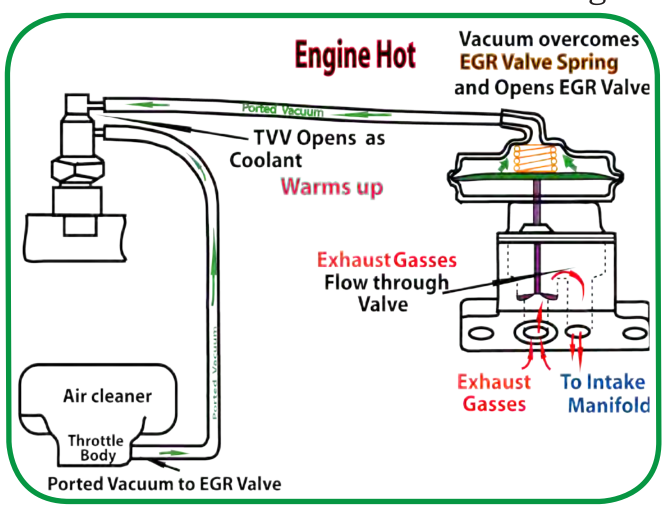


Fig. 8-25 is an example of a thermal vacuum valve (TVV) operating an EGR Valve. Engine **hot**,off idle. Ported vacuum is routed to the EGR valve.

SECTION 9
Fuel Injection

FUEL INJECTION

The basic function of a fuel injection system is to measure the amount of air drawn into the engine and to inject the precise amount of fuel under pressure based on that measurement. The result is better driveability and lower emissions.

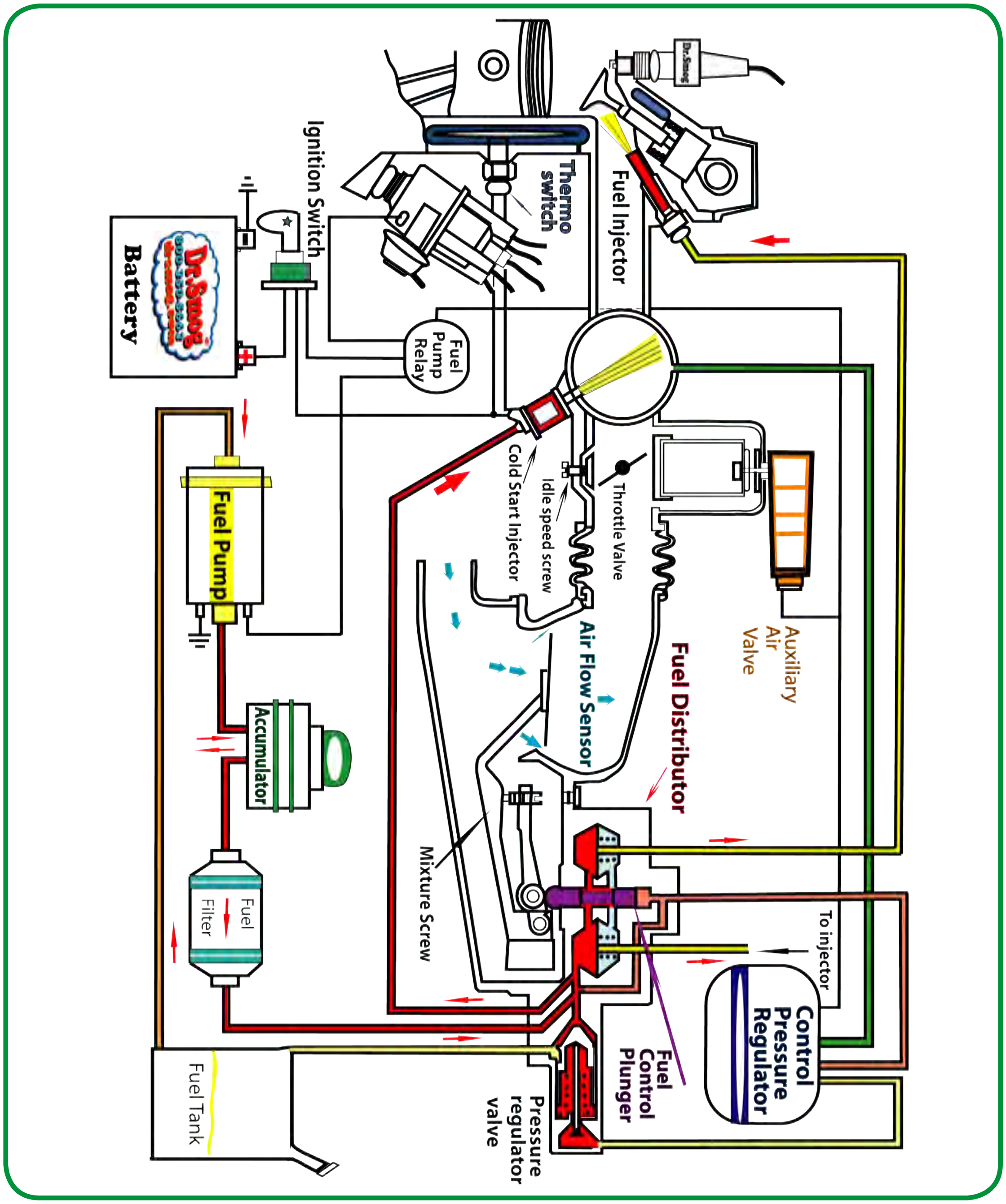
The following are the types of fuel injection:

a) Continuous or intermittent fuel injection. See figure 9-1.

b) Electronic or mechanical fuel injection.

c) Port or throttle body fuel injection.

Fig. 9-1 is an example of a Bosh K-Jetronic CIS system. Continuous Injection Systems continuously inject fuel into the intake port of each cylinder while the engine is running.



Electronic Fuel Injection Sub-Systems

There are four subsystems, which make up a fuel injection system.
1) Air induction system
2) Fuel delivery system
3) Sensor system
4) Computer control system

1) Air induction system

The air induction system cleans and delivers air to the cylinders. It consists of an air filter to clean the air, throttle body, throttle valve to control incoming air, intake manifold, and various connecting ducts.

2) Fuel delivery system

The fuel delivery system cleans and delivers the right amount of fuel for various driving conditions. The system consists of a electric fuel pump to deliver fuel from the fuel tank, a fuel filter to clean the fuel, a pressure regulator to regulate fuel system pressure, and fuel injectors to spray the fuel into the cylinders and connecting lines.

3) Sensor system

The sensor system keeps track of engine operating conditions and sends that information to the PCM for processing. The system typically consists of an O_2 sensor, engine coolant temperature sensor (ECT), intake air temperature sensor (IAT), throttle position sensor (TPS), intake manifold pressure sensor, which can be either a mass air flow sensor (MAF) or a manifold absolute pressure sensor (MAP).

4) Computer control system

The computer control system, also known as the power control module (PCM), processes input information from the input sensors and controls outputs. The sensors and output devices are all connected by a wiring harness, which carries voltage signal inputs from the engine, transmission, air conditioning, and other systems to the PCM. The PCM processes the information and sends output voltage signals to the fuel injectors, ignition system, transmission emission control system, and other components for the best driveability, fuel economy, and lowest emissions.
The PCM is a pre-programmed microcomputer, which has microscopic electronic circuits inside integrated circuits. An integrated circuit (IC) is an electronic chip, which enables the PCM to have hundreds of thousands of capacitors, resistors, and transistors in a very small space. Different circuits perform different functions. On board computers (PCMs) are sensitive to cold dirt, heat, moisture, and vibration, and for this reason, you will find them in the passenger compartment of a vehicle, usually under or behind the dash panel.

Fuel injection systems vary in design. The systems that are described here are examples of some of those you will find on many vehicles. However, you will still need to refer to the repair manual and latest service bulletins to make sure you have the most up to date information on the system that you are repairing.

Most fuel injection systems are either Bosch or are made with parts that are under patent to Bosch.

Fuel injection has many advantages over a carburetor and feedback carburetor fuel delivery systems. Fuel injection systems use pressure not vacuum to feed fuel to the engine. This makes the system very efficient.There is no venturi so carburetor icing is not a problem, and a cold start valve does away with the need a choke. Fuel injection systems have far fewer parts and are therefore, less prone to malfunction and are hence more reliable.

The following are some of the advantages of fuel injection systems:

1) More uniform distribution of fuel to each cylinder.
2) Fuel is forced into the intake manifold under pressure. The result is better fuel vaporization.
3) A leaner mixture can be used at idle because of even fuel distribution and better vaporization.
4) Precise fuel metering and increased air flow boost engine power.
5) Lower emissions because of lean efficient air /fuel ratios.
6) Precise fuel metering, good atomization and distribution of fuel improves fuel economy.
7) Fuel injection systems have fewer parts and are more reliable than feedback or non feedback carburetors.

Types of Fuel Injection Systems

Fuel injection systems can be classified as follows:

Mechanical or electronic

a) Mechanical fuel injection systems use fuel pressure to open injectors and are normally continuous injection systems which means that they inject fuel continually while the engine is running. They may have electronic parts depending, on the design.

Electronic injection systems use fuel injectors, which are operated by solenoids to spray fuel into the intake ports or intake manifold in timed pulses.

b) Port injection or throttle body injection

Port injection systems have an individual injector for each cylinder. Throttle body injection systems have one or two injectors to spray fuel into the intake manifold.

c) Continuous or intermittent

A continuous fuel injection system injects fuel into the engine continually while the engine is running. An intermittent fuel injection system sprays fuel into the engine depending on the design of the driver circuit, which determines when each injector delivers fuel in relation to the operating cycle of the engine.

Driver circuit design

Depending on the engine application, the drive circuit design may be either a **simultaneous**, **grouped (also known a non-sequential),** or **sequential** type. In most systems, voltage is applied to the injectors from the ignition switch or electronic fuel injection (EFI) relay, and the PCM controls injector operation by turning on the driver transistor grounding the injector circuit.

On simultaneous type drive circuits, all injectors are pulsed at the same time by one driver circuit. Injection occurs once per engine revolution just before TDC of No1 cylinder. Twice per engine cycle, one half of the calculated fuel is delivered by the injectors.

Grouped (also known a non-sequential) drive circuit design injectors are grouped in pairs and a separate drive circuit controls each group of injectors. Injection is timed to a pulse just prior to TDC for the leading cylinder of the pair.

S**equential** drive circuit design injectors are controlled, and each injector is timed to pulse just prior to each intake valve opening.

CIS Fuel Injection

Refer to figure 9-1.

Accumulator

The function of an **accumulator** is to:

a) Aid in engine start-up by maintaining the fuel injection system under pressure.
b) Protect the **fuel distributor** from rapid build up of fuel pressure during start-up.
c) Help maintain a constant fuel pressure during periods of acceleration.
d) Prevent vapor lock and improve hot starts by maintaining a constant pressure in the system. Idle speed is adjusted by adjusting the amount of air that bypasses the throttle plate. The idle screw is downstream of the **airflow sensor**, so idle adjustments do not effect A/F ratio.

Airflow Sensor

An **airflow sensor** is a circular plate positioned, so all incoming air must flow past it. The plate is attached to a lever, which moves up and down in direct proportion to the incoming air. This air measurement is translated into a fuel injection quantity by the fuel **control plunger** in the fuel distributor.

Auxiliary Air Valve

The extra fuel for cold starting requires additional air. The auxiliary air valve bypasses the required air around the throttle plate during cold starting.

Cold Start Injector

For cold starting, the engine requires additional fuel, which is supplied by a cold start injector. A thermo-time switch senses when the engine coolant is below 113^0F/45^0C and turns on the cold start injector when the starter is operating. The cold start injector injects additional fuel directly into the intake manifold. When the engine coolant temperature rises above this level or the starter is not operating, the cold start valve does not operate.

Control Pressure Regulator

The Control pressure regulator adjusts control pressure by returning excess fuel to the tank.

The higher the control pressure, the less the control plunger moves. The less it moves, the less gas and the leaner the mixture.

The lower the control pressure, the more the control plunger moves. The more it moves, the more gas, and the more gas, the richer the mixture.

The higher the control pressure, the more fuel that is returned to the tank and the leaner the mixture.

The lower the control pressure, the less fuel that is returned to the tank and the richer the mixture.

Fuel Distributor

The fuel distributor is the part of the mixture control unit that meters fuel and distributes it to each injector. Fuel metering takes place as the **control plunger** rises and falls. Fine-tuning of the mixture is accomplished by changes of fuel pressure in the fuel distributor.

Fuel Control Plunger

The fuel control plunger sits in a housing called a barrel. The fuel pump supplies fuel at system pressure to the lower portion of the barrel. As the plunger rises, fuel flows through precision slits (one for each injector), which injects fuel directly into the intake manifold.

Fuel Pump

When the key is turned on, the fuel pump is energized through a safety circuit, and system pressure is built up. If the engine does not start in one second, the pump is switched off even though the ignition switch is on.

The mixture control unit is the center of a Continuous Injection System. It is the combination of an **airflow sensor** and a **fuel distributor**. The air entering the engine flows around the airflow sensor plate and lifts it up. The plate is attached to a lever which it moves up and down, which in turn moves the **control plunger** in the mixture control unit to supply required amount of fuel. The fuel **control plunger** sits on the **airflow sensor** lever and rises and falls at the same rate as the sensor plate. Fuel pressure is critical to all fuel injection systems, but especially so for CIS systems where fuel pressure is used to overcome spring pressure in injectors (refer to figure 5-10) and control changes in A/F ratio for different operating conditions. Whenever intake air increases, both the **airflow sensor** and fuel **control plunger** rise proportionally increasing fuel flow. Fuel pressure counter force applied to the top of the control plunger balances the force of the air entering the engine thus stabilizing the fuel **control plunger** and **airflow sensor** plate movement. Fuel pressure counter force can be varied to affect fuel **control plunger** lift for a given air flow. This in turn changes the amount of fuel injected and hence A/F ratio. This counter force also balances airflow sensor plate movement. Otherwise, the plate would move so rapidly when the engine started that the fuel **control plunger** would rise to the top of it's barrel and stay there. When the fuel **control plunger** rises, metering slits in the plunger barrel are opened and fuel flows through separate differential-pressure valves for each injector. This ensures even fuel distribution to each injector, which atomizes the fuel in the intake port.

CIS Fuel Injection Lambda Control

Refer to figure 9-2.

For complete combustion to take place in an internal combustion engine, fuel must be atomized and metered in the correct proportion to air. It takes 14 parts of air to support the combustion of 1 part of
fuel. This is called the stoichiometric air fuel ratio 14 to 1.

Bosch describes the stoichiometric A/F ratio as Lambda, and it calls this the excess air factor.

Lambda=1

When the amount of air equals the amount of fuel for complete combustion and there is no excess air, Lambda equals 1. (The same as the stoichiometric air fuel ratio of 14:1.)

An air fuel ratio higher or lower than 14 to 1 will burn. However, there are problems.

Rich A/F ratio

A rich air fuel ratio is one that is <14 to 1. There is insufficient oxygen to support complete combustion. Refer to figure 5-8. This results in:

a) CO (carbon monoxide, a poisonous gas) emissions will be increased.
b) The engine oil will be diluted with gasoline.
c) HC (hydrocarbons/gas vapors, which cause cancer) will be increased.
d) Foul spark plugs.
e) Increased carbon deposits.
f) Increased fuel consumption.
g) Reduced power.

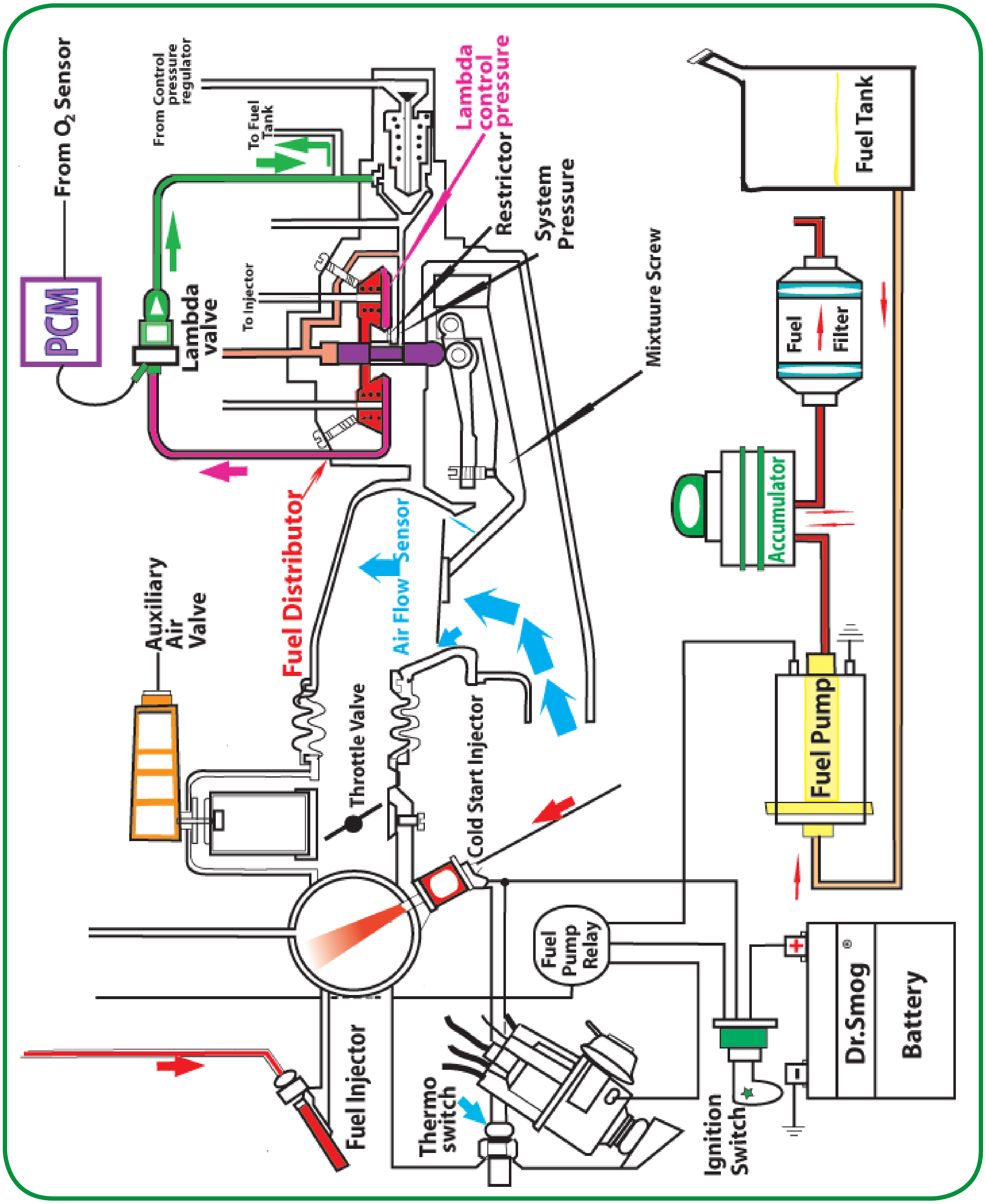
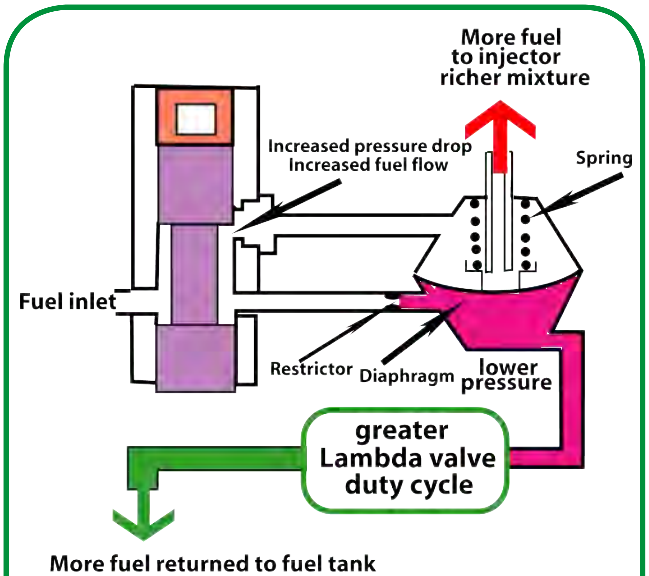


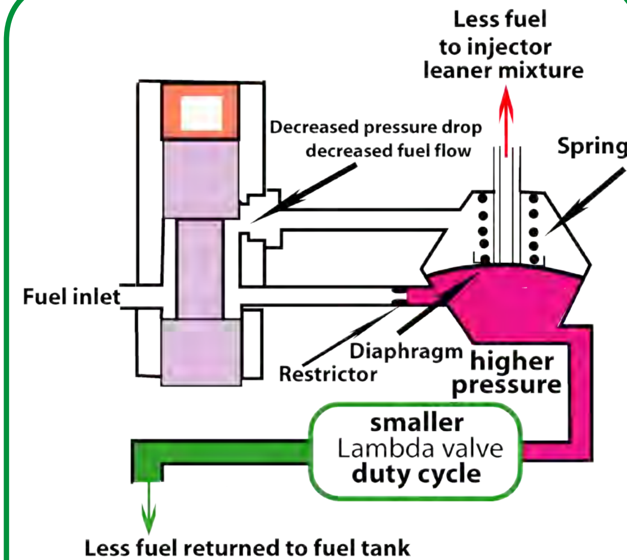
Fig.. 9-2. Bosch K-Jetronic CIS Lambda closed loop system. Note: lambda valve and lambda/ O_2sensor



The higher the duty cycle, the more fuel returned to the fuel tank.

The lower chamber pressure, the richer the A/F ratio.

Fig. 9-3. Bosch K-Lambda valve adjusts A/F ratio by changing pressure drop at the metering slits.



The lower the duty cycle, the less fuel returned to the fuel tank.

The higher the lower chamber pressure, the leaner the A/F ratio.

Fig. 9-4. Bosch K-Jetronic CIS Lambda closed loop system constantly adjusts A/F ratio, so lambda=1.

A variation in rich A/F ratios make less difference in power than the same variation in lean A/F ratio.

Refer to figure 9-5. Fuel pressure from the mixture control unit overcomes spring pressure and opens the injector. A weak spring will allow the injector to leak, resulting in a rich mixture.
Lambda < 1.
A/F <14.7 to 1.
High O_2 sensor voltage.
High CO emissions.

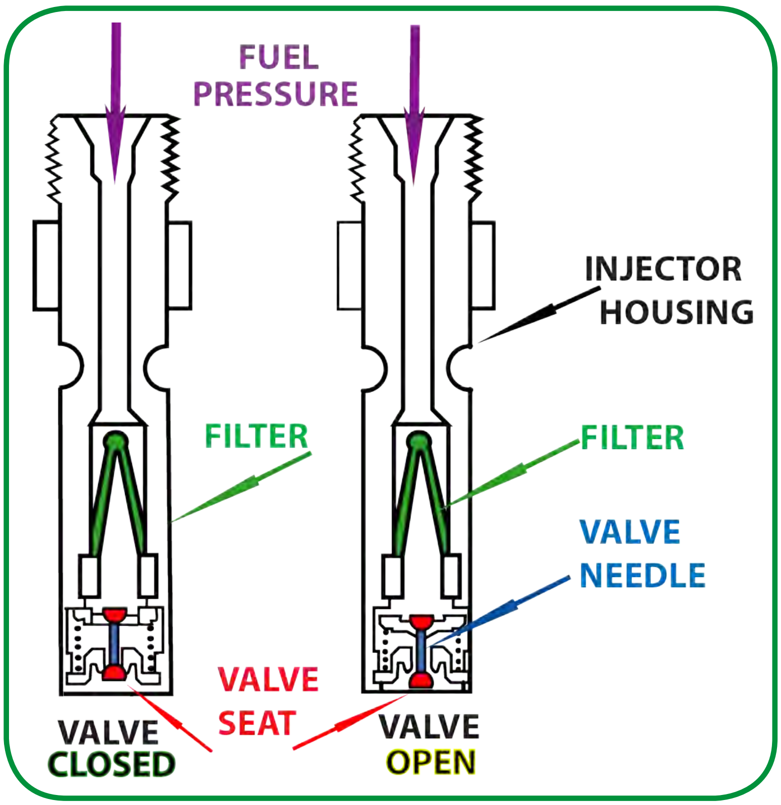


Fig. 9-5 . CIS fuel injectors

Lean A/F ratio

A lean air fuel ratio is one that is >14 to 1. There is more oxygen than is required to support complete combustion. Fuel will burn but at a higher temperature and slower. This results in:

a) NO_x (oxides of nitrogen, a poisonous gas) emissions increase.
b) Pre-ignition, which can cause severe engine damage.
c) Raised engine temperatures.
f) Reduce power.

Lambda=1

When the amount of air equals the amount of fuel for complete combustion, and there is no excess air, Lanbda =1 (The same as the stoichiometric air fuel ratio of 14:1)

When there is excess air, the air fuel ratio is > than 14:1. Lambda is >1.
When there is insufficient air, the air fuel ratio is <14:1. Lambda is <1.

K-Lambda CIS systems control fuel A/F ratio by:
a) The **control pressure regulator** changing the fuel **control plunger** slit size.
b) Changing the pressure drop at the control plunger slit by adjusting pressures in the lower 2 chambers of the differential-pressure valves in response to the lambda sensor (O_2 sensor) in the exhaust system. The result is fuel flow changes for a given fuel **control plunger**r lift.
The lambda CIS fuel injection system consists of:
a) Lambda sensor (O_2 sensor).
The lambda sensor sends a voltage signal to the PCM in response to the O_2 content in the exhaust gasses. A low voltage, lean signal <0.45 volts indicates low O_2 content in the exhaust gas. A high voltage rich signal >0.45 volts indicates low O_2 content in the exhaust gas.
b) **Lambda valve**.
The **lambda valve** is a duty cycle solenoid. The on/off frequency is controlled by the PCM in response to lambda sensor voltage (O_2 sensor voltage).
The amount of time the lambda valve is open determines the amount of fuel that is to returned the fuel tank, which controls the pressure in the lower chambers of the pressure differential valves.
This changes upper chamber pressure, which changes pressure drop, which in turn changes fuel flow at the slits, and hence A/F ratio.

CIS Diagnosis and Repair

1) Cold engine, hard start or won't start.
a) Air intake system leaking.
b) Air flow sensor plate sticking.
c) Cold start valve or thermo switch inoperative
d) Defective fuel pump.
f) Defective control pressure regulator.
g) ECT sensor faulty.
h) Low fuel pressure.

2) Hot engines won't start.
a) Air flow sensor plate sticking.
b) Cold start valve leaking.
c) Clogged or leaky injectors.
d) Defective fuel pump.
e) Defective control pressure regulator.
f) Lambda control problem.

3) Idle problems
Incorrect idle speed, stalls, or idles too fast.
Result: Misfires, flooding, high CO and HC.
a) Auxiliary air regulator faulty.
b) Clogged/leaky injectors.
c) ECT sensor faulty.
d) Incorrect CO adjustment.
e) Intake air leak.
f) Leaky cold start valve.

4) Poor performance.
Result: High CO and/or HC.
a) Air sensor plate sticking.
b) Fuel tank vent blocked.
c) Incorrect CO adjustments.
d) Low fuel pressure.
e) Throttle plate not opening fully.

5) Lack of power
Result: High CO and/or HC
a) Incorrect fuel pressure.
b) Control pressure regulator faulty.
c) Throttle plate not opening fully.
e) Pre-ignition.

6) Hesitation, missing, surging on acceleration and under load.
Result: High CO and/or HC.
a) Air flow sensor plate misadjusted.
b) CO out of adjustment.
c) Cold start valve leaking.
d) Control plunger binding.
e) Defective fuel pump.
f) Fuel injectors clogged.
g) Fuel pressure too low/high.
h) Vacuum leak.

7) High fuel consumption
Result: High CO and/or HC.
A/F ratio < 14.7:1 or Lambda <1
a) Blocked return line.
b) CO setting too rich.
c) Cold start valve leaking.
d) Defective control pressure regulator.
e) Defective fuel pump.
f) Fuel pressure too high.
Any condition that results in A/F ratio > 14.7:1 or

8) Lambda >1 are lean mixture conditions with excess air resulting in:
a) A slower burning mixture.
b) Higher temperatures.
c) Increased emissions of HC.
d) Increased emissions of NO_x.
e) Loss of power.
f) Possible engine damage.

Electronic Fuel Injection (EFI) L and LH Jetronic

Pulsed fuel injection systems meter fuel to the engine by electronically controlling the amount of time that the fuel injectors are open. The main components of the pulsed systems are the air flow meter, the fuel injectors, and the PCM. The PCM must know the amount of air flowing into the engine to accurately calculate the fuel requirements of an engine under all conditions. This can be accomplished directly using an airflow sensor (MAF) or indirectly using a manifold absolute pressure sensor (MAP). All air entering the engine of pulsed injection systems must first flow through an air flow meter. The air flow meter measures air flow, which is an indication of load. That measurement is converted into an electrical signal and sent to the PCM, which uses this air flow information together with engine rpm and other sensor inputs to calculate injection duration/pulse width and to achieve the best air fuel ratio for operating conditions. The PCM times the injections to the rotation of the crankshaft.

Air flow metering system

Direct airflow measurement.

This system of measurement is called airflow metering and directly measures either the volume or mass of the air entering the engine. Airflow sensors send the PCM a voltage signal that is proportional to the airflow into the engine.

The following are types of air flow sensors used by EFI systems:

a) Air Flow Meter.
b) Heated film.
c) Hot wire.
d) Karman-vortex.

Vane Air Flow

Located in the intake air duct between the air cleaner housing and the throttle body, the vane air flow meter provides the PCM with information on engine load by measuring intake air volume. Intake airflow moves the meter's measuring plate, which causes it to deflect in proportion to the volume of air entering the engine. This movement is transferred through a shaft to a movable arm on the meter's potentiometer (variable resistor). This provides a direct measurement of the air intake by the engine. The air flow meter system compensates for engine wear, combustion chamber deposits, and allows EGR emission control without affecting the measurement of intake air. In addition, varying temperatures and aging components have no effect on accuracy because of resistors in the circuit. Bosh L-Jetronic uses an air flow meter. Refer to figure 9-6 and figure 9-7.If scan tool readings indicate a problem or a code is set, check the following:

1) The VAF sensor is provided with a 5-volt reference by the PCM. Refer to figure 9-8.
2) With ignition-on engine-off, voltage should be 3.5 to 4.2 volts. Always check the maintenance manual for specification ons the make and model vehicle you working on.
3) Signal voltage should decrease as airflow increases. Again, always check the maintenance manual because some systems use opposite voltage logic. That is voltage increases with an increase in airflow.
4) When using a scan tool, be aware many applications have a fail safe substitution voltage in the event of an open, short, or illogical value being sent to the **PCM.**

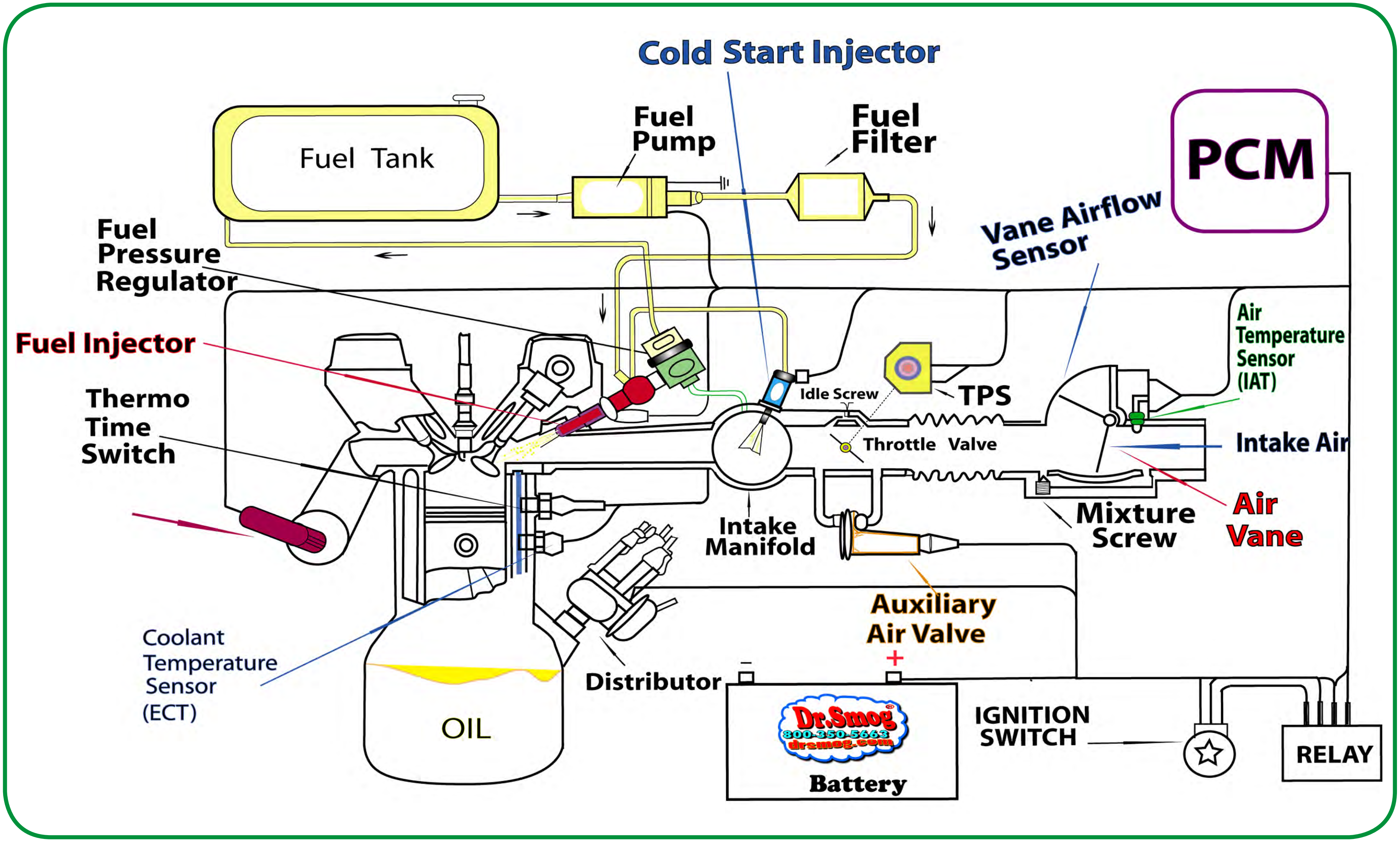


Fig. 9-6 is an example of a Bosh L- Jetronic Multi-Port Fuel Injection System (MPFI).
The LH-Jetronic is similar, except it uses a mass flow sensor (MAF) instead of a vane airflow sensor (VAF).

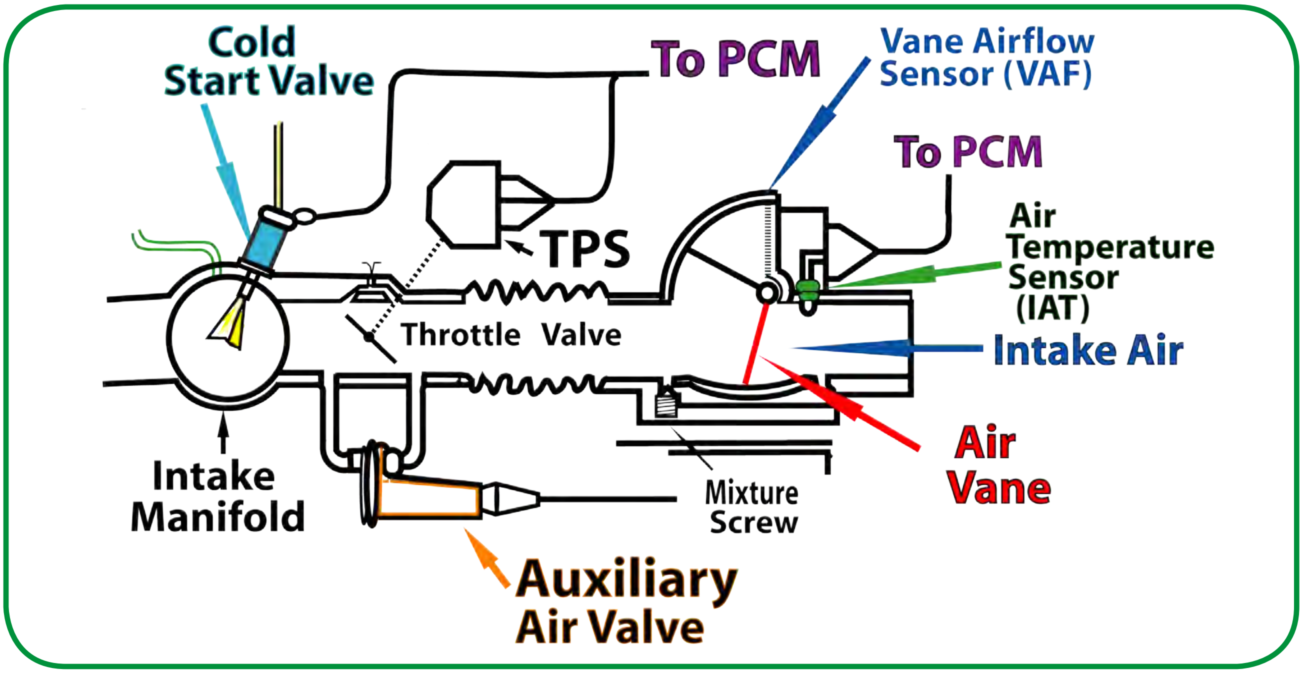


Fig. 9-7. Close up of the VAF of a L-Jetronic fuel injection system. The LH-Jetronic multiport fuel injection system (MFI) is similar, but it has a mass air flow sensor MAF instead of a VAF vane air flow sensor.

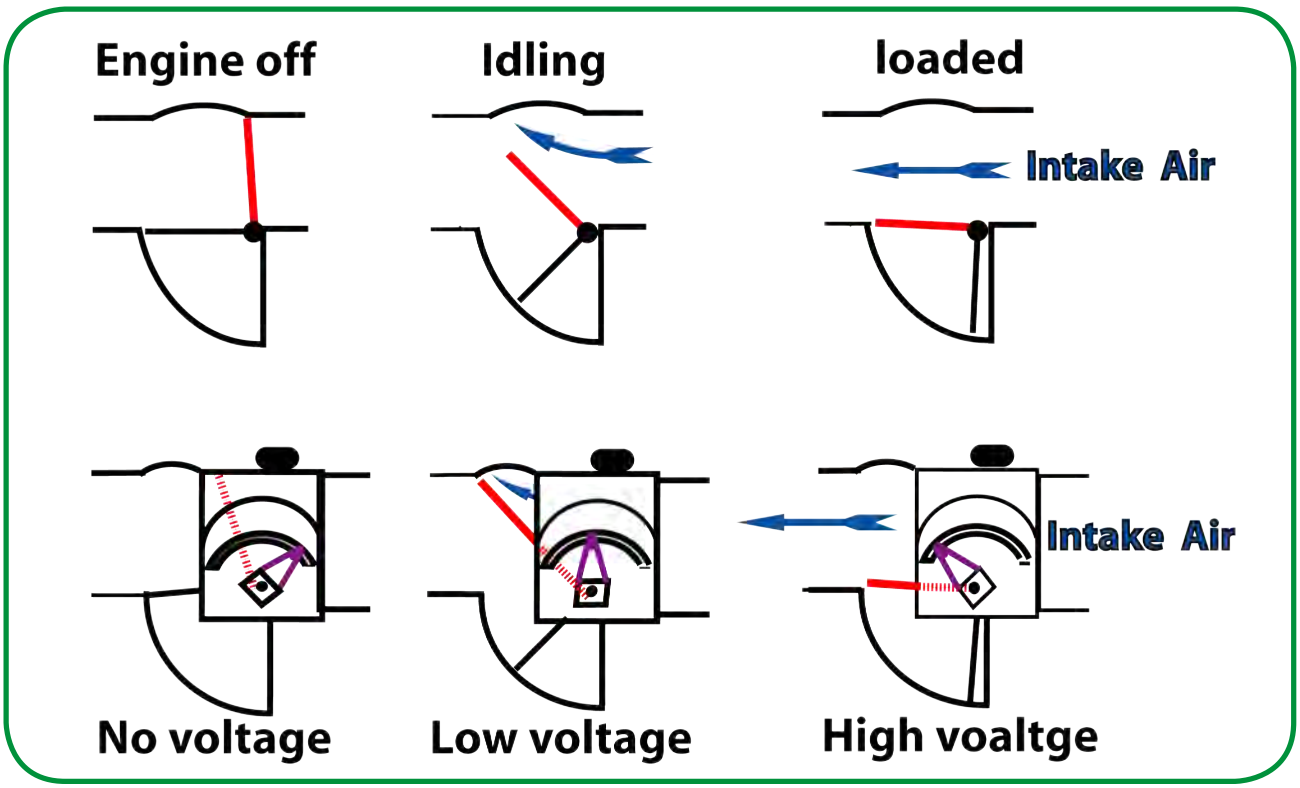


Fig. 9-8. The vane airflow sensor (VAF) is used by Bosch on their L-Jetronic fuel injection system and by many vehicle manufacturers on their MFI systems. The VAF sends a variable voltage signal to the PCM, which it uses for injector pulse width calculations.

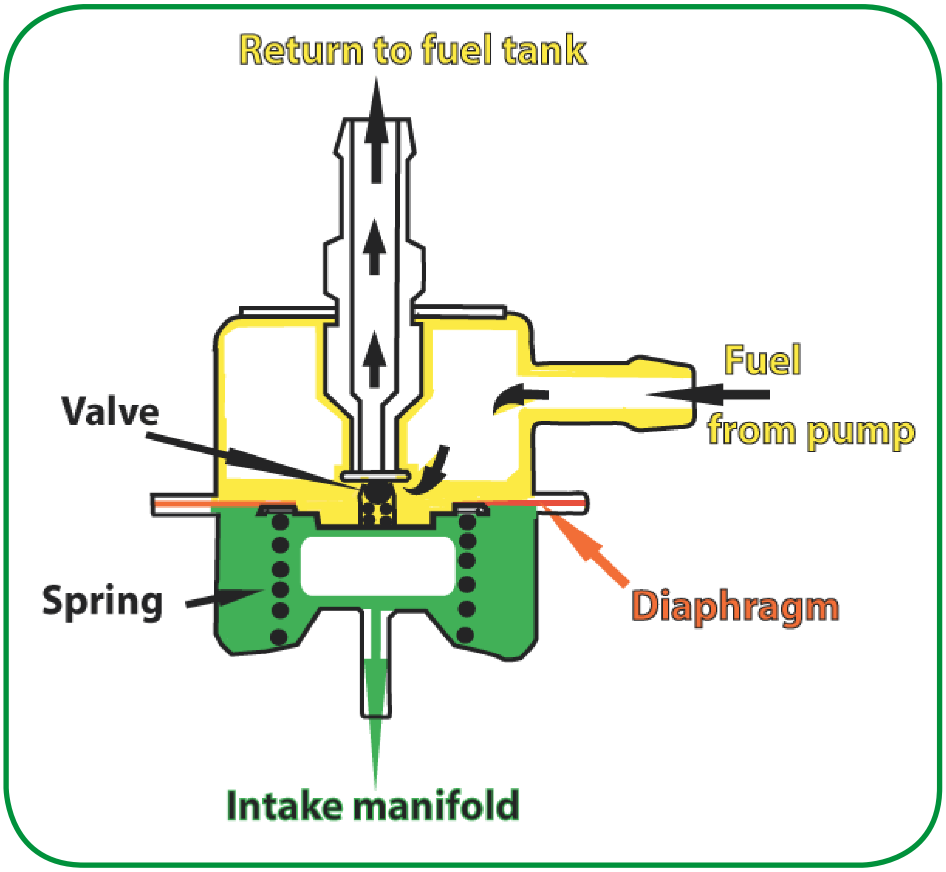


Fig. 9-9. The L-Jetronic fuel pressure regulator helps maintain a constant fuel pressure at the injectors under all conditions. Note:D-Jetronic fuel pressure regulator can be adjusted.

The electric fuel pump delivers approximately one gallon of clean pressurized fuel to the injectors every two minutes. This is more than is needed even under heavy load, so most of the fuel is returned to the tank by the fuel pressure regulator. The fuel tank is pressurized to 1-2 psi and controlled by a pressure relief valve in the fuel cap. Vapor lock is eliminated because the fuel is cooled by constant circulation, and the fuel is pressurized to approximately 60-90 psi (4.2-6.3 kg/cm2) by the fuel pump. Fuel is delivered from the pump through a check valve, which helps maintains constant pressure in the fuel rail and injectors ensuring quick starts and preventing vapor lock. A check valve, which closes when the fuel pump stops, holds pressure in the lines that ensures quick starts and prevents vapor lock.

Fuel Pressure Regulator

The fuel pressure regulator is a diaphragm operated relief valve with fuel injector pressure on one side and intake manifold pressure on the other. The function of the fuel pressure regulator is to maintain a constant fuel pressure at the injectors under all conditions. Refer to figure 9-9. Spring pressure keeps the regulator valve closed. When the pump is energized, fuel pressure presses on the diaphragm and compresses the spring. This opens the valve and allows fuel to return to the tank. The fuel pressure regulator compensates for engine load by increasing fuel pressure under low manifold vacuum conditions.

Fuel Injector

The port fuel injector is a solenoid valve. Refer to figure 9-10. The PCM opens the injector by grounding the circuit. The injector is closed by a spring. Fuel metering in pulsed injection systems takes place at the tip of the injector. The distance the needle valve opens is always the same, and since fuel pressure is regulated, the amount of fuel injected depends on how long the injector is energized/grounded by the PCM. The length of time the injector remains open is called pulse width and is measured in milliseconds. Pulse width ranges from 2ms to 16ms depending on conditions. See figure 9-11.

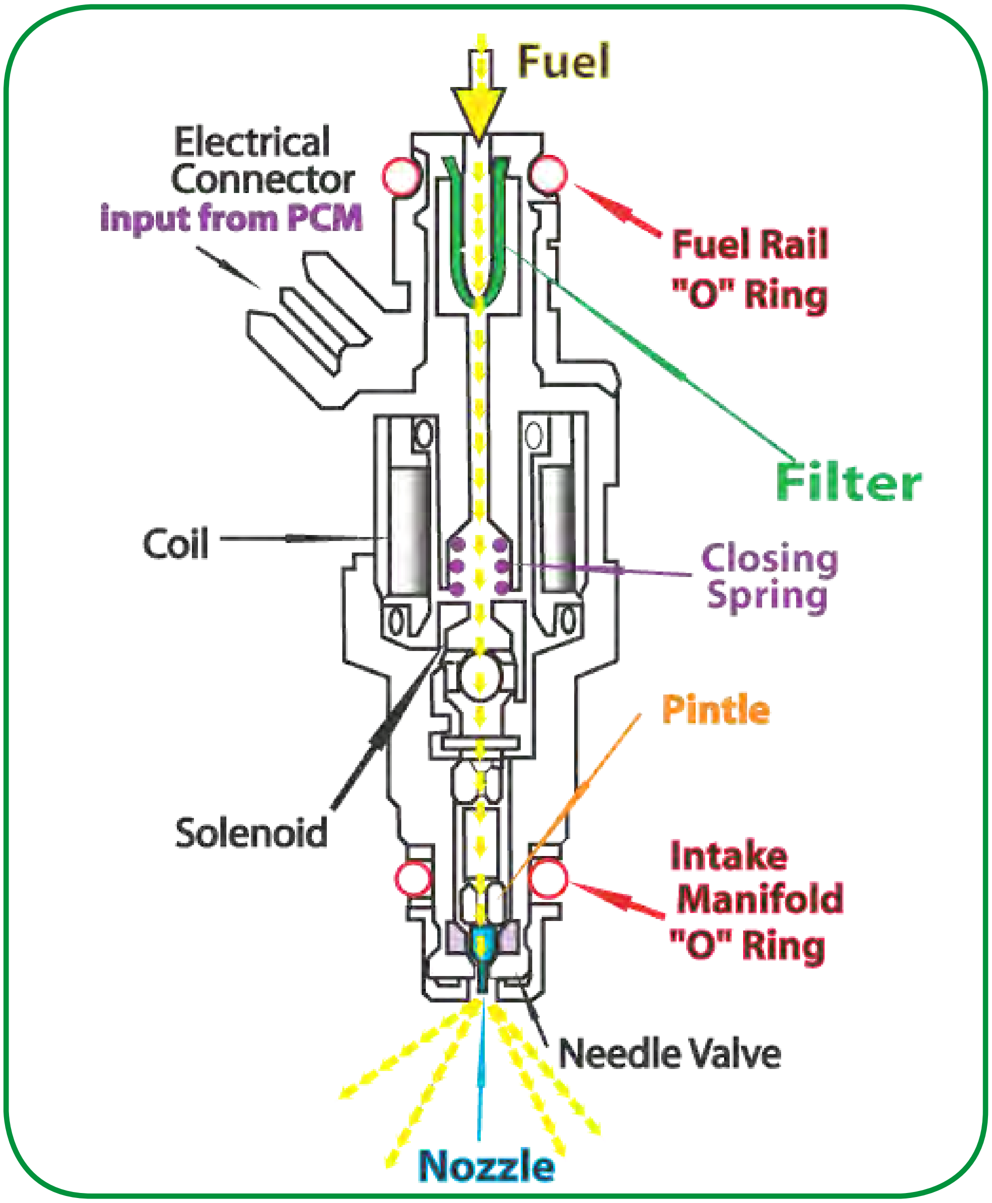


Fig. 9-10. A port fuel injector is a solenoid device controlled by the PCM grounding the circuit.

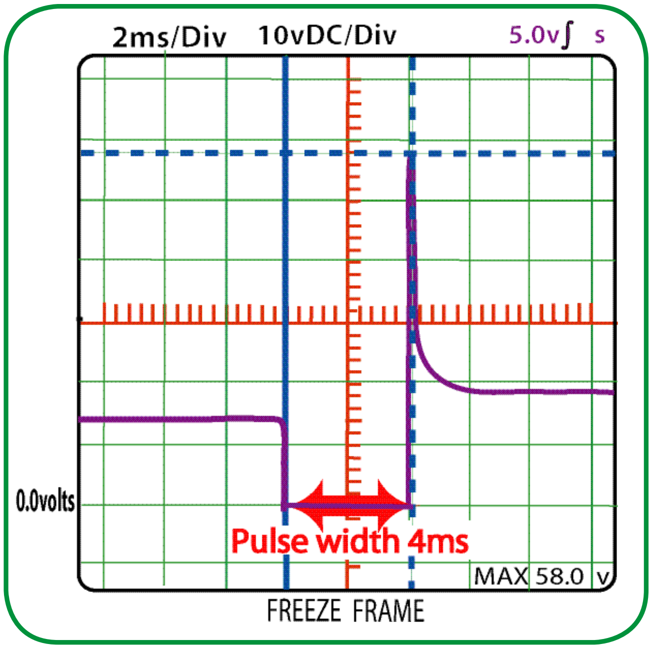


Fig. 9-11. Injector pulse width is the length of time a fuel injector is open after being grounded by the **PCM**.
Note:The voltage signal drops to 0v (ground) to open the injector.

Cold Start injector

The **cold start injector** is used to provide additional fuel during cold start cranking. The injector is only operational during cranking. Cold start injector circuit power is normally supplied directly from the starter solenoid. The circuit is fused separately. **Cold start injector**, sometimes called a cold start valve, does not usually operate through the PCM. A thermo time switch provides a ground path for the cold start injector when coolant temperature is below 95^{0}F (35^{0}C). The injector is held open for 1-8 seconds rather than milliseconds. A leak will cause the engine to run rich under all conditions.

Coolant Temperature Sensor (ECT)

The **ECT** is a thermistor, which changes resistance with temperature. Refer to figure 9-12. Most are NTC,which is Negative Temperature Coefficient. The PCM applies a voltage to the sensor. When the engine is cold, the sensor resistance is high, and the PCM will see a high voltage drop. As coolant temperature increases, resistance decreases and voltage drop decreases.

ECT input is used by the PCM for:

a) Cooling fan operation.
b) Injector pulse width.
c) Idle Air Control Valve (IAC).
d) Timing.
e) Torque Converter Clutch (TCC).

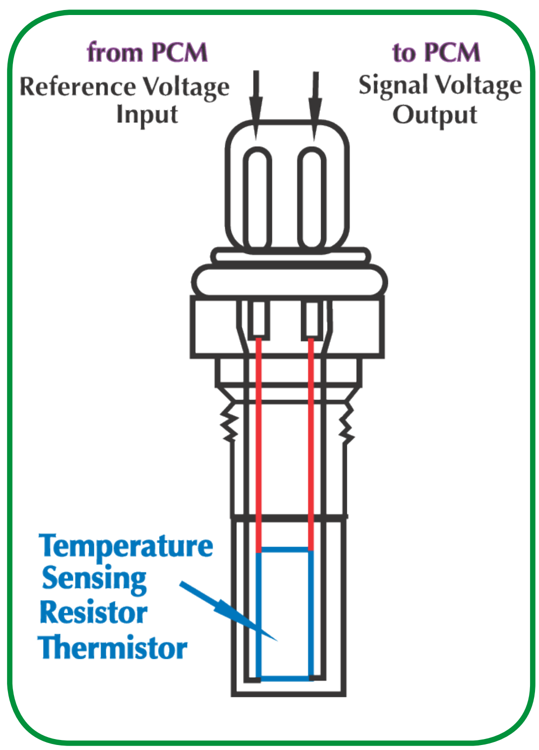


Fig. 9-12. An **ECT** uses a temperature-sensing resistor called a thermistor. The **PCM** applies a fixed voltage to the temperature-sensing resistor and receives a low voltage input signal back from a cold sensor with high resistance.

Intake Air Temperature Sensor (IAT)

The **intake air temperature sensor** is also a negative temperature coefficient (NTC) sensor. Since cold air weighs more than warm air and needs more fuel, a cold air, high voltage signal will result in the PCM increasing fuel injector pulse width and hence the amount of fuel injected.

Air/fuel ratio is a weight relationship. 14.7 lbs of air to 1 lb of fuel is the ideal air/fuel ratio. The combination of the input signals of air volume from the air flow sensor (VAF) and intake air temperature from the (IAT) sensor are the same as the inputs of weight or mass of air entering the engine. Refer to figure 9-13.

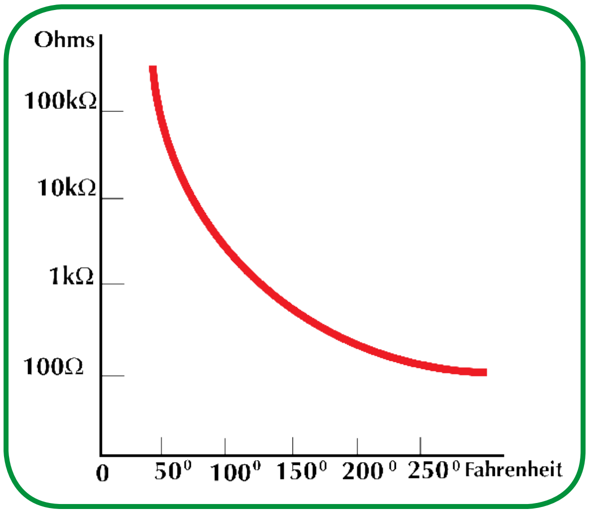


Fig. 9-13. Resistance of a NTC thermistor decreases as temperature increases.

Auxiliary Air Valve

The **auxiliary air valve** helps the engine idle smoothly when cold and takes the place of a fast idle cam on carbureted engines. Refer to figure 9-14. The air that bypasses the throttle valve has been measured by the **airflow sensor**. This means that the required fuel is being delivered by the injectors. There are two types of **auxiliary air valves**. Earlier ones are coolant heated, and later ones use a **bimetallic arm** wrapped with an electric heating element. When cold, the bimetallic arm moves a **blocking plate** to allow maximum bypass air. When warm, the **bimetallic arm** bends and spring tension closes the **blocking plate**. The position of the bimetallic arm depends on engine temperature and the length of time current flows through the heating element. When the engine is warm, the bimetallic arm is influenced mainly by the block temperature. When the engine is cold, the heating element is the main influence.

If the **auxiliary air valve** fails to open for cold starts, idle rpm will be too low. In this way, the **auxiliary air valve** can control the amount of bypass air as a function of engine temperature and maintain a target engine rpm at idle. If the auxiliary air valve fails to close when the engine is warm, idle will be too fast.

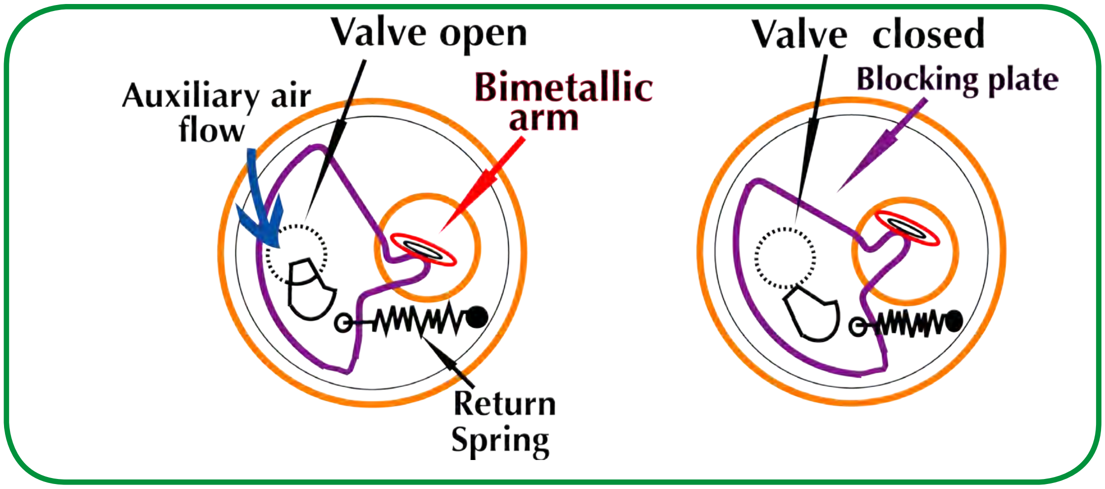


Fig. 9-14. The auxiliary air bypass valve closes when the **bimetallic arm** bends, and spring tension pulls the blocking plate closed.

On LH2-Jetronic systems, an idle speed stabilizer takes the place of the auxiliary air valve. On other systems, an idle air control valve (IAC) is either a stepper motor or a solenoid operated controls idle speed.
Refer to figure 9-15.

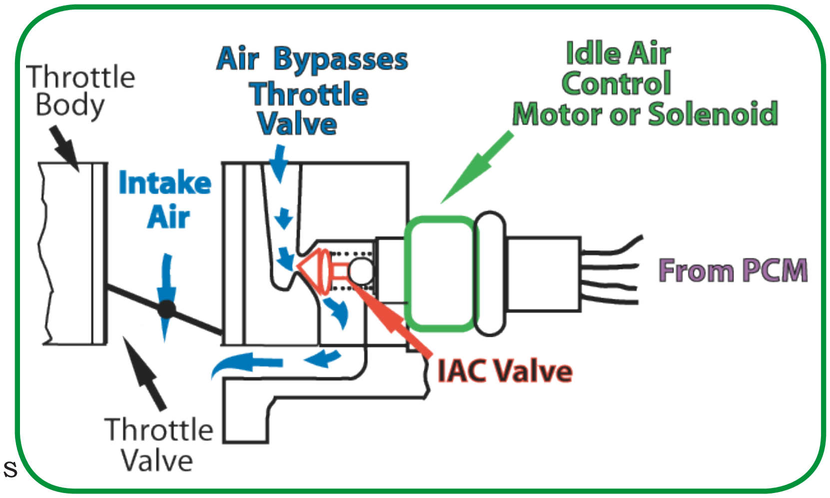


Fig. 9-15 is an example of an idle air control valve operated by a motor. Some systems use a variable duty cycle solenoid.

Hot wire Air Flow Sensors

The LH-Jetronic uses a mass airflow sensor, which has an advantage over the volume type sensors because it directly measures air mass not just volume. It also takes into account any factor effecting air mass or density, such as air temperature, humidity, and al altitude.

Hot wire (MAF) uses a platinum wire placed in the path of intake air and a temperature compensation resistor/IAT to measure intake air temperature. Refer to figure 9-16 . The PCM sends a constant current to the platinum hot wire to keep it at a specific temperature above the incoming ambient air temperature (200°C) depending on manufacturer's specifications. The greater the air flow (throttle opening), the more the hot wire cools, and the more current that the PCM must send to the hot wire to maintain it's temperature differential. The current is measured as a voltage drop by the PCM. Signal voltage increases with higher intake air mass.

The amount of intake air increases or decreases the temperature of the **hot wire**, and hence the voltage drop. The PCM uses this varying voltage signal to measure air flow and calculate injection pulse width. When the engine is shut down, the PCM heats the wire enough to burn off any dirt, thus maintaining its accuracy. Heated Film mass air flow sensors work on the same principles. Both send a digital square wave signal to the PCM. Figure 9-16 is another **hot wire** mass air flow sensor.

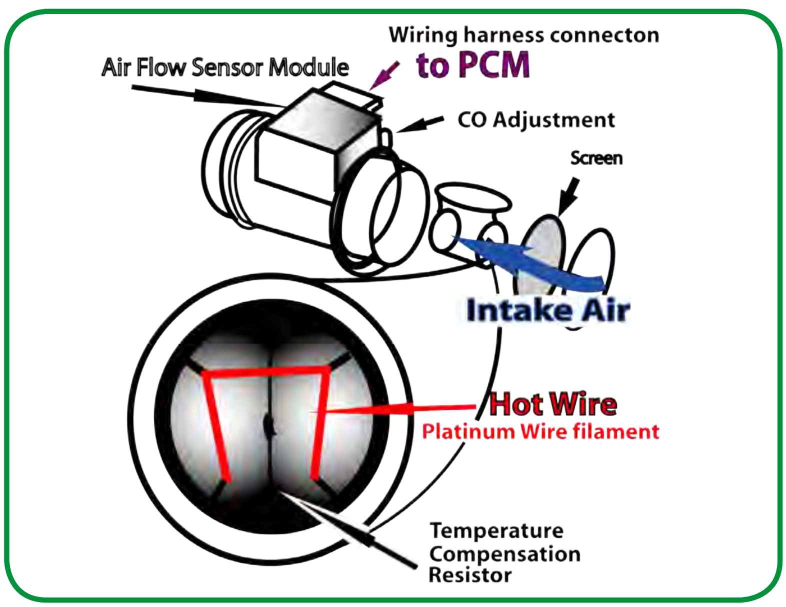


Fig.9-16. The LH-Jetronic fuel injection system uses a hot wire mass airflow sensor. Some systems use a heated film, which works the same way as the hot wire air flow sensor.

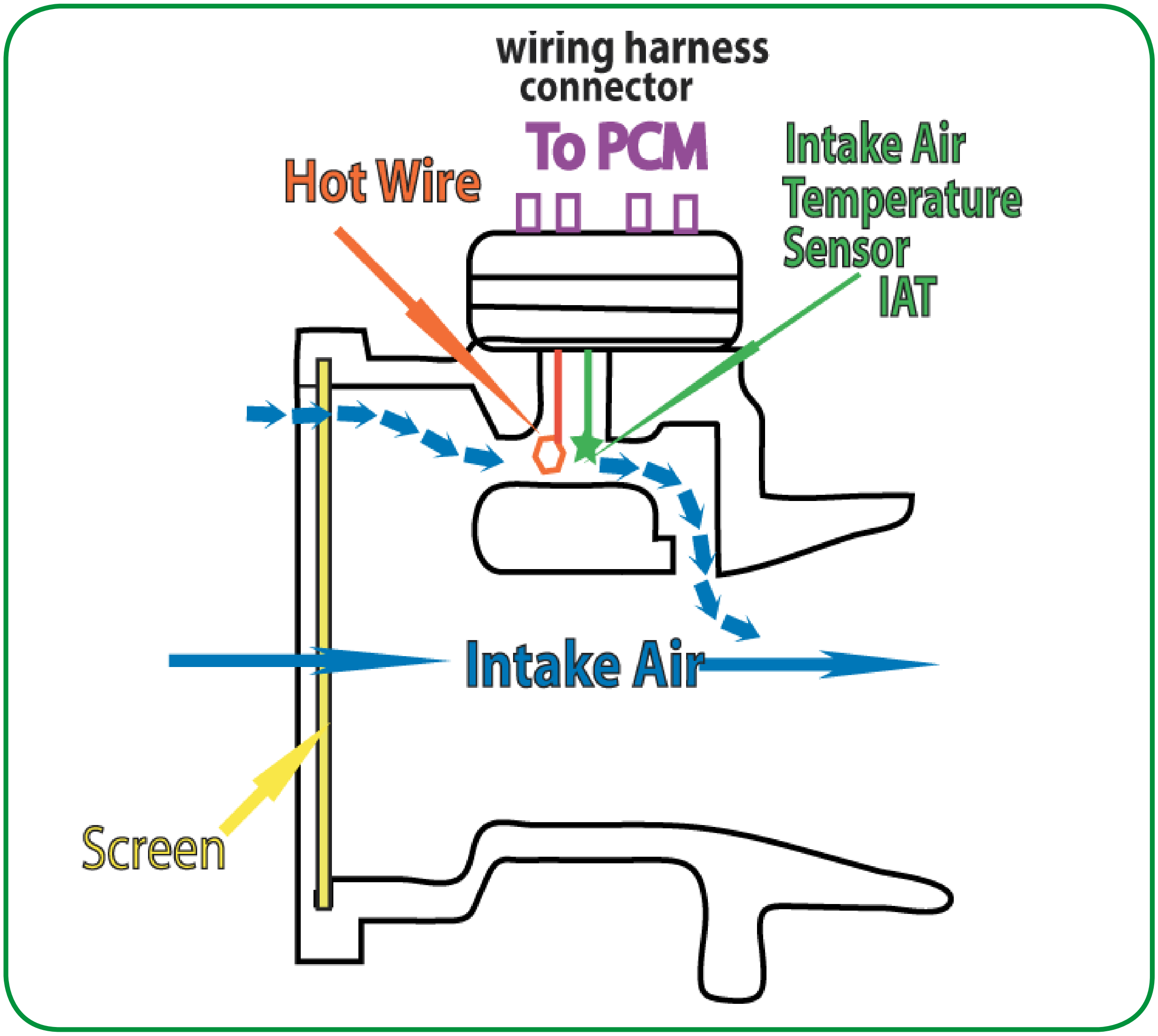


Fig. 9-17. An example of another design of a hot wire mass air flow sensor.

Hot wire

Unlike volume airflow sensors, hot wire airflow sensors use battery voltage B+ rather than a 5-volt reference. When this is the case on OBD II vehicles, the following rules apples:
1) A MAF reading of 0gm/sec indicates an open in the B+ circuit.
2) A MAF reading of 270 gms/sec or more indicates an open in the ground circuit.
As always, the technician must check the maintenance repair manual for the specifications of year/make/model you are working on. Refer to figure 9-17.

Karman-Vortex

Like the VAF, the Karman Vortex generator is located between the air cleaner housing and the throttle body. Refer to figure 9-18. As intake air passes through the air flow meter, the vortex generator creates a swirling effect. A sample of this pulsating air is then applied to a moveable foil mirror, which causes the mirror to flutter.

The oscillating mirror causes light from the LED to be alternatively applied and diverted from a phototransistor. The result is that the 5-volt Karman Vortex signal to the PCM is switched. This signal increases proportionally with intake airflow. Refer to figure 9-20. Some systems use ultra sonic sound waves, which strike the vortices. They speed up or slow down and create a variable signal at the receiver that rises and falls. The frequency of the signal is directly proportional to the airflow. This sound signal is converted to a square wave of variable frequency and sent to the PCM. Signal frequency changes with engine load.

a) Low frequency equals low airflow.
b) High frequency equals high airflow.

A temperature sensor is integrated into the meter assembly. A DSO (Digital Storage Oscilliscope) provides the best diagnostic information. Refer to figur e 9-19.

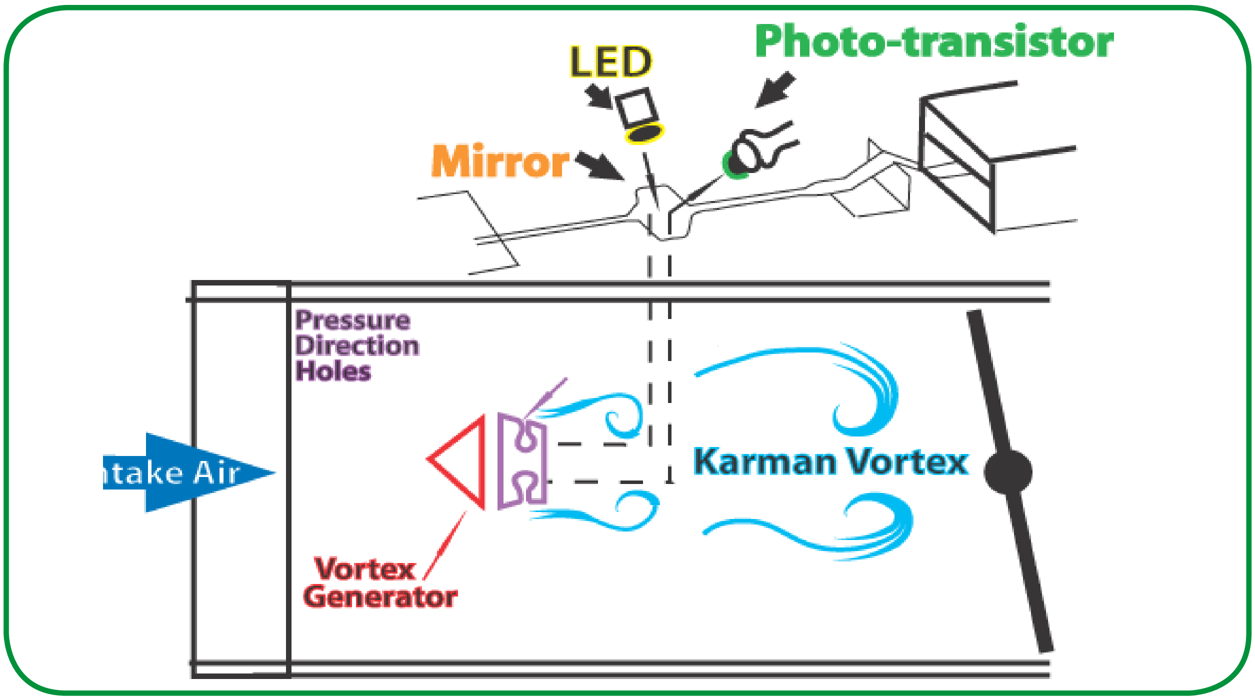


Fig. 9-18. Karman Vortex air flow meter.

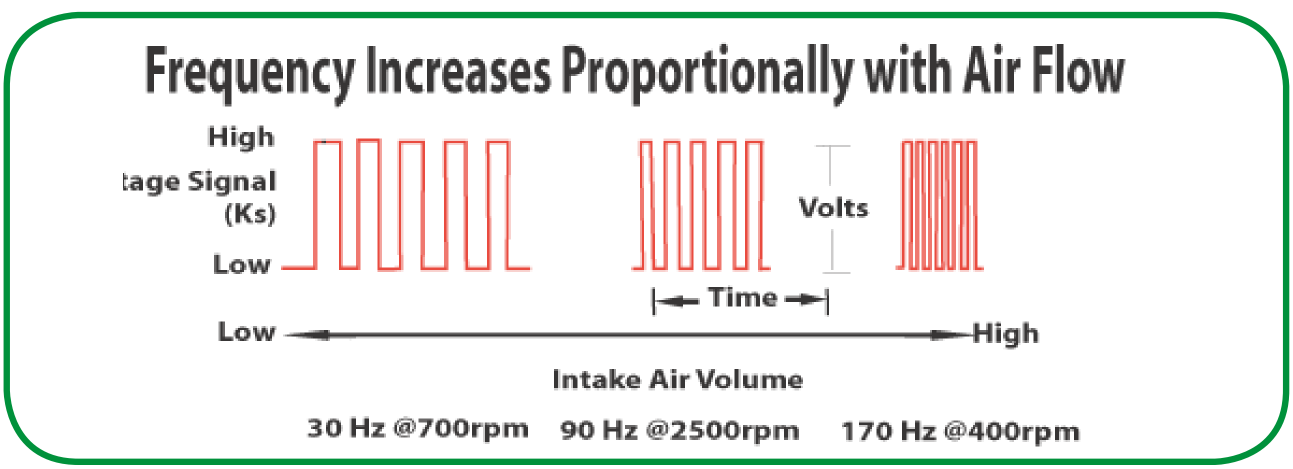


Fig. 9-19. Karman Vortex air flow meter square wave.

Throttle Body Injection Systems (TBI)

Throttle body fuel injection systems, which use one or two solenoid operated fuel injector(s), are located above the throttle plate. Refer to figure 9-20. The system is not as accurate as multi-port fuel injection systems. The same air fuel ratio is supposed to be supplied to all cylinders. However, as with carbureted engines, fuel may collect in the intake manifold. Thus resulting in puddling and cylinders at either end of the intake manifold receiving a richer mixture. Multi port fuel injection (MPI) solves this problem by having an injector for each cylinder. TBI systems provide feedback and are controlled by the PCM. They require the same input sensors as MPI systems, including a system to measure intake airflow, a coolant temperature sensor (ECT), a fuel pump pressure regulator, an idle air control valve (IAC), an intake air temperature sensor (IAT), an O_2 sensor, and a throttle position sensor (TPS). The actual type and number of sensors and actuators depends on the manufacturer.

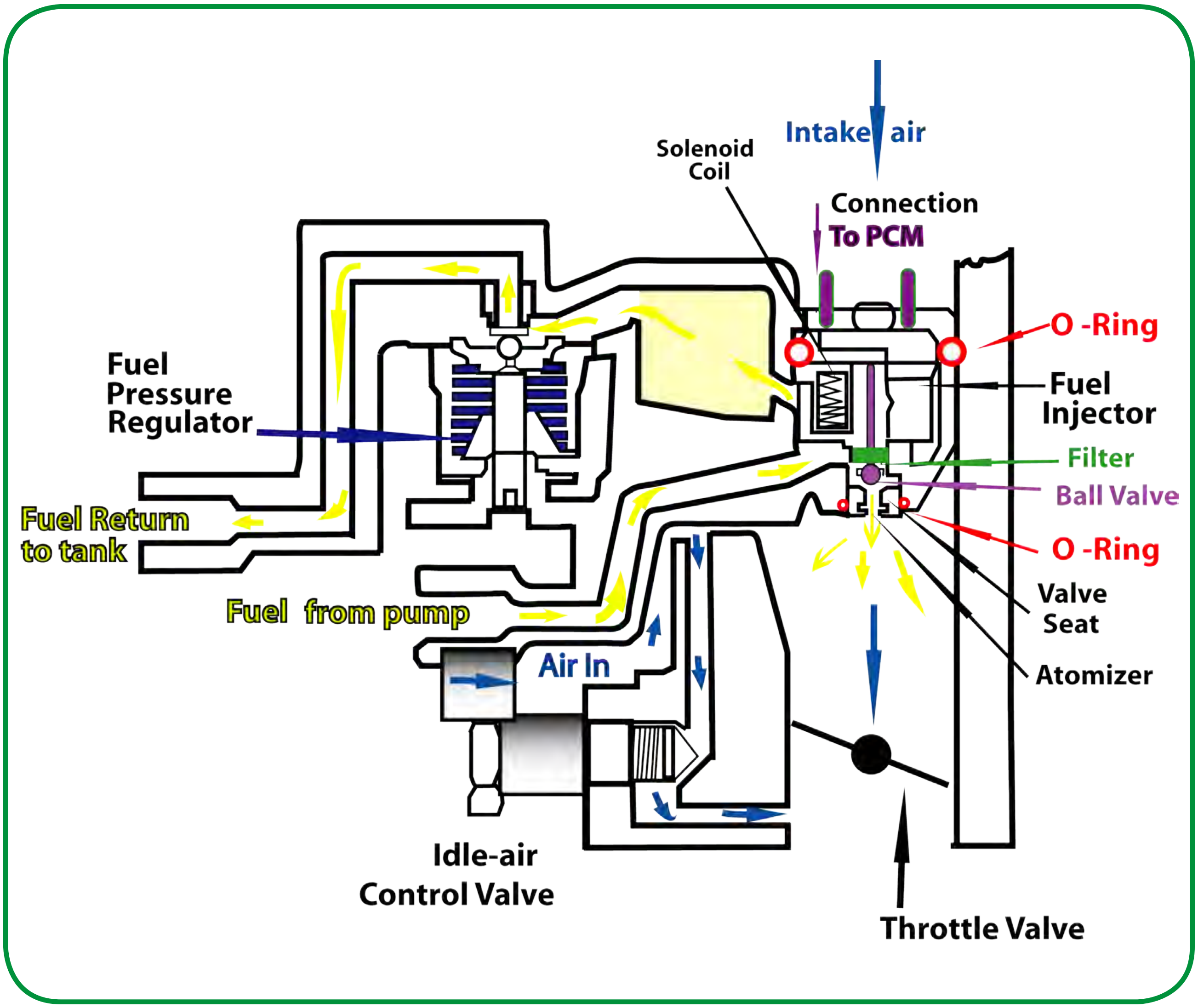


Fig. 9-20. Throttle body fuel injection assembly.

Speed density system

Indirect airflow measurement

The major inputs of a speed density system to the PCM are throttle position (TPS) or rpm and intake manifold vacuum (MAP) or engine load. The PCM uses these and other inputs for its fuel injector pulse width calculations. A MAP sensor provides the PCM with intake air volume information by monitoring changes in manifold absolute pressure, which varies in proportion to the amount of load on the engine. Refer to figure 9-21.

a) Low vacuum occurs when manifold pressure and engine load are high. Under these conditions, the engine requires a rich mixture and less spark advance.

b) High vacuum occurs when manifold pressure and load are low. Under these conditions, a lean mixture and more spark advance is appropriate.

The most common sensor uses a piezo-resistive element that flexes with changes in intake manifold pressure. This flexing causes the resistance of the element to change, which in turn changes the sensor output voltage signal to the PCM. This type of MAP sensor receives a 5-volt reference voltage from the PCM. The voltage signal is used by the PCM in combination with other inputs to calculate how much fuel is required (injector pulse width) for current engine operating conditions.

MAP sensor

A manifold absolute pressure sensor (MAP) is usually located on the engine compartment with a vacuum line to the intake manifold. Refer to figure 9-21. The sensor provides the PCM intake air volume/load information by monitoring changes in manifold absolute pressure. Voltage changes in proportion to engine load. The sensor uses a piezo-resistive element that flexes with intake manifold pressure. The flexing causes the resistance of the element to change, which in turn changes the sensor's output voltage signal to the PCM. Refer to figure 9-22,which represents the relationship between MAP sensor voltage and absolute pressure.

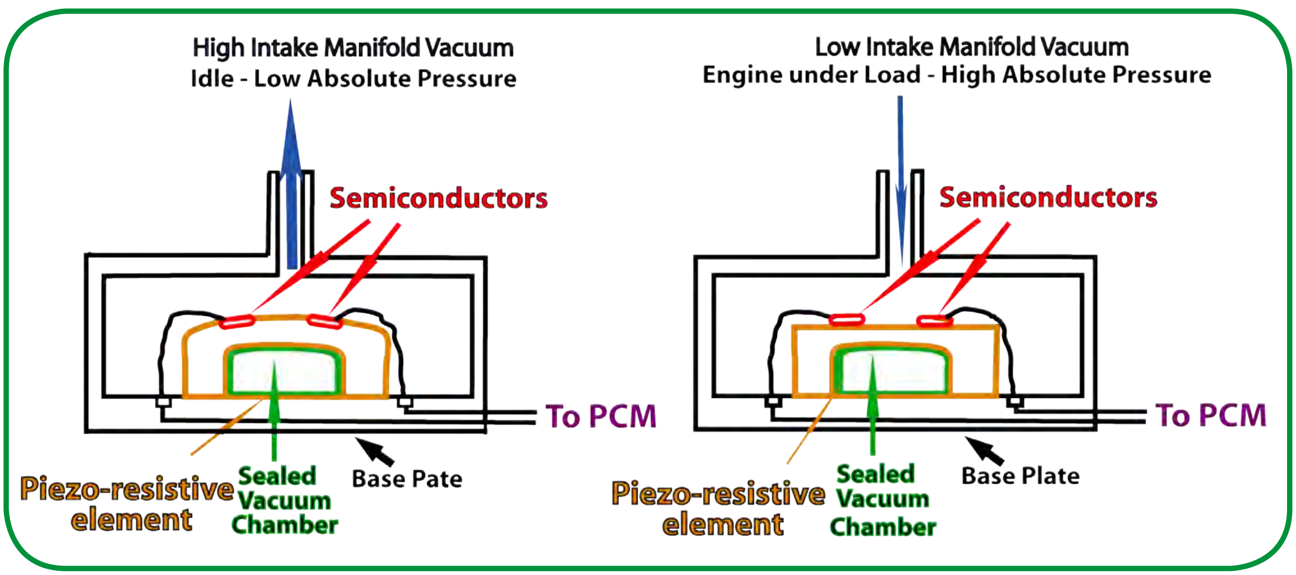


Fig. 9-21. Map sensor

The MAP sensor receives 5 volts reference from the PCM.
If the voltage at the PCM voltage input terminal is fixed once the engine is running and load is changed, the problem may be a restricted or plugged vacuum line or vacuum port.
MAP sensor calibration can be performed by using a hand held vacuum pump and the MAP sensor pressure/voltage values shown on the graph. Refer to figure 9-22.
When checking MAP sensor voltage output, keep in mind the effect of changes in altitude. The higher the altitude, the lower the voltage signal. Refer to figure 9-2 3.

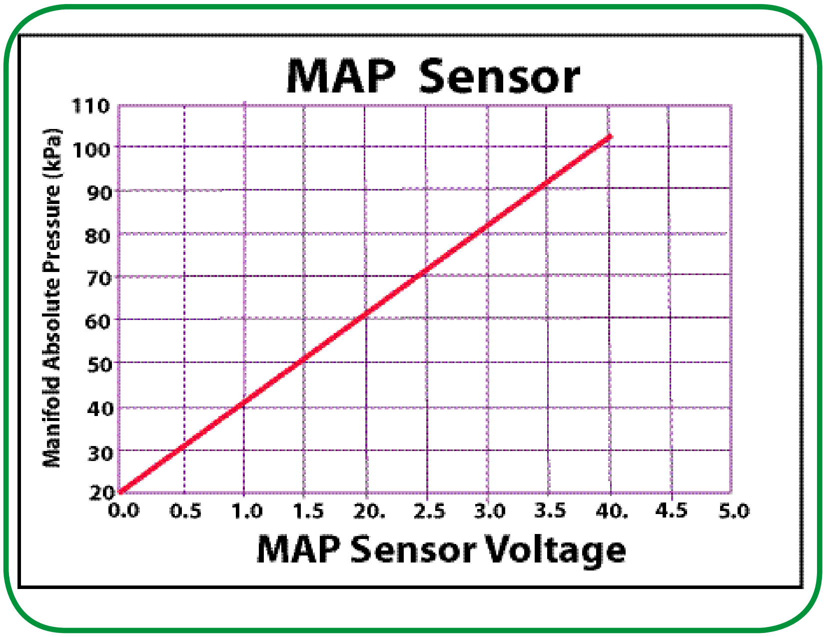


Fig. 9-22. Sensor voltage/ pressure graph.

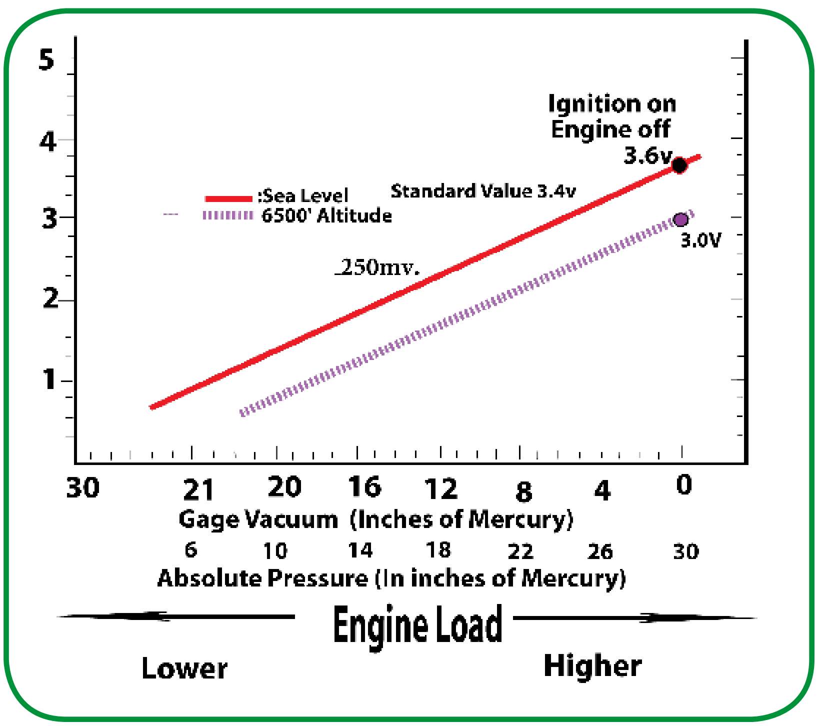


Fig. 9-23. The higher the altitude, the lower the MAP sensor signal voltage to the PCM.

The serial data stream represents manifold absolute pressure in inches of mercury. At sea level, atmosphere pressure equals approximately 30 inches of mercury.

Pulsed Injection

The design of the injector driver circuit determines when each injector delivers fuel in relation to the operating cycle of the engine. Depending on the engine manufacturer and application, the drive circuit may be either:

a) Simultaneous.
All injectors are pulsed together.

b) Grouped.
Injectors are grouped in pairs, and a separate driver circuit controls each group of injectors.

c) Sequential.
Each injector is timed to pulse separately just before each intake valve opens.

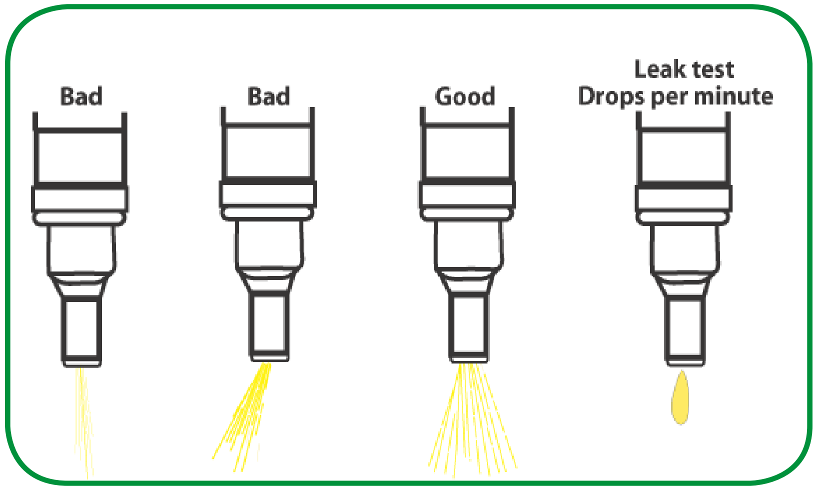


Fig. 9-24. Poor injector spray pattern causes lean driveability problems. The solution is the use of high quality detergent fuels and injector cleaning at major service intervals. Check drops per minute to diagnose a leaky injector.

Injector maintenance

The continuous use of high quality fuel with a level of detergent high enough to keep injector nozzles clean is the best maintenance and will reduce the need for injector replacement due to nozzle build up.

Engines using hole type injectors have fewer problems than those using injectors with pintle type injectors. Refer to figure 9-24.

When an injector has poor spray or bad spray pattern, fuel is not atomized or vaporized correctly.

The correct amount of fuel may even be delivered to the cylinders. However, the fuel will enter the cylinder as liquid droplets and will not burn. This will cause increased HC emissions and lean driveability problems.

Poor spray pattern and clogged injectors will cause similar symptoms.

2) To determine if fuel injectors are being pulsed, use an injector test light to access the injector wiring harness. A blinking light indicates normal driver circuit operation. Do not relay on serial data. The system may be in fuel cut off fail-safe mode, and serial data may display an injector pulse width even though the injectors are not operating.

3) To confirm that fuel delivery is taking place during cranking, use an exhaust gas analyzer to check HC in the exhaust. 2000 ppm is an indication that the injectors are delivering fuel. If the engine has a cold start injector, disconnect it for the test.

1. Cold engine: hard start, won't start.
a) Air flow meter faulty.
b) Defective fuel pump.
c) ECT faulty.
d) Injectors clogged.
e) Low fuel pressure.

2. Hot engine: hard start, won't start.
a) Air flow meter faulty.
b) Cold start valve leaking.
c) Residual fuel pressure problem.

3. Idle problems:
Incorrect idle speed, stalls, idles too fast.
Result: Misfires, flooding, high CO and HC.
a) Clogged / leaky injectors.
b) IAC faulty.
c) ECT sensor faulty
d) Incorrect CO adjustment.
e) Intake air leak.
f) Leaky cold start valve.
h) Low fuel pressure.

4. Poor performance
Result: High CO and/or HC.
Engine hesitates, misses, and/or stalls under load.
a) Air flow meter faulty.
b) Fuel injectors clogged.
c) Low fuel pressure.
d) Throttle plate not opening fully.
e) Throttle switch faulty.

5. Lack of power
Result: High CO and/or HC.
a) Air flow meter faulty.
b) Incorrect fuel pressure.
c) Throttle plate not opening fully.
d) Throttle switch faulty or misadjusted.

6. Hesitation, missing, surging on acceleration and under load
Result: High CO and/or HC.
a) Air flow meter faulty.
b) Cold start valve leaking.
c) Defective fuel pump.
d) Fuel injectors clogged.
f) Fuel pressure too low/high. No fuel delivery.
g) Throttle switch faulty.
h) Vacuum leak.

7. Emissions test failure, high fuel consumption
Result: High CO and/or HC.
a) Blocked return line.
b) CO setting too rich.
c) Cold start valve leaking.
d) Defective fuel pump.
f) Faulty Lambda/O_2 sensor.
g) Fuel pressure too high.
h) Fuel pressure regulator diaphragm leaking.

SECTION 10

Section 10 Engine Management-OBD

OBD HISTORY
OBD I was required by the California Air Resources Board (CARB).

OBD I REQUIREMENTS
Warning Light.
Detection of faults with Fuel System, EGR system and related emission components.
Store and transmit emission related code failures.
However, there was no standardization between manufacturers. As a result, CARB got together with the EPA and SAE. The result was OBD II.

OBD II REQUIREMENTS
An OBD II system meets government regulations by monitoring the emission control system. When an emission component or system exceeds thresholds or a component operates outside of tolerance a DTC and Freeze Frame will be stored and the MIL illuminated.

OBD II REGULATIONS
OBD II is a set of rules and regulations developed by CARB, EPA (Environmental Protection Agency), and SAE (Society of Automotive Engineers). Automobile manufacturers are required to comply with the OBD II rules and regulations on all 1996 and newer vehicles depending on the vehicle's Gross Vehicle Rating.
OBD II regulations specify what components and systems are to be monitored and the number of trips as well as defining specific types of systems and component monitoring and tests. When systems or components exceed emission standards a DTC will be stored and the MIL will be illuminated no later than the end of the second drive cycle if the fault is either repeated or remains from the previous drive cycle. Fault detection and MIL operation are associated with Trips and Drive Cycles.
Each OBD II monitor has its own requirements for setting and clearing DTCs, erasing Freeze Frame information and controlling the MIL. These requirements vary between manufacturers.

OBD II GOALS
The goal of OBD II's regulations is to provide an onboard diagnostic system which is capable of continually monitoring the efficiency of the emissions control system and to improve diagnosis and repair when failures occur. The result is that we all breathe cleaner air.

STANDARDIZATION (CARB, EPA, SAE)
Standard DLC connector and repair tools.
Store freeze frame data in memory when a DTC fault occurs and is stored.
Scan tool access to DTCs, freeze frame data, DTC clearing and readiness tests.
Monitor on board emission related components.
Manufacturers must provide tampering protection for PCMs that are programmable.

DATA LINK CONNECTOR

The data link connector (DLC) is a 16 pin connector designed and keyed so a scan tool can be connected only one way and with one hand. Generic scan tools must be able to connect to the DLC and access the diagnostic serial data.

SERIAL DATA

Serial data is a series of rapidly changing voltage signals pulsed from high to low voltage. This is how computers communicate with each other. In this case, the PCM and your scan tool do the communicating.

BAUDE RATE

The rate at which bits of computer information are transmitted.

ENABLING CRITERIA

Enabling criteria are the operating conditions necessary before the OBD II system can run a diagnostic check on a particular system or component. They **may** include elapsed time since engine start up, warm-up parameters, acceleration, deceleration or maintaining a certain RPM for a specified time period.

FREEZE FRAME DATA

This is a picture in time, a minature snapshot (one frame of data) that is automatically stored in the PCM memory whenever an emissions related Diagnostic Trouble Code (DTC) is stored. If the DTC is for fuel control or engine misfire and the fault occurs at a later time under similar conditions, the newest data is stored and the earlier information is lost. The stored information can be retrieved on a scan tool at a later time for analysis. The ability to see the values and circuit conditions when the fault acutally occurs is a valuable tool, especially when dealing with intermittant faults. The following information is captured in Freeze Frame:

Calculated Load Value	Engine Coolant Temperature
Engine RPM	MAP
Short Term Fuel Trim	Open Closed Loop Status
Long Term Fuel Trim	DTC stored with Freeze Frame
Vehicle Speed	Cylinder ID if a misfire is detected

MIL

The MIL alerts the the driver the PCM has detected an OBD II emission related component or system malfunction. When this happens an OBD II DTC will be set. The MIL is for emission faults only. There may be drivability codes in memory, however, they will not illuminate the MIL. The MIL is located on the dashboard and labeled “Check Engine.” (CARB, EPA). There is power to the MIL whenever the ignition switch is in the on or run position. The MIL is extinguished after repair by using a reset command from a scan tool. If the battery is disconnected it will extinguish the MIL and erase both the DTC and Freeze Frame information. The MIL is only used for emssion related faults.

If the engine completes three consecutive trips, that is, three consecutive trips in which the monitor setting the DTC is run and passes, the MIL will be turned off. However, the Freeze Frame data and DTC will remain in memory. If the vehicle completes 40 warm up cycles without the same fault reoccuring, the DTC and Freeze Frame data are automatically erased from the PCM memory.

MANUAL CLEARING

The MIL can be turned off and any stored DTC, or Freeze Frame data can be erased using a scan tool. Although not recommended, if the battery is disconnected any stored DTCs or Freeze Frame data will be erased from memory. In addition, the PCM will extinguish the MIL when all the enabling criteria for a particular diagnostic monitor are met and the diagnostic monitor is run on three consecutive trips without the fault reoccurring. A trip is completed when the ignition switch is turned off.

SIMILAR CONDITIONS

To illuminate the MIL or to extinguish it when it is illuminated for Misfire or Fuel System Monitor the vehicle must meet similar operating conditions, that is:

1. Engine speed within 375 RPM.
2. Engine load within 10%.
3. Engine operating temperature (cold or warmed-up)

WARM-UP DEFINITION

Most OBD II stored DTCs and Freeze Frame data will be erased after 40 warm-up cycles if the fault is not repeated after the MIL is turned off. (CARB, EPA). A warm-up cycle is engine operation after an engine-off period with engine coolant temperature rising at least 40° F and reaching at least 160 °F.

OBD II DRIVE CYCLE

A drive cycle is the specific method used to satisfy all of the different Trip Enabling Criteria and to run all of the OBD II diagnostic monitors. This requires the vehicle to be operated under a variety of conditions. What follows is a possible list:

1. Ensure the fuel tank is between a quarter and three quarters full.
2. Start cold (below 86° F/30° C) and warm up until the engine coolant is at least 160°F/71° C - one minute minimum.
3. Accelerate to 44-55 MPH at 25% throttle and maintain speed for five minutes.
4. Decelerate without using the brake (coast down) to 20 MPH or less, then stop the vehicle and allow the engine to idle for 10 seconds, turn the key off, wait one minute.
5. Restart the engine, accelerate to 40-55 MPH at 25% throttle and maintain speed for two minutes.
6. Decelerate without using the brake to 20 MPH or less, then stop the vehicle.
7. Allow the engine to idle for 10 seconds, turn off the key and wait for one minute.

The OBD II DRIVE CYCLE is a specific method used to perform all Trip Monitor tests.

ONE TRIP DETECTION LOGIC

This means that on the first trip that an OBD II monitor detects a misfire or fuel system fault the MIL is illuminated and DTC and Freeze Frame data are stored in PCM memory

TWO TRIP DETECTION LOGIC

This means that on the first trip that an OBD II monitor detects a fault a maturing code is set. The Maturing Code is set and the MIL illuminated when the fault occurs on two consecutive trips.

MATURING CODE

A maturing code occurs when a DTC and Freeze Frame are stored in PCM memory on a temporary basis because the fault that set the DTC has not occurred on two consecutive trips and caused the MIL to illuminate.

OBD II OPERATING SYSTEM

The computer program that operates OBD II is called the Diagnostic Executive or Task Manager.

DIAGNOSTIC EXECUTIVE / TASK MANAGER

The DIAGNOSTIC EXECUTIVE is the computer program inside the PCM that coordinates the self-monitoring system. The EXECUTIVE continually tests OBD II (that is, itself) to evaluate system and component performance and to coordinate all of the self monitoring functions. The program software initiates, directs, processes and communicates the results of these tests. The OBD II diagnostic system continually monitors all engine and transmission sensors and actuators for opens, shorts and out of range values as well as values that do not logically fit rationally with other engine data.

A. Executive Testing

The EXECUTIVE conducts the following categories of tests:

1. Passive

A passive test monitors a component or system without effecting its operation. An example would be open or a short circuit. When a passive test fails, an active test starts. An example would be an open in the ECT sensor.

2. Active

An active test is when the EXECUTIVE sends a test signal on a circuit that has failed to evaluate the response. Active tests do not suspend system control or operation. For example, by momentarily switching secondary air upstream of the oxygen sensor during closed loop, the PCM can monitor the oxygen sensor response and corresponding injection pulse width increase to determine if the secondary air is functioning within normal parameters.

3. Intrusive

An intrusive test effects engine performance and emissions. The EXECUTIVE only runs this test after the passive and active tests have failed. An example of this would be when the degree of rich correction to the fuel delivery system is measured by the PCM when it momentarily interrupts EGR flow to check that the EGR system does in fact put exhaust gas in the intake manifold.

B. Monitoring Delays

The EXECUTIVE must prioritize and sequence all monitors and often must delay completion of a monitor because not all the criteria for completion have been met. When a delay occurs they fall into the following categories:

1.Conflicting

Conflicts occur when different monitors use the same circuits and or components. The EXECUTIVE makes sure one test is complete before another begins. This way a test being run does not adversely effect the outcome of another. For example, both EGR and EVAP tests of some systems monitor Short Term Fuel Trim for response. To avoid conflicts the EXECUTIVE runs one test at a time.

2.Pending

The EXECUTIVE runs some secondary tests only after the system has passed some primary tests. When these secondary tests are delayed awaiting the results of primary tests they are considered pending. For example, the HO2 monitor fails and a DTC and Freeze Frame data are stored and the MIL illuminated. The EXECUTIVE will not run the CAT efficiency monitor "pending" the resolution of the HO2 sensor problem.

3.Suspended

Each test is prioritized. A suspended test occurs when a test with a low priority is suspend so that one with a higher priority can run. For example, the EXECUTIVE may have a first trip fault DTC and Freeze Frame data stored in memory for a two-trip system on, for example, the HO2. The EXECUTIVE will run the EGR monitor but suspend the results until the HO2 sensor has passed or failed the second trip. This way, the EXECUTIVE can determine where the fault lies because both monitors use the HO2 sensor.

COMPREHENSIVE COMPONENT MONITOR (CCM)

The OBD II diagnostic system **continuously** monitors all engine and transmission sensors and actuators for: (CARB, EPA)

1. **Shorts** - Oxygen sensor insulation burnt through to the wire and shorted to the exhaust manifold.
2. **Opens** - The ECT wire broken at the terminal.
3. **Out of range values**
4. **Rationality** - In addition to the CCM monitoring input and output signals for opens or shorts, rationality is monitored. That is, input signals are compared with other input data to see if they fit logically with other current operating data.
5. **Functionality** - Functionality tests monitor output circuits by comparing voltage signals from one device to another. An example would be the comparison of the upstream and the downstream oxygen sensor wave form/cross counts to monitor CAT efficiency. The EGR system and oxygen sensors are also monitored for functionality. On the first trip in which the CCM detects a fault that will result in emission levels exceeding the Federal Test Procedure (FTP) by 1.5 times the PCM will:

a. Store a DTC
b. Illuminate the MIL
c. Store a Freeze Frame.

Freeze Frame data is for the first failure and not updated, except for misfire and fuel monitors, both of which are updated with the latest event data. By monitoring the O2 sensor and injection as the EVAP canister is being purged, the PCM can detect the reduction in exhaust oxygen content and the corresponding decrease in injector pulse width to correct for the momentarily rich condition. In this way the PCM can detect a failure in the canister purge control system, illuminate the MIL and store a DTC and Freeze Frame in memory.

MAIN SYSTEM MONITORS

The OBD II diagnostic system actively tests some systems for proper operation while the vehicle is been driven. The following are Main System Monitors:

1. Continuous Monitoring (CARB, EPA)

The following systems are monitored continuously, i.e., during the entire time the vehicle is in operation:

a. Fuel Control System
b. Engine Misfire Detection System

Note - The Freeze Frame data for both the Fuel Control and Misfire System is updated each time a failure occurs.

2.Tested Once per Trip (CARB, EPA)

On the first trip that the fault occurs a DTC and Freeze Frame data are stored. On the second consecutive trip the MIL is illuminated. The following are monitored once per trip, that is, one time per key-on/key-off cycle:

a) Catalytic Converter Efficiency System
b) EGR System
c) EVAP System
d) Oxygen Sensor System
e) Oxygen Sensor Heater System.
f) Secondary Air System

CONTINUOUS MONITORING

1. The Fuel Control System Monitor

The fuel system is required to be monitored continuously to evaluate its ability to control fuel delivery. The OBD II diagnostic system uses two parameters to evaluate how well the control system is regulating the air fuel ratio, Short Term Fuel Trim and Long Term Fuel Trim. Short Term Fuel Trim is a temporary correction to fuel delivery which changes with every cycle of the oxygen sensor. Under normal conditions it fluctuates around its ideal value, 0% correction and is only functional during closed loop operation.

Short Term Fuel Trim is a parameter on the OBD II data stream that can be displayed on a Scan Tool. Its normal range is +/- 20% but under normal operating conditions rarely goes beyond +/-10%. When, for example, the oxygen sensor, engine coolant temperature sensor, and time conditions are met and the throttle opening is less than 80%, the system goes onto closed loop. Closed loop means that the PCM adjusts fuel injector pulse width based on the varying signals from the upstream heated oxygen sensor (HO2S).
Short Term Fuel Trim responds to changes in HO2S output. If basic injection duration results in a lean air fuel ratio, Short Term Fuel Trim responds with positive corrections (+1% to+20% to add fuel or enrich the mixture). If basic injection duration is too rich, Short Term Fuel Trim responds with a negative correction -15 to -20% to subtract fuel or leaning the mixture.

The PCM uses the Long and Short Term Fuel Trim together to adjust pulse width for low emissions power and economy. When the system is in closed loop the PCM's adaptive strategy learns the changes to pulse width required to compensate for a bias rich or lean condition. If after a specific time Short Term Fuel Trim is still compensating, the PCM learns this and makes the necessary changes to Long Term Fuel Trim.

For example, if Short Term Fuel Trim is compensating for a lean condition and is +14%, after a specified time the PCM learns this and adds this value to Long Term Fuel Trim. If the Long Term Fuel Trim becomes excessively high or low it indicates a loss of fuel control. This will be the case when Long Term Fuel Trim reaches a +% or -% value that would allow emissions to exceed 1.5 times the FTP.

On the first trip that a Long Term Fuel Trim value is detected by the Fuel Control Monitor that could result in emissions exceeding the FTP by 1.5, a temporary DTC and Freeze Frame Data are stored in the PCM memory. If the fault **does not** occur on the second consecutive trip the DTC and Freeze Frame Data are erased from memory. If the fault occurs on the next trip, that is, the same fault occurs on two consecutive trips, the DTC becomes a hard code, the Freeze Frame Data is updated to reflect the latest fault and the MIL is illuminated. If the fault does not occur for three consecutive trips after this, the MIL will be extinguished and after 40 warm-up Cycles without the same fault the DTC and Freeze Frame Data will be erased from memory.

2.The Engine Misfire System Monitor

OBD II dictates that the engine must be monitored continuously for misfires under all operating conditions. That means at idle, acceleration and cruise the misfiring cylinder must be identified, and sequential fuel injectors shut off to the misfiring cylinder. The monitor can detect single or multiple misfires. When a single misfire occurs the misfire monitor must identify the cylinder in the freeze frame. Most misfire monitors use a camshaft position sensor (CMP) and a crankshaft position sensor (CKP).

Whenever a cylinder misfires occurs combustion pressures drop, slowing down the piston and causing the camshaft and crankshaft slow down as well. The wave form signal of an engine with no misfires appears as a series of evenly spaced peaks and valleys; a misfire slows down the crankshaft and interrupts the even spacing of the waveform. By comparing the CMP and CKP sensor waveforms the PCM can identify which cylinder has misfired.

To prevent false DTCs from occurring the monitor has a cylinder specific misfire counter. The counter for each cylinder counts the number of misfires that occur during 200 and 1000 crankshaft revolutions. When the monitor reports a misfire, the EXECUTIVE checks all the cylinder misfire counters. A DTC is set if one or more of the counters has a significantly larger number of misfires counts. This strategy reduces misfire error due to background noise or operating conditions such as an uneven surface, among others.

OBD II Can Identify Three Types of Misfire Conditions

1. Type A (One Trip Monitor or One Trip Logic)

This is the case when the monitor detects a misfire in 15% of the cylinder firing opportunities during 200 crankshaft revolutions. The misfires are severe enough to damage the CAT. The MIL will flash once per second as long as the vehicle misfiring will damage the CAT. This should warn the vehicle driver that continued operation under similar conditions will cause damage, although the driver might not know that the damage will be to the CAT. A DTC and Freeze Frame will be stored. When the vehicle is no longer operating under the conditions which caused the misfiring sufficient to damage the CAT, the MIL will stop flashing but will remain illuminated.

The MIL will be extinguished after three consecutive trips without a misfire in the same cylinder under similar operating conditions.

2. Type B (Two Trip Monitor or Two Trip Logic)

This is the case when the monitor detects a misfire in 2% of the cylinder firing opportunities during 1000 crankshaft revolutions. These misfires are capable of causing exhaust emissions to exceed the FTP standard by 1.5 or 50%.

The EXECUTIVE will illuminate the MIL a set a maturing DTC and Freeze Frame. If the monitor detects misfires on two consecutive trips under similar conditions (that is at similar engine RPM, load, and temperature) the MIL is illuminated, a hard code set and Freeze Frame data updated.

The MIL will also be illuminated if a misfire is detected under similar conditions on two non-consecutive trips that are not more than 80 warm up cycles apart. The MIL will be extinguished after three consecutive trips without a misfire in the same cylinder under similar operating conditions.

3. Type C (Two Trip Monitor or Two Trip Logic)

This is the case when the monitor detects a misfire in 2-3% of the cylinder firing opportunities during 1000 crankshaft revolutions. These are misfires that would cause the vehicle to fail the California I/M (Inspection/Maintenance) test.

The MIL will illuminate when misfires are detected and a DTC set and Freeze Frame stored. If the monitor detects misfires on two consecutive trips under similar conditions the MIL is illuminated a hard code set with the most current failure parameters stored in the Freeze Frame data. If a misfire is detected under similar conditions on two non-consecutive trips that are not more than 80 warm up cycles apart the MIL is turned off after three consecutive trips without a misfire in the same cylinder under similar appearing conditions. (CARB, EPA).

The MIL will also be illuminated if a misfire is detected under similar conditions on two non-consecutive trips that are not more than 80 warm up cycles apart.

A maturing DTC is set upon detection of a Type B or C misfire. This is known as Two Trip Detection Logic. If the fault reoccurs on the next trip, that is the fault occurs on two consecutive trips, the MIL is illuminated and the DTC becomes a hard code. Because this is a misfire monitor the Freeze Frame data is updated. If the fault does not occur for three consecutive trips under similar conditions the MIL is extinguished. The DTC and Freeze Frame are erased after 40 consecutive warm up cycles without a misfire under similar conditions. (CARB, EPA)

The Following System Monitors Are Tested Once Per Trip

A "trip" for monitoring purposes is a key on cycle in which all enabling criteria are met and the diagnostic monitor runs. Enabling criteria which include ECT, RPM, MAP, O_2, etc. or other combination of sensor voltage inputs required for a particular diagnostic monitor to run are met.

1. CAT Efficiency Monitor

The CAT must be monitored once per trip so that deterioration will not allow emissions to exceed 1.5 times the FTP. The voltage signals from a heated oxygen sensor upstream (HO2S1/1) from the CAT is compared to the voltage signal from a heated oxygen sensor downstream (HO2S1/2) of the CAT to determine the CAT's ability to store O_2.

When the mixture is lean, the O_2 content of the exhaust gas is high and the O_2 is absorbed by the catalyst materials. When the mixture is rich, the O_2 is used in the oxidation process. Since the amount of O_2 that a catalyst absorbs determines how well it promotes oxidation, this can be used to determine CAT efficiency. The EXECUTIVE compares the voltage signal of the upstream oxygen sensor with the downstream oxygen sensor.

A catalyst that is working efficiently will have no crosscounts for the downstream (HO2S1/2) heated oxygen sensor and many for the upstream (HO2S1/1) heated oxygen sensor. The more the voltage trace of a downstream (HO2S) heated oxygen sensor becomes like the voltage trace of an upstream HO2S the more the CAT is degraded.

On the first trip the converter's capacity to absorb O_2 becomes sufficiently degraded so that emissions will exceed the FTP by 1.5 (50%) a DTC and Freeze Frame will be stored and on the second trip the MIL will be illuminated. If the same fault does not occur for three consecutive trips the MIL will extinguish. If the same fault does not occur after 40 warm up cycles the DTC and Freeze Frame will be erased from memory.

2. EGR System Monitor

The EGR system must be monitored once per trip for flow rate so system deterioration or malfunction will not allow emissions to exceed 1.5 times the FTP. To determine flow rate, the EGR system monitor must test the sensors, solenoids, electrical circuits, pressure signal devices (DPFE valve), Delta Pressure Feedback sensor, hoses and electronic vacuum regulators (EVR), and EGR valve that make up the EGR system.

Every manufacturer has a method of complying with this CARB and EPA requirement. Methods include monitoring changes in MAP or O_2 sensor voltage, back pressure, differential pressure and Short Term Fuel Trim percent change. When a malfunction is detected, a DTC and Freeze Frame are stored. If the malfunction occurs on two consecutive trips the MIL is illuminated. Note the Freeze Frame Data is NOT updated. If the fault does not occur for three consecutive trips the MIL will extinguish. If the same fault does not occur after 40 warm up cycles then the DTC and Freeze Frame will be erased from memory.

3. EVAP System Monitor

The EVAP (Evaporative Emission Control System) is monitored once per trip for purge volume and leaks as small as 0.040"
(1mm). The most common EVAP monitor system in use works as follows:
The monitor turns on the EVAP Vent Solenoid to block the fresh air supply to the EVAP canister. The EVAP Purge Solenoid is then turned on so that a slight vacuum is drawn on the entire EVAP system. A pressure sensor inside the fuel tank monitors how quickly vacuum increases inside the EVAP system, including the fuel tank. Then the EVAP Purge Solenoid is turned off which seals the system, and checks for leaks.
The monitor uses the fuel tank EVAP Pressure Sensor signal to determine if the EVAP system has any leaks. The requirement is that the monitor be able to detect a 0.040 inch opening or hole in the EVAP system. If the vacuum decays too rapidly (pressure increases) a DTC and Freeze Frame data are stored in memory on the first trip as a maturing code. On the second consecutive trip that the fault occurs the MIL will be illuminated and the code will no longer be a maturing code but becomes a hard code. However, the Freeze Frame will not be updated. If the same fault does not occur for three consecutive trips the MIL will extinguish. If the same fault does not occur after 40 warm-up cycles then the DTC and Freeze Frame will be erased from memory.

4. Oxygen Sensor System Monitor

The Oxygen Sensor System (OSS) monitors both up stream and downstream HO2Ss once per trip for minimum and maximum voltage and response time for system deterioration and/or malfunction. Both Oxygen Sensors must be monitored. The monitor will not allow emissions to exceed 1.5 times the FTP. The upstream HO2S that controls Short Term Fuel Trim and the downstream catalyst efficiency HO2S have separate tests and are both monitored once per trip.
The upstream and downstream sensors are monitored for minimum and maximum voltage. The monitor looks at voltage under rich and lean conditions. When the engine is running rich the monitor looks for a minimum and maximum voltage as well as amplitude. Signal voltage that is below or exceeds a threshold indicates a fault. On the second consecutive trip that the same fault occurs the MIL is illuminated. If the fault does not occur for three consecutive trips the MIL will extinguish. If the same fault does not occur after 40 warm-up cycles the DTC and Freeze Frame will be erased from memory.

Additional Upstream Sensor Monitoring

1. Switching

The time between signal switches is continuously monitored. Also known as crosscounts, this is the number of times signal voltage crosses the .450mv midpoint of the HO2S range in a specific time. Excessive time between switches indicates a faulty sensor. A rule of thumb is 8 switches in 10 seconds at 2500 RPM. On the first trip a fault in the OSS is detected and a DTC and Freeze Frame is stored in memory. If the same fault occurs on the second consecutive trip, the MIL is illuminated. After three consecutive trips without the fault occurring the MIL is extinguished. After 40 warm up cycles the DTC and Freeze Frame are erased from memory.

2.Response time

The response time is the time it takes the HO2S to go from a rich to lean and lean to rich condition. An HO2S operating correctly should have a response rate of less than 100ms. If average response time is not within limits, the PCM stores a DTC and Freeze Frame in memory the first trip. If the fault occurs for two consecutive trips the MIL is illuminated. After three consecutive trips without the fault occurring the MIL is extinguished and after 40 warm up cycles the DTC and Freeze Frame are erased from memory.

The Downstream/Post CAT HO2S

The voltage in the post CAT HO2S changes very little and is monitored for excessively high voltage. Peak rich and lean voltages are compared to threshold voltages stored in the PCM. The monitor looks at voltage under rich and lean conditions. Under a rich condition the monitor looks for a fixed low voltage signal. Under a lean condition the monitor looks for a fixed high voltage.

On the first trip a fault with the Oxygen Sensor System is detected a DTC and Freeze Frame is stored in memory. If the fault occurs on two consecutive trips the MIL is illuminated. After three consecutive trips without the fault occurring the MIL is extinguished. After 40 warm up cycles the DTC and Freeze Frame are erased from memory.

5.Oxygen Sensor Heater System

OBD II regulations require that heaters of the upstream and downstream HOSs be monitored for operation and deterioration . Manufacturers have various methods for compliance.

One of the most popular is the "Time to Active" test, The PCM monitors the time it takes the HO2S to become active after a cold start and compares that to a value in the PCM memory. If the time is too long, a fault is indicted in the heater. On the first trip that a fault in the Oxygen Sensor Heater System is detected, a DTC is set and Freeze Frame Data is stored in memory. If the fault occurs on the second consecutive trip the MIL is illuminated. After three consecrative trips without a fault occurring the MIL is extinguished. After 40 warm up cycles the DTC and Freeze Frame are erased from memory.

6.Secondary Air System

OBD II regulations require AIR systems to be monitored for:

1. Rate of flow
2. Operation of the divertor and switching valves
3. Pump operation
4. Pump efficiency by measuring air flow rate.

The most common way to check the secondary AIR system functionally is to monitor the exhaust gas for high O_2 using the upstream HO2S. On the first trip a fault occurs with the Secondary Air System that would allow emissions to exceed 1.5 the FTP (that is 50% greater than the FTP). When the fault is detected a DTC and Freeze Frame are stored in memory. If the fault occurs on the second consecutive trip the MIL is illuminated. After three consecutive trips without the fault occurring the MIL is distinguished. After 40 warm up cycles the DTC and Freeze Frame are erased from memory.

7. Readiness Test (Monitor Readiness Status)

The OBD II system continually monitors misfire and fuel system faults, and performs functional tests on the CAT, EGR EVAP, HO2Ss and Secondary AIR systems once every "trip." Trip enabling criteria must be met before the CAT, EGR EVAP, HO2Ss or Secondary AIR system monitors run. For example,the trip criteria for the EGR system monitor to run may require any or all of the following conditions to be met:

1. Certain calculated load value
2. A target operating temperature
3. The fuel tank a quarter to three quarters full
4. Acceleration criteria
5. Temperature range
6. Cruise at specified MPH for a designated time period
7. Idle for a specified time period.
8. And more depending on manufacturer specifications

The readiness test is a flag, an indicator which is used during I/M inspections to indicate that the OBD II system cannot supply the information required during the test. Under these conditions the vehicle must be operated until all the readiness test criteria have been completed. As the technician you need to inform customer of the need for the additional driving. An OBD II Drive Cycle will satisfy **all** the trip criteria. OBD II must complete and pass all the monitors before an I/M test. This means there are a lot of tests going on at the same time. One of the monitor tests may be in conflict, suspended or pending, or the trip criteria not be met for some other reason.

If trip criteria is not met for a particular monitor, the PCM has not completed its so called I/M Readiness or I/M Test and the scan tool will not be able to display supported data because not all supported readiness tests are complete. In this case, the scan tool indicates the Monitor Readiness Status.

Readiness Status

The Monitor Readiness Status indicates whether an OBD II diagnostic monitor has run or not since the last time DTCs and Freeze Frame date were erased from memory, either by a scan tool or having the battery disconnected. A“ Yes” means the monitor has run, but does not indicate if a fault was found. A “No” means the monitor has not run, but does not indicate that no fault was found, only that the particular diagnostic monitor has not run. After repairs the monitor readiness status test should be run and memory checked for DTCs before the vehicle is returned to the customer.

There are no monitor readiness status tests for the Misfire System Monitor, Fuel System Monitor or Comprehensive Component Monitor because they run continually.

SECTION 11

Emission Controls Theory,Design,and Operaton

TAC

The function of the thermostatically controlled air cleaner is to provide warm air during warm up and colder air at normal engine operating temperature. Refer to fig. 11-1 and fig. 11-2. The TAC routes warm air from around the exhaust manifold into the air cleaner to help fuel vaporization when the engine is cold.

A TAC that does not route hot air to the intake manifold when the engine is cold will result in:

a) Throttle valve icing.
b) Hard starting when cold.
c) Misfiring when cold.
d) Hesitation when cold.
e) Cold idle problems
f) Stalling when cold.
g) High HC due to misfires when cold.
h) Long warm-up times.
i) Poor fuel economy.
j) Failure of a functional emissions test.

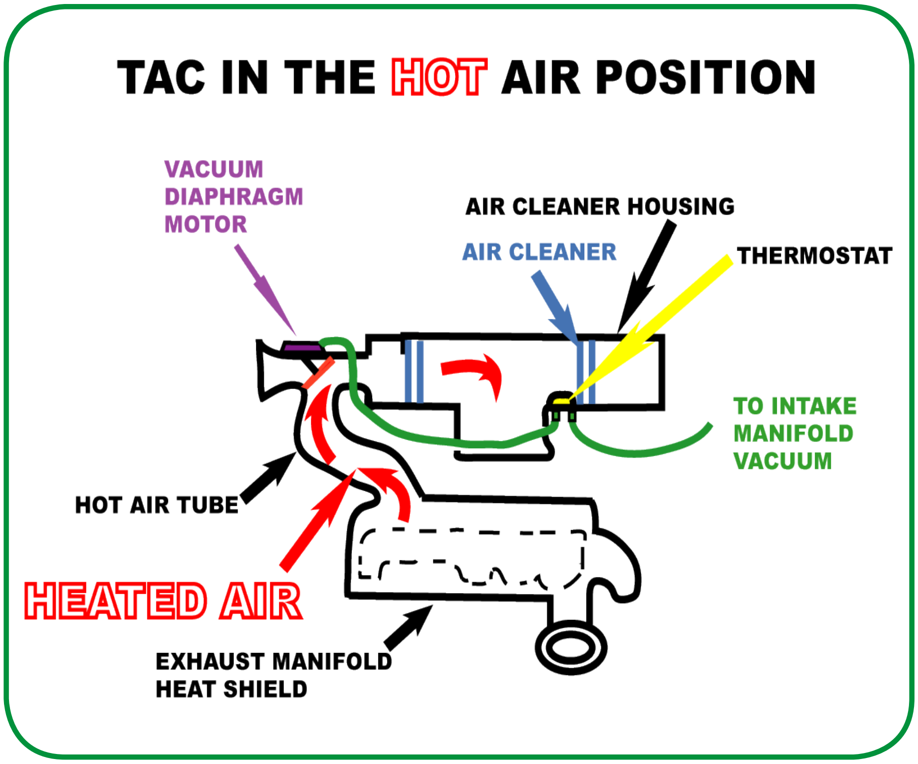


Fig. 11-1 TAC in the hot air position routing warm air to the intake manifold to help fuel vaporization for quick warm-up, to help lower emissions, and to improve cold driveability.

If a TAC fails in the on position, routing hot air to the engine at all times will result in:

a) Detonation, which may result in internal engine damage.
b) Lack of power.
c) High NO_x emissions.
d) Failure of a visual emissions test.

The reason is, when the TAC routes warm air from around the exhaust manifold into the air cleaner, this air is too hot for an engine at normal operating temperature and will raise combustion temperatures.

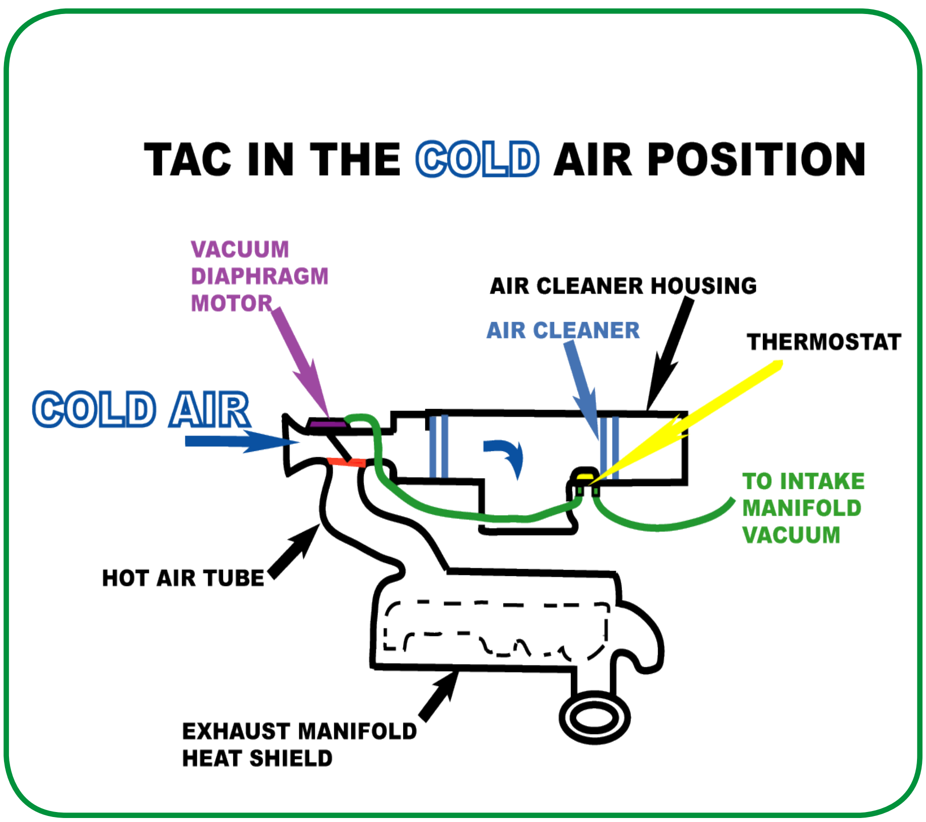


Fig. 11-2 TAC in the cold air position routing cold air to the intake manifold once the engine reaches normal operating temperature.

Warming the Fuel Charge

Thermostatic Air Cleaner (TAC)

Thermostatically controlled air cleaners use a vacuum diaphragm operated flapper valve in the air cleaner snorkel. This valve can direct warm air from the exhaust manifold heat store to warm the intake air charge, when the engine is cold, or under hood air, when the engine is at operating temperature. This aids fuel vaporization for quicker warm up times; lower HC and CO emissions during warm up, and helps prevent carburetor icing. Refer to Figure 11-3.

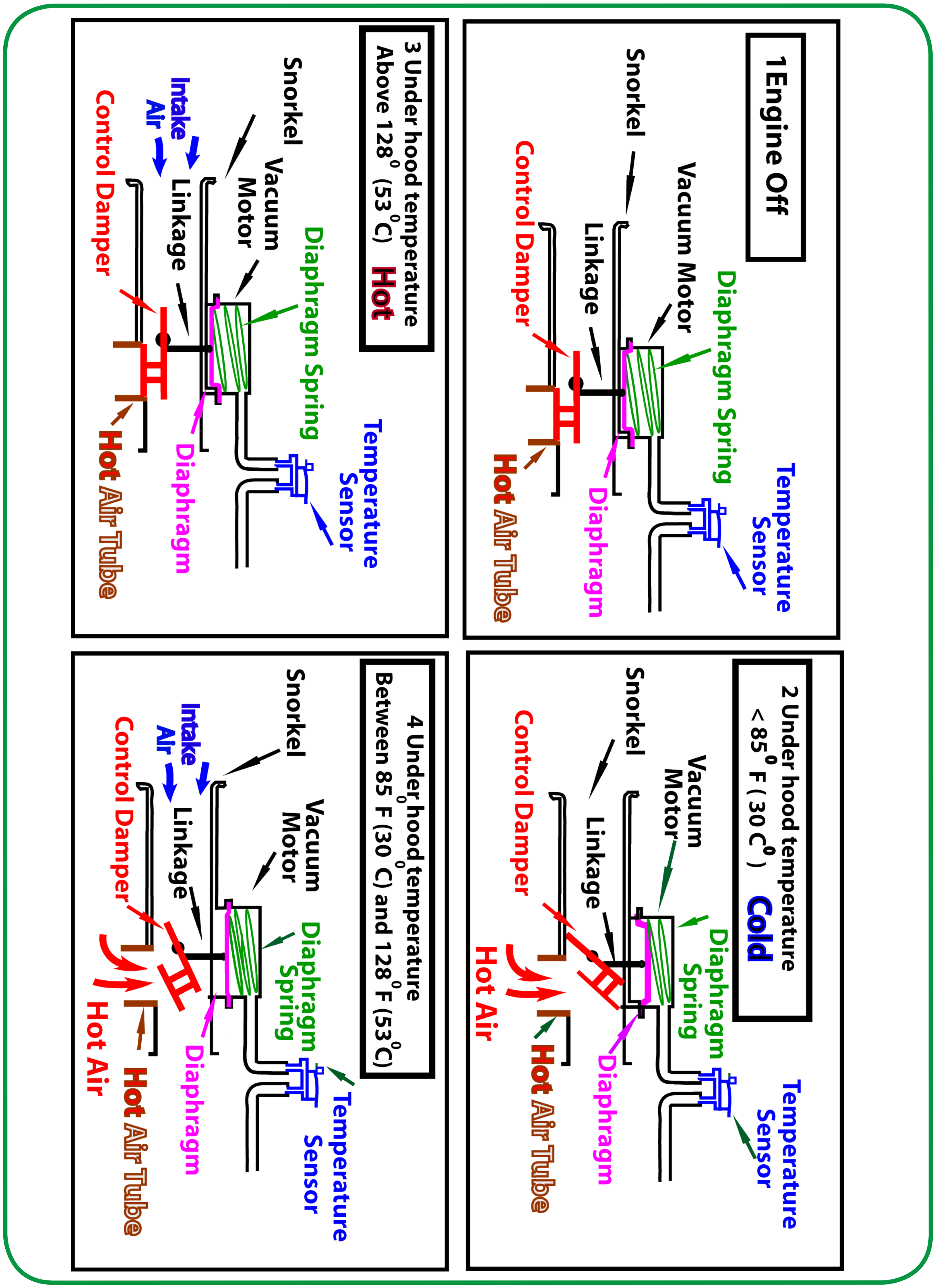


Fig. 11-3 TAC system operation.

Driveability and emissions problems

Too much EGR flow or EGR at the wrong time will result in:	Not enough EGR flow will result in:
a) Engine runs rough during warm-up. b) Hesitation. c) Low engine vacuum. d) Misfires at idle. e) Poor acceleration. f) Rough idle. g) Stalling. h) Surge at cruise.	a) Loaded mode test failure for NO_x. b) Spark knock.

For an EGR valve to function properly, three conditions must be satisfied.
1) Vacuum or signal from the PCM must be supplied to the valve at the right time.
2) The stem of the valve must move freely, and there must be no leaks.
3) All passages from the valve to the intake system must be free of obstructions (such as build up of carbon). This in turn lowers NO_x production about 60 percent. The TWC cleans up the rest.

Types of EGR valves:
1) Ported vacuum.
2) Integral backpressure transducer (negative or positive).
3) Separate backpressure transducer.
4) Pulse-width modulated.
5) Digital.
6) Linear.

1) Ported vacuum EGR

A ported vacuum EGR valve is operated by ported vacuum on both fuel injected and carburetor equipped engines. Ported vacuum to the EGR valve (which is only available off idle) is controlled by a (TVS) Thermostatic Vacuum Switch, which allows vacuum to reach the EGR valve once the engine has reached operation temperature. Refer to figure 11-5 and figure 11-6. When the vacuum increases enough, it overcomes the spring pressure, which holds the diaphragm closed. This opens the EGR valve and allows exhaust gasses to enter the intake manifold and dilute the incoming air fuel charge.

The amount of the flow depends on the strength of the vacuum versus calibrated spring tension. Refer to figure 11-4

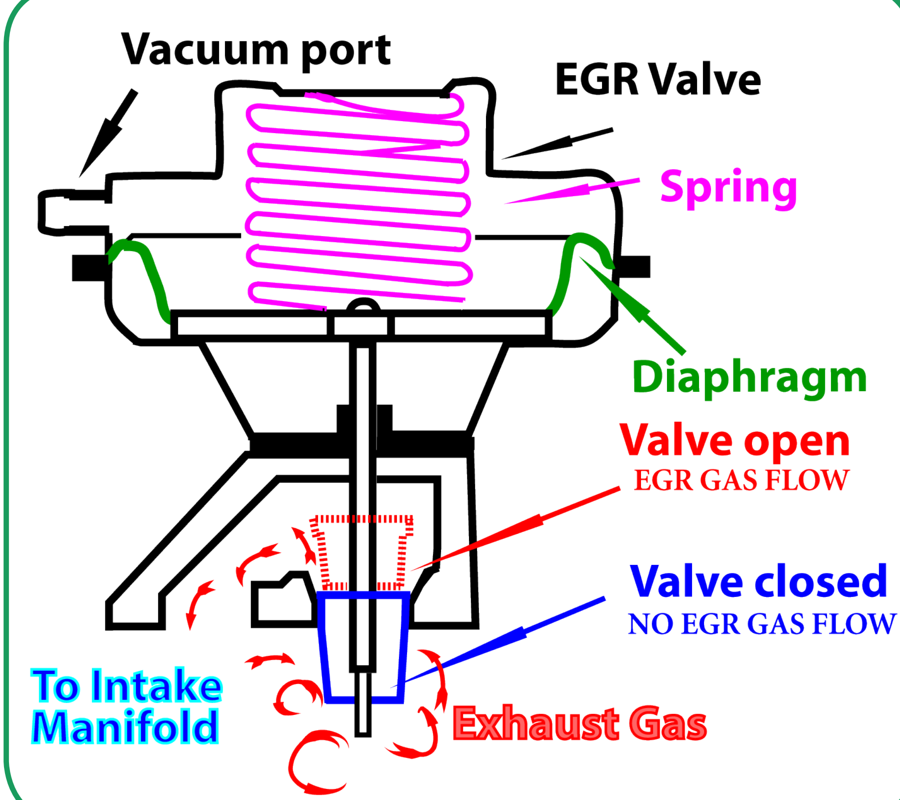


Fig. 11-4. This is an example of a ported vacuum EGR valve.

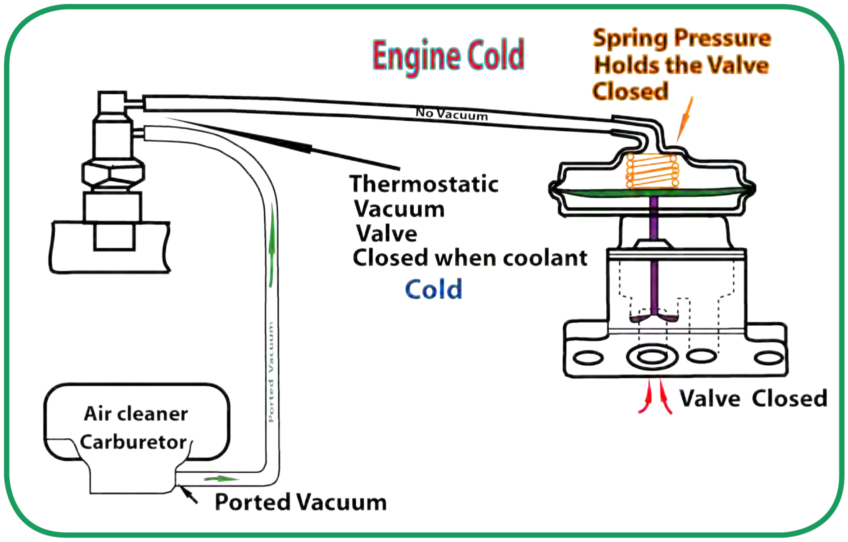


Fig. 11-5. An example of ported vacuum EGR valve controlled by a (TVS) thermostatic vacuum valve in the **cold** position. In this position, there is no EGR gas flow.

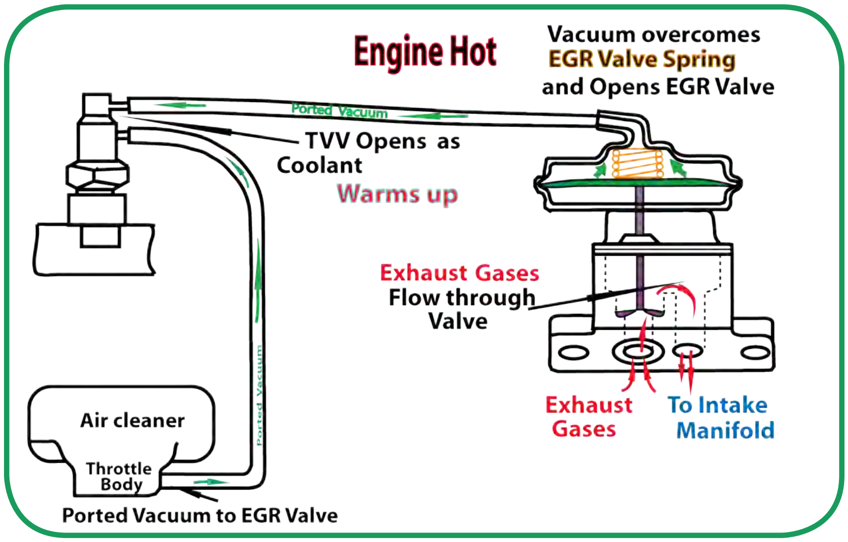


Fig. 11-6 is an example of a ported vacuum EGR valve controlled by a (TVS) thermostatic vacuum valve in the hot position. In this position, the EGR gas is flowing.

2) EGR with Integral Backpressure Transducer (negative or positive)

The positive integral backpressure transducer EGR valve has a vacuum bleed hole, which acts as a vacuum regulator. Refer to figure 11-7. For the valve to operate, there must be sufficient exhaust backpressure to close the vacuum bleed valve. Until the bleed valve closes so there is enough exhaust backpressure (load), the EGR valve does not open. Exhaust backpressure increases as load increases, which is when combustion temperatures and formation is highest. Once exhaust backpressure is high enough in the transducer to close the bleed valve, vacuum is applied to the **diaphragm**, and the EGR valve opens allowing exhaust gasses to flow into the intake manifold.

The negative integral backpressure transducer EGR valve works the same way as the positive backpressure valve, except the vacuum bleed valve is normally closed.

3) Separate backpressure transducer

Some EGR valves have a separate backpressure transducer, which uses exhaust backpressure operating on a diaphragm to open and close an EGR vacuum bleed. Refer to figure 11-8 and figure 11-9. When exhaust backpressure is low at idle and light load, a spring moves the **diaphragm** open allowing vacuum to bleed off. When exhaust backpressure is high under heavy load conditions, the diaphragm is moved and closes off the EGR vacuum bleed, which results in the EGR valve opening. Refer to figure 16-b. In this way, combustion temperatures are lowered when they would otherwise be above the critical 2500^{0}F (1371^{0}C), the temperature at which NO_x is formed.

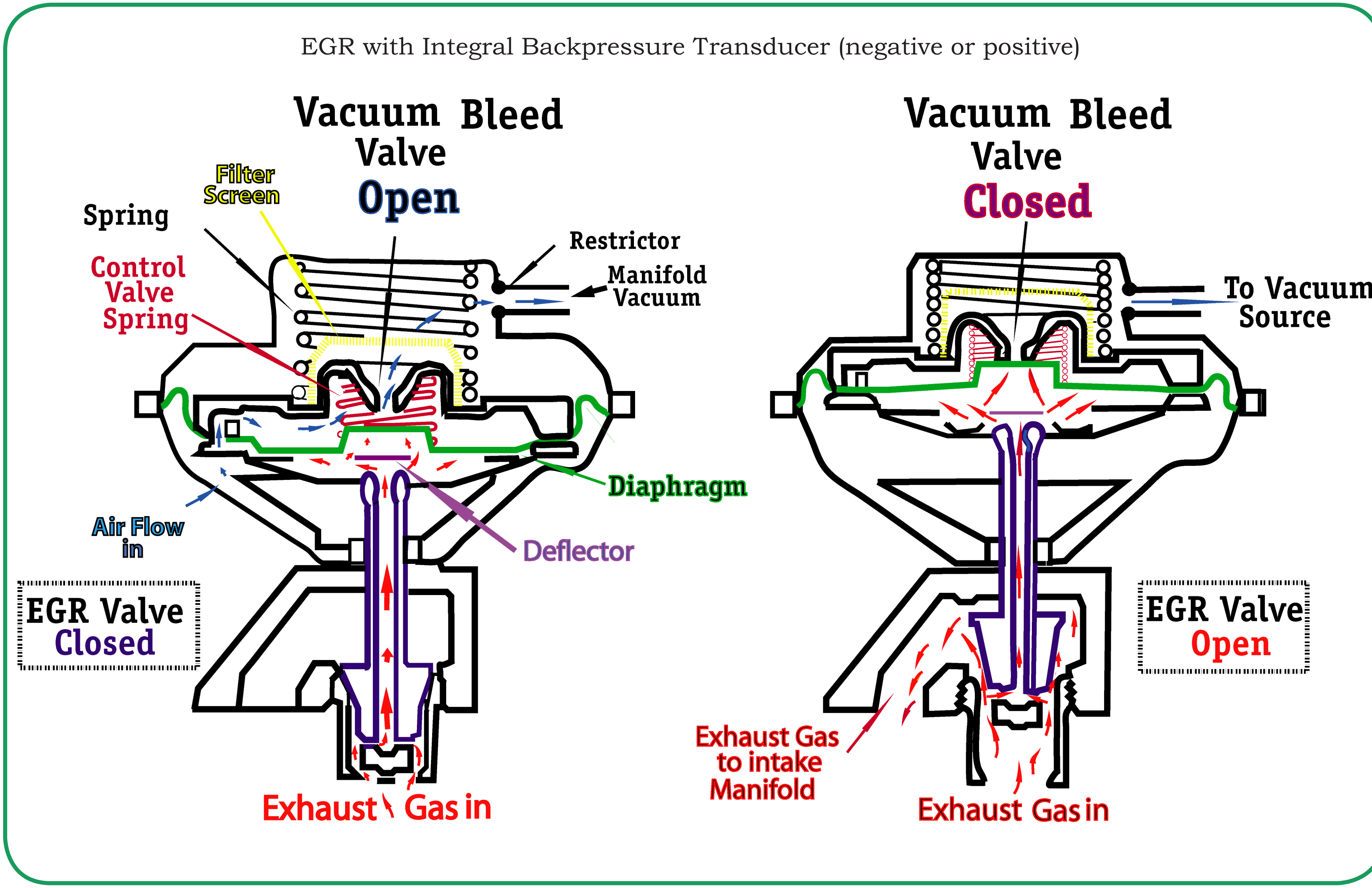


Fig. 11-7. Positive backpressure EGR valve with an integral backpressure transducer. The transducer controls EGR flow by venting control vacuum in relation to exhaust pressure.

EGR Valve with a separate back pressure transducer

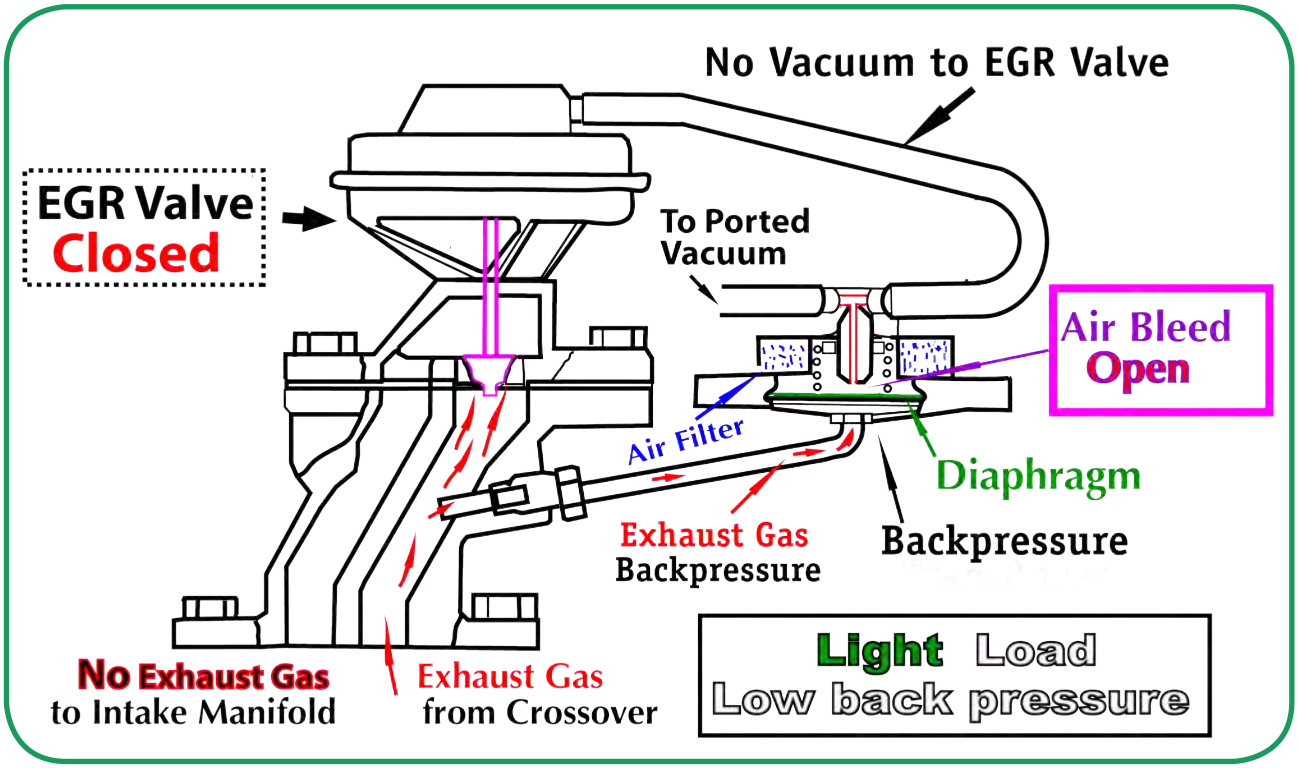


Fig. 11-8. Under light load, the exhaust backpressure is not strong enough to overcome diaphragm spring pressure, and some or all EGR vacuum is bled off to the atmosphere,thus reducing EGR flow.

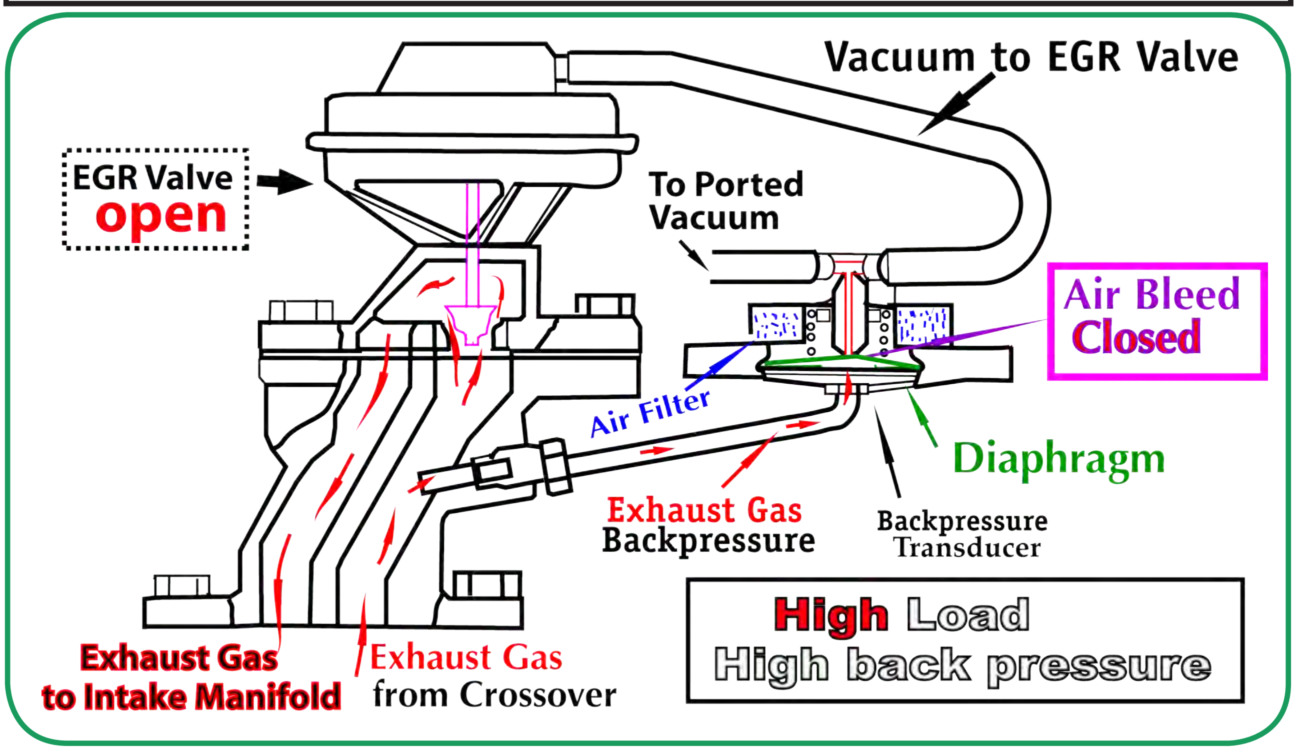


Fig. 11-9. Under heavy load conditions, but not wide open throttle, exhaust back pressureis strong enough to move the diaphragm, so that the bleed is closed and all vacuum is routed to the EGR valve with a corresponding increase in EGR gas flow.

4) Pulse-width modulated.

The pulse-width modulated EGR system is controlled by the PCM. The PCM controls EGR flow rate through a duty cycle controlled solenoid. When energized, the solenoid supplies manifold vacuum to the diaphragm operated type EGR valve. When the solenoid is not energized, vacuum is blocked, and the EGR valve's diaphragm is vented to close the valve. The EGR valve opening varies with the pulse width modulated signal from the PCM. EGR serial data on a scan tool can be represented as a percent of EGR flow, EGR duty cycle, or EGR on/off. In the case of a malfunction, a DTC will be set. The generic DTC for an OBD II compliant vehicle EGR malfunction is P0400. A value of 0% indicates a PCM command to fully close the EGR valve. A value of 100% indicates a PCM command to fully open the EGR. The PCM may use ECT, MAP, TPS, and other inputs, depending on the system, to determine EGR vacuum solenoid operation.

5) Digital EGR.

A digital EGR valve controls EGR flow through three different size orifices for seven different combinations of EGR flow rates. A digital EGR uses a solenoid energized by the PCM to move a pintle up and down to open and close the orifices for the desired flow rate.

6) Linear EGR (electronically controlled)

Linear controlled EGR valves have a vacuum controlled solenoid and a metering rod position sensor, which sends a feedback signal to the PCM.
Refer to figure 11-10.
The sensor is a potentiometer mounted on top of the EGR housing and connected to the EGR valve by a metering rod. The position sensor works the same way as a TPS. By looking at the return voltage, the PCM knows the amount that the EGR valve is open, and hence the flow rate. By pulsing the signal to the EGR vacuum control solenoid, the PCM achieves a better control of EGR flow rate than with only a ported vacuum signal.

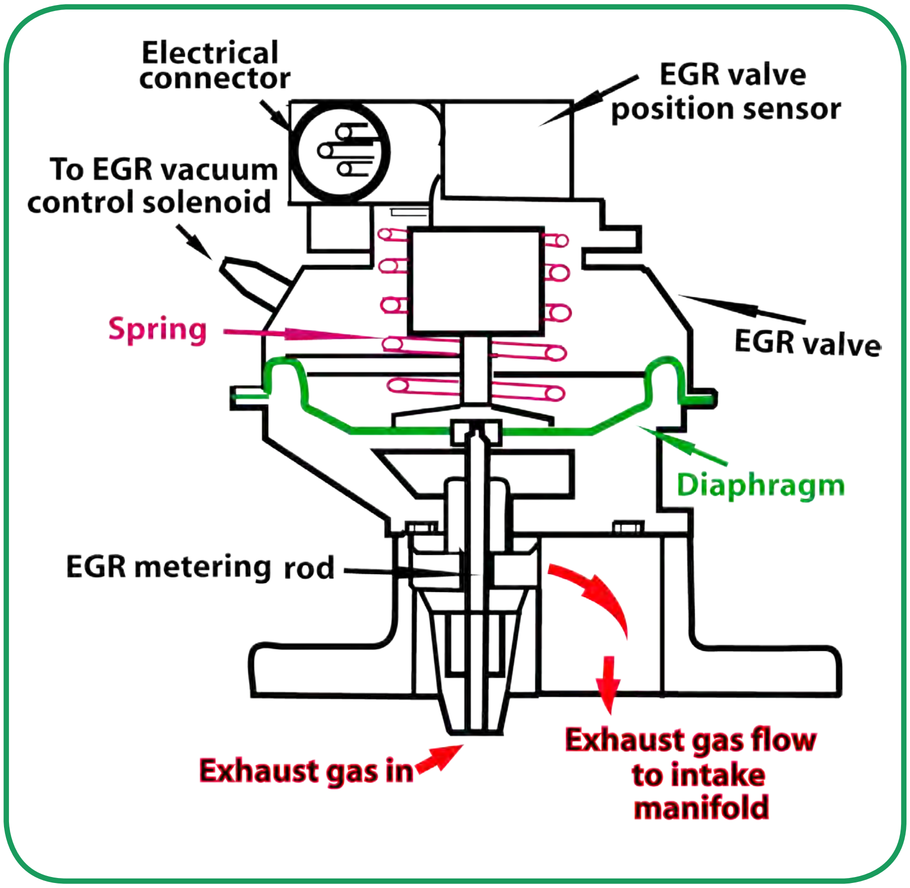


Fig. 11-10. Signal voltage from the potentiometer mounted on top of the EGR is sent to the PCM indicating flow rate.

Causes of EGR system malfunctions

1) EGR passages or valve blocked

EGR system failure may be due to plugged passages or a stuck valve. Carbon, moisture, and other particulate matter combine to block EGR passages. A small piece of carbon stuck between the pintle and the EGR valve seat can stop the valve from closing completely. Thus causing rough idle due to misfires (high HC) and hesitation.

2) EGR valve malfunctions

The diaphragm may be leaking, or the EGR valve spring on high mileage engines may have become weak, which results in the valve opening too soon. The result will be hesitation and surge at cruise.

3) Vacuum control system malfunctions

Look for broken, loose, pinched, or incorrectly routed vacuum hoses or inoperative TVVs (thermal vacuum valves). Most vehicles have an underunhood label with a vacuum routing diagram.

4) Computer control system malfunctions

Depending on the vehicle, the PCM controls the EGR flow using on/off or duty cycle solenoids. These solenoids must operate correctly. Check wiring and connectors for routing and integrity.

Computer controlled EGR systems use inputs from the ECT, IAT, and TPS. Systems used include a potentiometer on the tip of the EGR valve that signals pintle position to the PCM or sensors to measure pressure above and below the EGR valve or in the exhaust stream. This information is used by the PCM for it' s EGR flow calculations.

Note: Low exhaust backpressure or "free flow" exhaust systems will prevent backpressure EGRs from functioning correctly.

EGR functional checks

EGR valves should be checked using the procedures outlined in the your repair manual. The following ways to check EGR valves are to aid in comprehension only and are NOT to be used as a substitute for repair manual procedures.

a) Ported vacuum EGR

The valve should be closed at cold idle. If it is open, check temperature operated ported vacuum switches. Use a hand vacuum pump to apply 6 in Hg vacuum to the EGR valve. Without the engine running, the valve should open and the diaphragm should hold the vacuum. At idle, the engine should run rough.

b) Negative back pressure EGR

Apply vacuum to the EGR valve. It should open, and the diaphragm should hold vacuum. When the engine is cranked, the valve should close.

c) Positive back pressure EGR

Restrict the exhaust. Apply vacuum to the valve that should hold vacuum. Start the engine and put the transmission in gear. The engine should stall when the backpressure builds up enough to open the EGR valve at idle.

d) Computer controlled EGR

These systems usually have a solenoid, which controls vacuum to the EGR valve. To check valve operation, "tee" a vacuum gauge between the EGR valve and the solenoid. With the engine running at normal operating temperature, put the transmission in gear and lightly press the throttle. There should be a vacuum reading on the gauge. Open the solenoid's electrical circuit. The vacuum should drop to zero. Note: some systems have filters, which if they become clogged, hold the EGR valve open.

OBD II EGR System Monitor

The EGR system must be monitored once per trip for flow rate, so system deterioration or malfunction will not allow emissions to exceed 1.5 times the FTS. To determine flow rate, the EGR system monitor must test the sensors, solenoids, electrical circuits, pressure signal devices (DPFE valve), Delta Pressure Feedback sensor, hoses and electronic vacuum regulators (EVR), and EGR valve that make up the EGR system.

Every manufacturer has a method of complying with CARB and EPA requirements. Methods include monitoring changes in MAP or O_2 sensor voltage, backpressure, differential pressure, and Short Term Fuel Trim percent change. When a malfunction is detected, a DTC and Freeze Frame are stored. If the malfunction occurs on two consecutive trips, the MIL is illuminated. Note: The Freeze Frame Data is NOT updated. If the fault does not occur for three consecutive trips the MIL will extinguish. If the same fault does not occur after 40 warm up cycles, then the DTC and Freeze Frame will be erased from memory.

Controlling emissions with a Catalyst

No matter how perfect an engine is operating there will always be some harmful emissions. For this reason, three way catalytic converters are installed on vehicles. A three-way catalyst (TWC) is placed in line in the exhaust system to complete the oxidation of HC and CO. In addition, a TWC reduces oxides of NO_x back to nitrogen and CO_2.

There are two types of TWC construction used: The earlier ones used pellets packed in a steel shell an the later type are a monolith honeycomb design. Both types perform the same function, however, the monolith type creates less backpressure, but still provides enough surface are to effectively convert feed gasses. Feed gasses are the gases, which enter the catalyst from the engine. The part of a three-way catalyst, which performs the feed gas conversion, has a honeycomb-like, monolithic structure. The monolith contains small channels, each about 1 mm in diameter (300-600 channels per square inch). The washcoat, which includes the active catalyst material, is impregnated on these channel walls. The washcoat consists of porous oxides and precious metals and is very thin, resulting in low backpressure, but a large surface area to allows close to 100% conversion with a high catalytic activity. The following materials are used:

Platinum/Palladium: Oxidizing catalysts for HC and CO.
Rhodium: Reducing catalyst for NO_x.
Cerium: Promotes oxygen storage inside the converter.

How a TWC operates:

As exhaust gasses flow through the catalyst they come in contact with the surface of the catalyst, which promotes the catalytic reaction, and the following reaction occurs: Oxides of nitrogen are reduced to nitrogen (N_2) and carbon dioxide (CO_2.). Hydrocarbons (HC) and carbon monoxide (CO) are oxidized to create water (H_2O) and carbon dioxide (CO_2).

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Catalyst efficiency depends on two factors:

1) Temperature

A catalytic converter starts to work at approximately 550^{0}F (288^{0}C). However, it will not perform efficient purification until the catalyst reaches at least 750^0 F (400^{0}C). The efficient temperature for a CAT is 900^{0}F to 1600^{0}F (482^{0}C to 871^{0}C).

2) Conversion feed gases

Converter feed gasses must switch rapidly between high CO content to reduce NO_X and high O_2 to oxidize HC and CO.

Closed Loop and the TWC

The closed loop system is designed to rapidly change the air/fuel ratio from slightly rich to slightly lean of 14.7 to 1 (lambda =1). By doing this, the amount of CO and O_2 content of the exhaust alternates.

Lean A/F ratio >14.7:1

Lambda>1

When the A/F ratio is leaner than 14.7 to 1 (lambda >1), the oxygen content of the exhaust gas rises, and the CO content falls. The result is a highly efficient environment for the oxidizing catalysts platinum and palladium. During this lean cycle, the catalyst uses cerium to store excess oxygen, which is released during the rich cycle to promote better oxidation.

Rich A/F ratio <14.7:1

Lambda<1

When the air fuel ratio is greater than 14.7 to 1 (lambda <1) the CO content of the exhaust rises and the oxygen content falls. This provides an efficient environment for the reducing catalyst rhodium. The oxidizing catalyst maintains its efficiency because oxygen stored by the cerium is released.

Precise closed loop control relies on accurate feedback information from the O_2 sensor. If the system is operating correctly in closed loop and fuel trim is near neutral, generally speaking the fuel delivery and sub-systems will be operating normally. If closed loop is not working properly, the impact on catalytic converter efficiency and emissions will be considerable.

Effects of O_2 sensor degradation

O_2 sensors are the main component of the closed loop system therefore efficient operation is critical for an efficient control of emissions. The following will cause the oxygen sensor signal to degrade.

1) Silicon contamination from seals and contaminated fuel.
2) Lead due to incorrect fueling and additives.
3) Carbon contamination is caused by a malfunction, which results in an excessively rich mixture.

Excessive short trip driving will also cause carbon to contaminate the O_2 sensor. The effect of O_2 sensor degradation is a slight shift in air fuel ratio to an inoperative closed loop system. A silicon-contaminated sensor will cause the most problems from a driveability and emissions prospective. When silicon is burned in the combustion chamber, it causes a glaze to form on the O_2 sensor. The glaze causes the O_2 sensor to become lazy/sluggish from rich to lean and may increase the sensor's minimum voltage on the lean switch. The result is that the system is lean for an excessively long time.

In many cases, driveability is not affected by significantly. However, even slight sensor degradation will have an effect on NO_x during an ASM or I/M 24 test. A slightly lean mixture will have a dual effect on emissions. When the mixture is leaner, combustion temperatures are higher, so more NO_x is produced. In addition, since less carbon monoxide is present in the catalyst feed gas, the reduction efficiency of the catalyst is lowered considerably. The result is that the vehicle may fail because of excessive NO_x emissions.

Controlling emissions with a Catalyst

There are two main types of catalytic converter:

a) Two-way catalysts (OC)

b) Three-way catalysts (TWC or ORC)

Effective catalytic control of HC, CO, and NO_x is possible only if the exhaust gas contains a very small amount of oxygen. This is accomplished by keeping the air/fuel ratio close to stoichiometric. Refer to figure 11-11.

This is a diagram of the curve of efficiency for a three-way catalyst as a function of air/fuel ratio. When the air/fuel ratio is lean (excess O_2), the control of HC and CO is excellent.

However, the control of NOx is not very effective. When the air/fuel ratio is rich (deficiency of O_2), the control of NO_x is very good, but the control of HC and CO is poor.

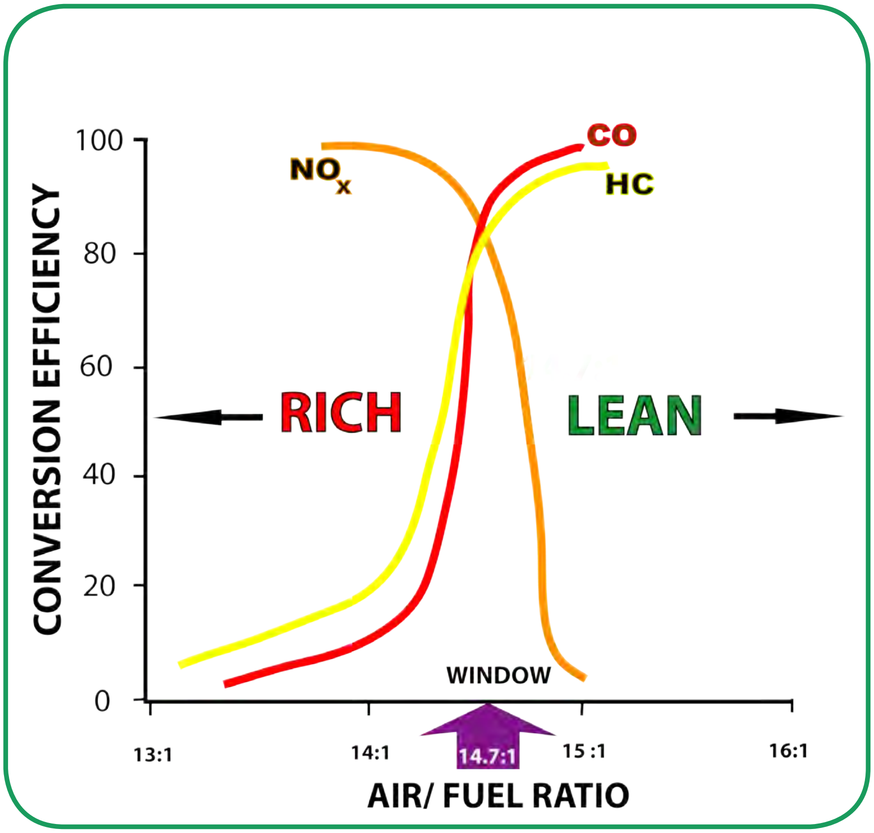


Fig. 11-11 . Conversion Efficiencies of a OC/TWC.

At the chemically correct mixture, a narrow window exists where the control of all HC, CO, and NO_x is good.

Maintaining the exhaust gas contents at the precise value, where the three-way catalyst is most effective, is the purpose of the O_2 sensor closed loop feedback system.

A catalytic converter triggers a chemical reaction, which changes the exhaust gasses that pass through it but not the catalyst itself. This reaction breaks the HC and CO bonds and results in the formation of Carbon dioxide CO_2 and water vapor H_2O. The two main types of oxygen catalyst are honeycomb or pellet.

Both require the proper operating temperature at least 550^0F (288^0C) for this reaction to take place and at 750^0F (400^0C) before the CAT becomes efficient.

a) Oxidation or two-way catalysts

Oxidation catalysts are designed to change HC and CO into CO_2 and H_2O. This occurs by adding O_2 to HC and CO in the presence of **heat, at least** (560^0 F), and the right catalytic material, **Platinum or Palladium**. Refer to figure 11-12.

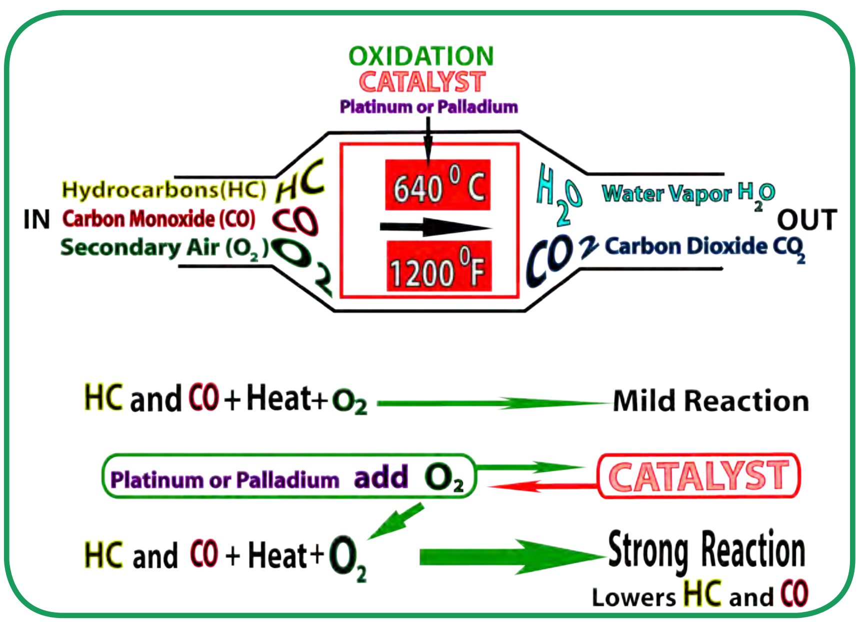


Fig. 11-12. OC, oxidation catalyst, reduces HC and CO by adding O_2 to exhaust gasses.

b) Oxidation Reduction Catalyst ORC/TWC

There are two types of TWC, with air and without air. Refer to figure 11-13. Three-way converters use rhodium as a catalyst for NO_x. The process “reduces” NO_x to harmless nitrogen and oxygen. Instead of O_2 being added, it is taken away. The chemical reaction is the opposite of the oxidation catalyst. In fact, excessive amounts of O_2 in the exhaust could actually inhibit the reduction process. Because of varying loads on a vehicle, additional air is sometimes necessary to provide enough O_2 for a TWC to work. On vehicles that have a TWC with air, the converter has two chambers separated by an air inlet pipe. The front chamber contains rhodium to reduce NOx. The second chamber contains platinum and palladium and is located downstream of the air inlet. It uses the additional air to oxidize HC and CO. The only difference between a TWC with air and without air is the pipe entering the CAT between the chambers. Correct air /fuel control is essential for a TWC to effectively reduce HC, CO, and NO_x.

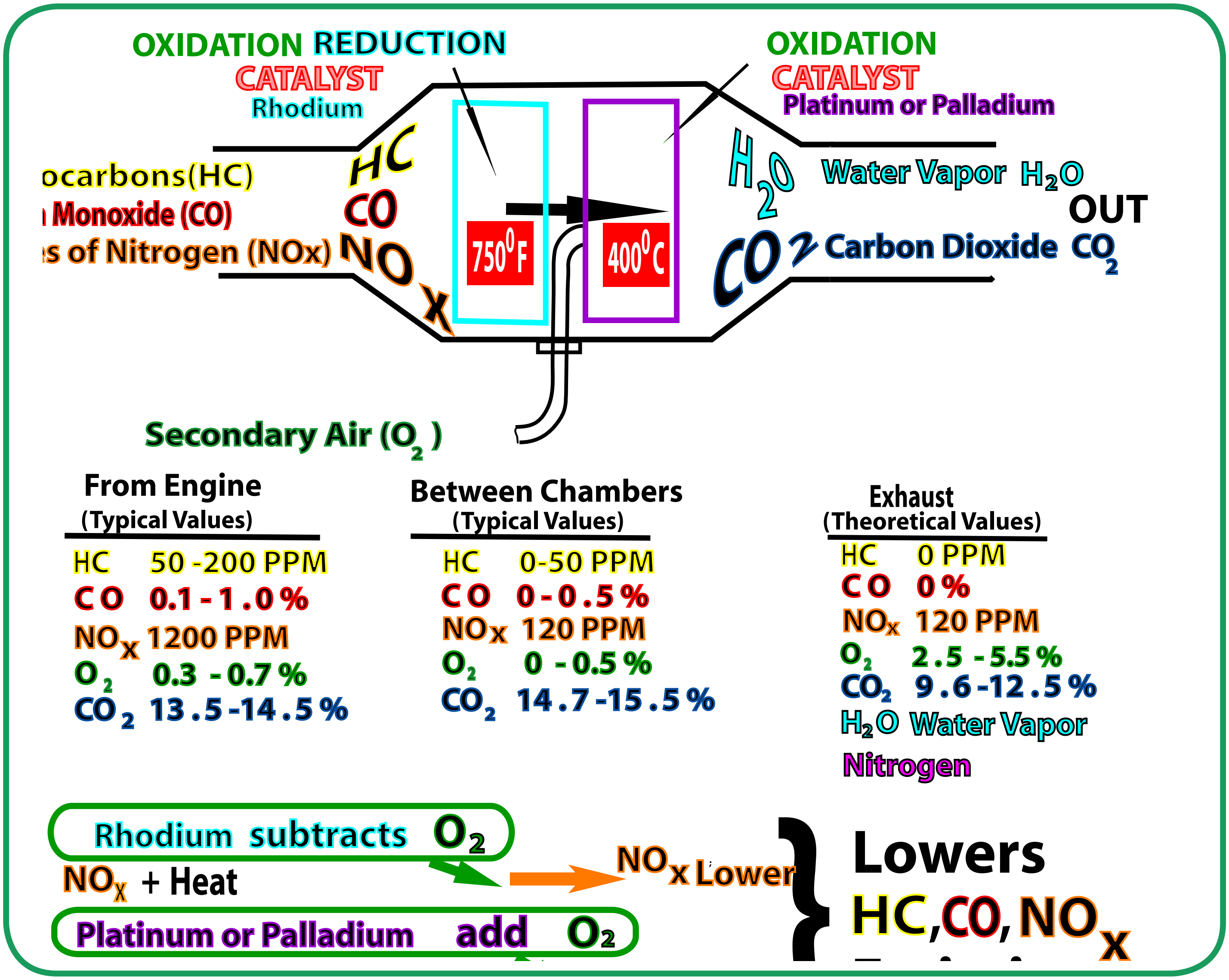


Fig. 11-13. This is an example of **O** xidation **R**eduction **C**atalyst, ORC (TWC), with secondary air.

Exhaust gas temperatures are critical to CAT functioning. The desired chemical reaction starts to occur at high temperatures of about 550⁰F (288⁰C). However, excessive temperatures can damage a catalyst. Misfires can cause excessive temperatures which may damage a catalyst.

Catalyst Degradation

Converters can become less efficient over time, the following are some of the primary causes:

1) **High temperatures** oxidize rhodium (Rh), which irreversibly affects its HC, CO, and NO_x conversion ability.

2) **Contamination** due to low operating temperatures. Contaminants collect on the catalyst surfaces at low operating temperatures and stop the exhaust gasses from coming in contact with catalyst materials. Hydrocarbons are affected most because HC molecules are larger than CO and NO_x molecules.

3) **Loss of air/fuel control** can result in lean mixtures and excessively high temperatures. Lean air/fuel mixtures can cause irreversible reactions of rhodium and other metal oxides, when CAT exceeds temperatures of 932^0F (500^0C).

Note: Changing the CAT as a quick fix without correcting the root cause of high emissions could damage the new CAT as well.
All other components that effect emissions **must** be checked, before replacing the CAT.
When diagnosing emissions problems, verify base engine performance first since any mechanical problem can lead to excess emissions. This is especially true when there are no codes.

Check the following:

1. Compression-within specifications.
2. Engine vacuum-within specifications.
3. Exhaust system-free from restrictions.
4. Fuel-must be correct octane and contaminant free.
5. Fuel injectors-check for clogged, leaking, or incorrectly wired injectors.
6. Power brake booster-must have no leaks.
7. PCV-system must be the correct application.
8. Valve timing-within specifications.

Non-Feedback systems

When diagnosing and repairing non-feedback systems for a loaded mode I/M failure the following systems and components must be taken into consideration:

Thermostatic Air Cleaner (TAC) On non-feedback engines with carburetors, venturi icing is possible at outside air temperatures below 45°F (4.4°C). To avoid this problem, a Thermostatic Air Cleaner (TAC) is installed on many engines. Refer to figure 5-4 and figure 5-5. The TAC routes warm air to the intake manifold, when the engine is cold. The result is that gasoline is more easily vaporized in the intake manifold. This allows for quick warm up times, shorter periods of choke operation, lower HC and CO, and improved cold engine driveability. TACs fail most often with the flapper valve in the cold air position. The result will be poor cold driveability and in particular poor acceleration and stalling. If the flapper valve fails in the warm air position while delivering preheated air continually, the result will be knocks, surging, lack of power, and increased NOX emissions.

Early Fuel Evaporation (EFE)

Early Fuel Evaporation (EFE) systems are designed to also be called heat risers and are controlled by a Thermal Vacuum Valve (TVV). A passageway in the intake manifold allows hot exhaust gasses to heat an area under the carburetor. This helps to vaporize the incoming fuel and reduces HC and CO emissions when the engine is cold, hence the name Early Fuel Evaporation. By providing heat in the area where fuel enters the engine, the tendency for gasoline to puddle in a cold intake manifold is overcome. Cold driveability is improved, the choke opens sooner, and of course, emissions of HC and CO are reduced. The exhaust gasses are routed away from the intake passages and directly into the exhaust manifold. The result of a system failure causes problems including stumbling and stalling.

If the valve fails in the closed position, the result will be high engine temperature, pinging, carbon build up inside the engine, and of course, high NO_x emissions.

If all the heat riser control components are operating correctly and the valve does not open, the problem could be an incorrect thermostat. If a low-temperature thermostat has been substituted in place of the one specified by the manufacturer, coolant temperature could be lowered to the point where the TVV does not cut off the vacuum to the valve. The valve will not close and the result will be high temperatures and high NO_x emissions.

Electric grid EFE heater

Some late model vehicles use an electric grid EFE heater. This usually consists of a resistance type ceramic grid heater mounted between the base of the carburetor and the intake manifold. The electric EFE systems eliminate much of the hardware of non-electric ones, which is the main cause of the non-electric EFE failures. Some electric grid EFE heaters are controlled by the PCM while others use a TVV. In either case, current is supplied to the grid when the ignition switch is on. You can check the grid by removing the air cleaner, and with engine off and ignition on, opening the throttle valve. Gas should vaporize as soon as it comes in contact with the grid. The temperature of the grid is self-regulating and automatically varies current demand with temperature. An open circuit will result in poor cold driveability and high CO during an emission test.

Fuel Evaporation

There are two major sources of automobile emissions:
1) Evaporative emissions
2) Exhaust emissions
Approximately 20 percent of all hydrocarbon (HC) emissions from an automobile come from fuel evaporation. The EVAP system is designed to store and dispose of fuel vapors created in the fuel system, thus preventing their escape into the atmosphere. The EVAP system delivers HC vapors to the intake manifold to be burned by the engine as part of the normal air/fuel mixture. Evaporative emissions are unburned fuel vapors that escape into the atmosphere due to some fault in the EVAP system. The system is closed and designed to maintain a stable fuel tank pressure and prevent HC emissions from escaping into the atmosphere. Vaporization is a result of the property of gasoline to vaporize at low temperatures. Just as water evaporation fills the atmosphere with vapor, gasoline evaporation can fill the atmosphere with hydrocarbon vapors.
The evaporative emission control system performs the following functions:
a) Traps fuel vapors and prevents them from reaching the atmosphere.
b) Delivers fuel vapors to the engine for burning.
c) Stores fuel vapors.
d) Contains liquid gasoline during a vehicle rollover.
Evaporative emissions systems control fuel vapors and reduce the tendency for fuel to evaporate. The fuel tank, where the fuel is stored, is sealed with a pressure relief filler cap to reduce the fuel's boiling point. The pressure/vacuum cap releases vapors to the atmosphere at 44" of water column and draws air in to the system at vacuum of 4" water column. Hoses route vapors for storage in a charcoal canister. The charcoal absorbs fuel vapors until a control valve purges vapors from the charcoal. The vapors are purged into the engine where they are burnt instead of being released into the atmosphere. This prevents hydrocarbon pollution in the air we breathe and the creation of photochemical smog. Before the use of evaporative control systems, hydrocarbon vapors from fuel systems including the fuel tank and carburetor float bowls were released into the atmosphere and the air we breathe. Nobody wants to breath gasoline fumes. The following is a list of fuel evaporation system components:

When the fuel is drawn out of the tank by the fuel pump to be used in the engine, a slight vacuum is created in the tank. To prevent the tank of from collapsing it needs to be vented to allow air to enter the tank and replace the fuel. The evaporative control system allows this ventilation to take place within a closed circuit, so the hydrocarbons stay in the fuel system and do not escape into the atmosphere.
Refer to figure 11-13.The components of a evaporative emissions control system are:

1) Charcoal canister
2) Evap hoses
3) Fuel Tank
4) Liquid separator
5) Overfill valve
6) Purge solenoid
7) Rollover valve
8) Vacuum/Pressure filler cap

System operation

When the engine is not operating, called the 'hot soak period', HC vapors that accumulate in the thermal expansion space of the fuel tank pass though the EVAP hose vapor lines and the rollover/check valve into a charcoal granule filled canister where they are stored.

Early systems stored the HC vapors in the crankcase. However, this proved a dangerous place to store fuel vapors. A typical canister holds about 350 to 600 grams, and each gram of charcoal has a surface area of approximately a quarter of a square mile. The result is that the surface of the granules in an average canister is equivalent to 100 to 180 football fields. Fuel vapor molecules (HC) attach readily to the surface of the charcoal. However, the attaching force is not very strong, so that air entering the canister through a filter can easily dislodge the molecules of HC vapor, which are purged into the engine by intake manifold vacuum and burnt. A filter prevents dust and other contaminants from entering the canister purge air. Some systems have two canisters.

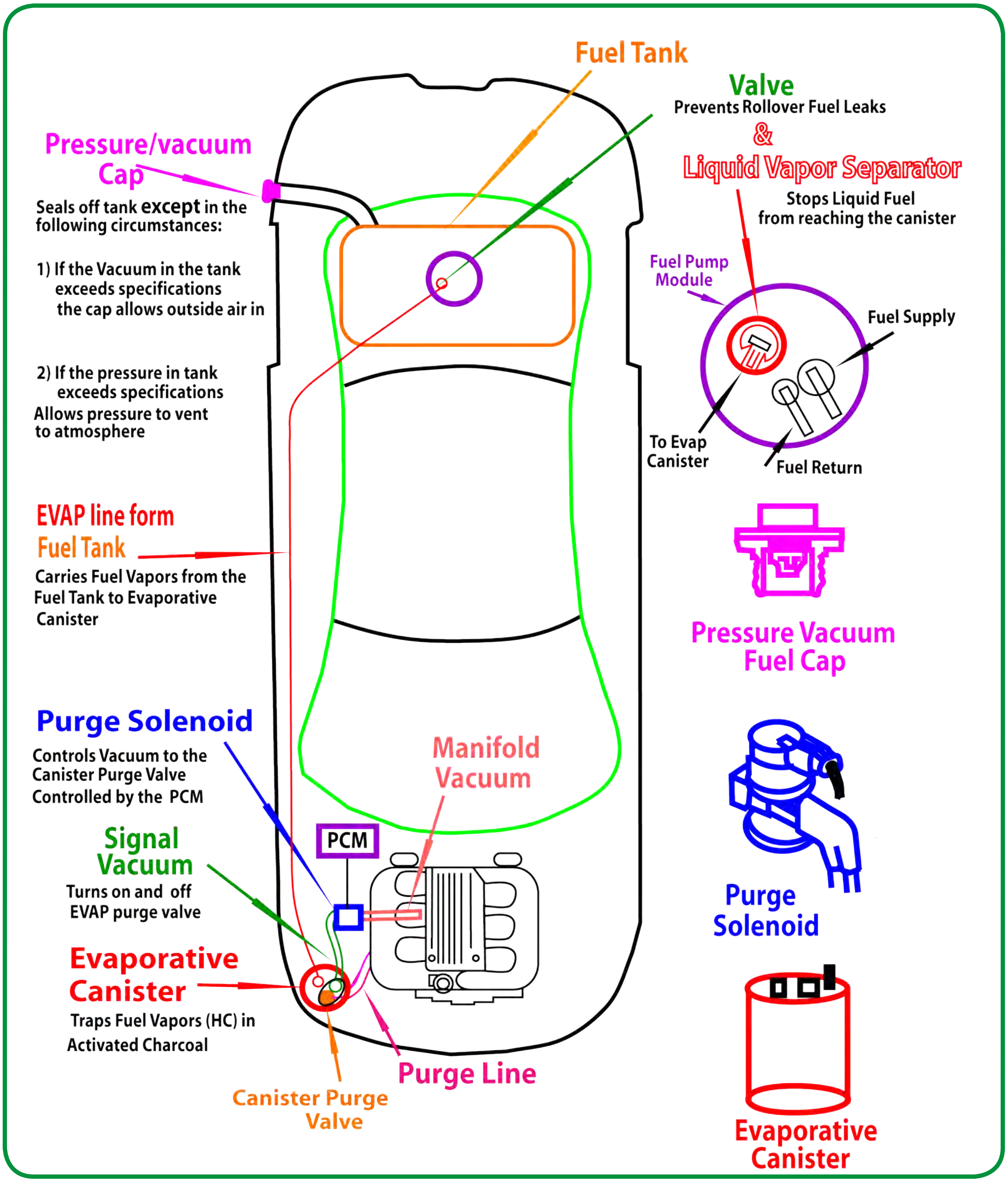


Fig.11-13. Major components of a typical Evaporative emissions control system.

An evaporative line runs from the fuel tank to the canister, which is filled with activated charcoal granules to trap HC vapors. Refer to figure 11-14. On carburetor-equipped vehicles, a line runs from the carburetor float bowl to the canister. This eliminates the release of unburned HC into the atmosphere and provides pressure relief for the fuel system.

The function of the purge system is to apply pressure or vacuum to the HC in the canister and force the HC molecules into the engine under certain conditions. In the case of PCM controlled engines the HC, is added during closed loop when the additional fuel can be managed by the closed loop fuel control system.

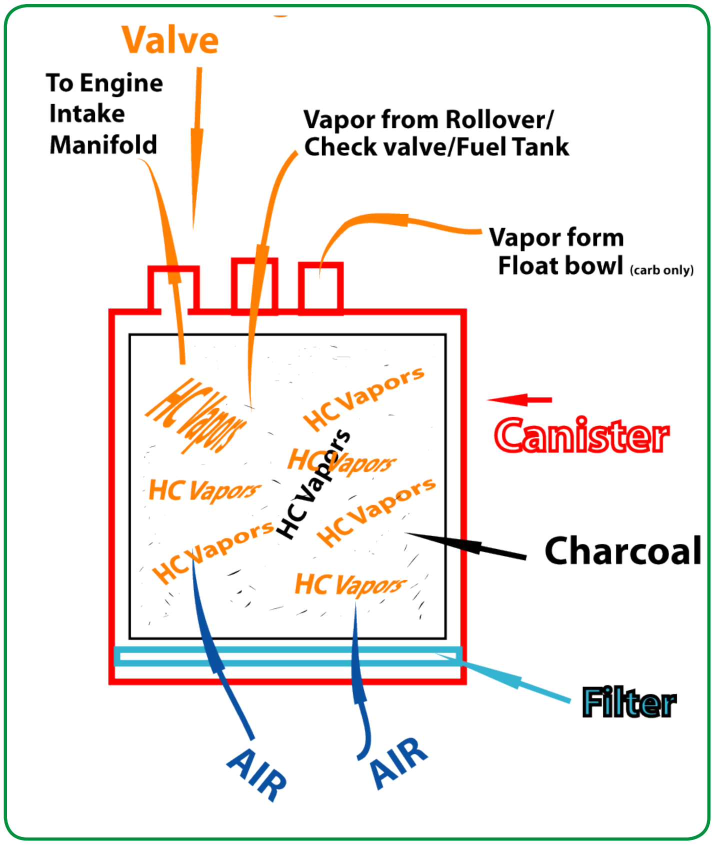


Fig.11-14. An open bottom carbon canister stores fuel vapors (HC).

Types of canister purge control systems

1) Constant Purging

When this system is used, the amount of purged air through the canister is fixed regardless of the amount of air used by the engine. This is accomplished by teeing into the PCV line. Intake manifold vacuum draws air through the canister thus dislodging the fuel vapor HC molecules, which are then burnt. Manifold vacuum varies with engine load, so by placing an orifice in the purge line, there is a fairly constant airflow rate through the canister when the engine is running.

2) Variable Purging

The variable purge system has a line connected to the air cleaner. Air entering the air cleaner snorkel creates a vacuum and draws vapors out of the canister into the intake air, which then enters the engine where they are burnt. Since the amount of air entering the canister is proportional to the amount of air entering the engine, the more air that enters the engine, the greater the vacuum on the purge line, and the more of air entering the canister, the greater the flow of vapors being purged.

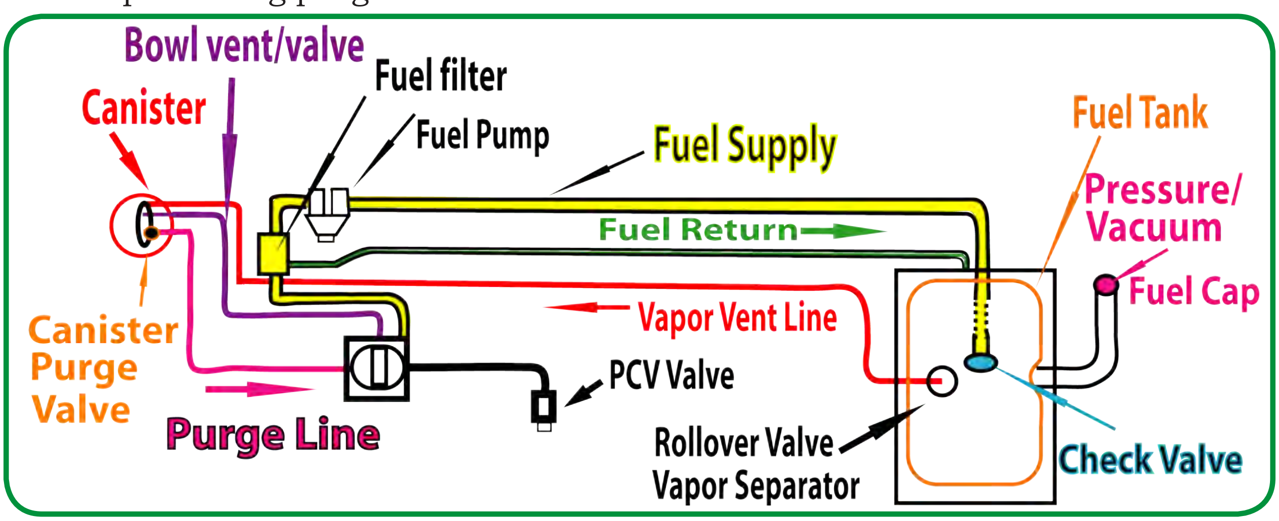


Fig. 11-15 An evaporative Emissions Control System on a carbureted engine.

3) Two Stage Purging

This system uses a purge valve which usually located on top of the canister. Refer to figure 11-16 and Figure 11-17. The valve is operated by a ported vacuum signal that opens a second passage from the canister to the intake manifold. Ported vacuum comes from above the throttle plate, and therefore is only available off idle. There is no vacuum to the purge valve when the throttle is closed at idle. However, as soon the throttle starts to open, the ported vacuum signal to the purge valve increases in proportion. This system eliminates purge at idle which improves hot idle operation. Most EVAP systems use some sort of temperature control of vacuum like a Thermal Vacuum Valve (TVV), which only allows vacuum to reach the purge control valve when the engine is fully, warmed up. This helps reduce HC and CO emissions during warm up. Late model PCM controlled engines use a solenoid to switch vacuum to the canister purge valve on and off as a function of the PCM program.

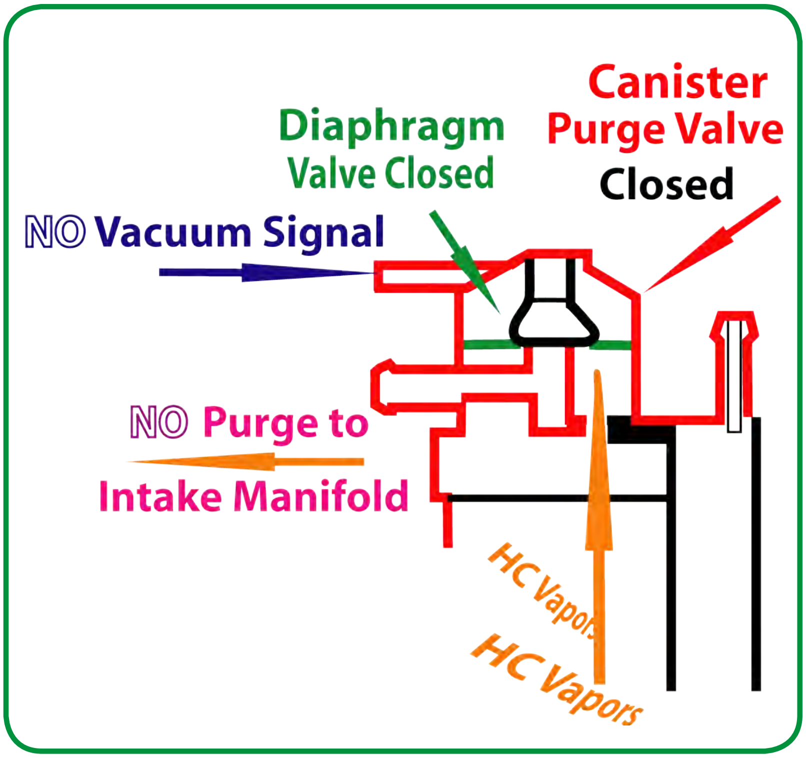
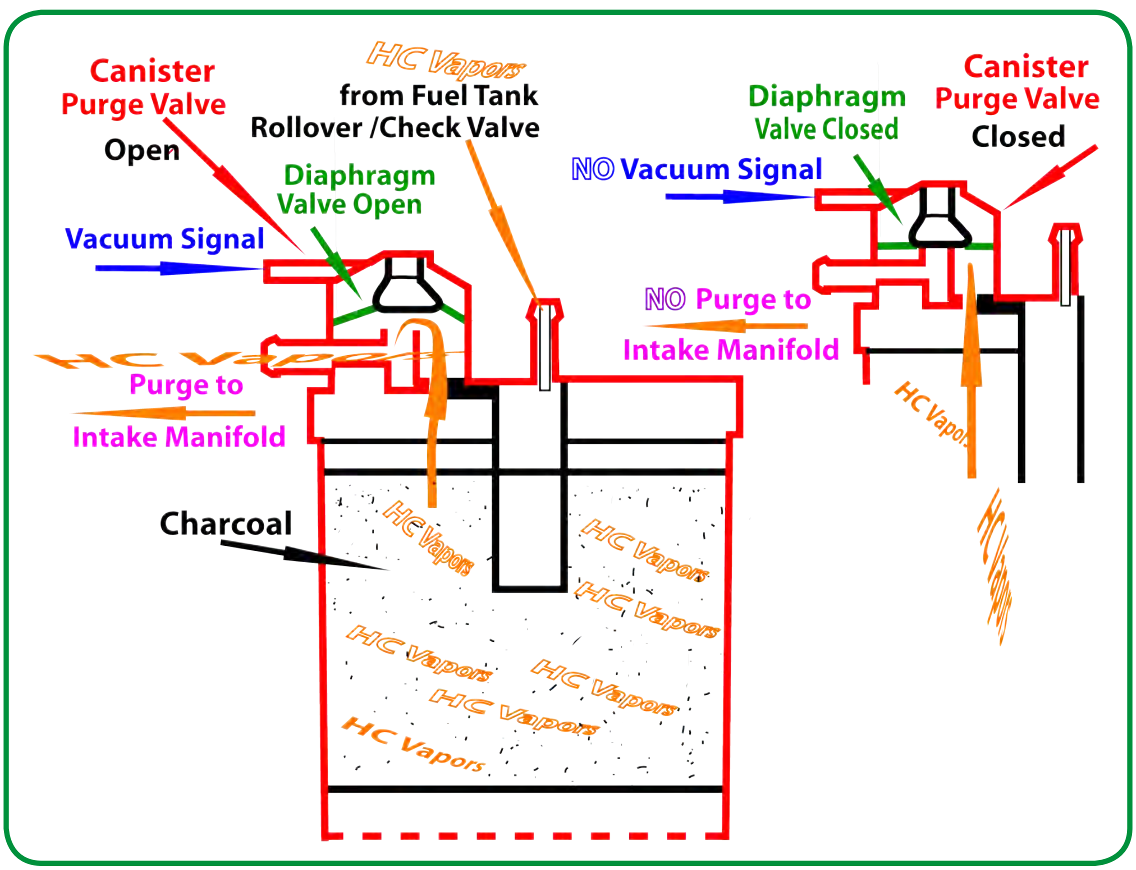


Fig.11-16 The canister purge valve is usually located on top of the EVAP canister. It is operated by a vacuum signal either controlled by a TVV or PCM controlled solenoid. When vacuum is applied to the valve, it opens and stored HC vapors are drawn into the engine and burnt.

Fig.11-17.The EVAP charcoal filled canister stores HC vapors during the hot soak period. When the engine is at normal operating temperature, HC vapors are drawn into the intake manifold and burnt.



Liquid Separator

All EVAP systems have a liquid vapor separator. Refer to figure 11-18. The function of the liquid vapor separator is to stop liquid fuel from entering the charcoal canister. There are three main types:
1) Open cell foam
2) Standpipe
3) Float
They all perform the same function, which is to prevent liquid fuel from saturating the charcoal in the canister. If the canister becomes soaked with liquid fuel,it must be replaced.

11-198-7 for an example of a diagram of an EVAP system on an engine with fuel injection.

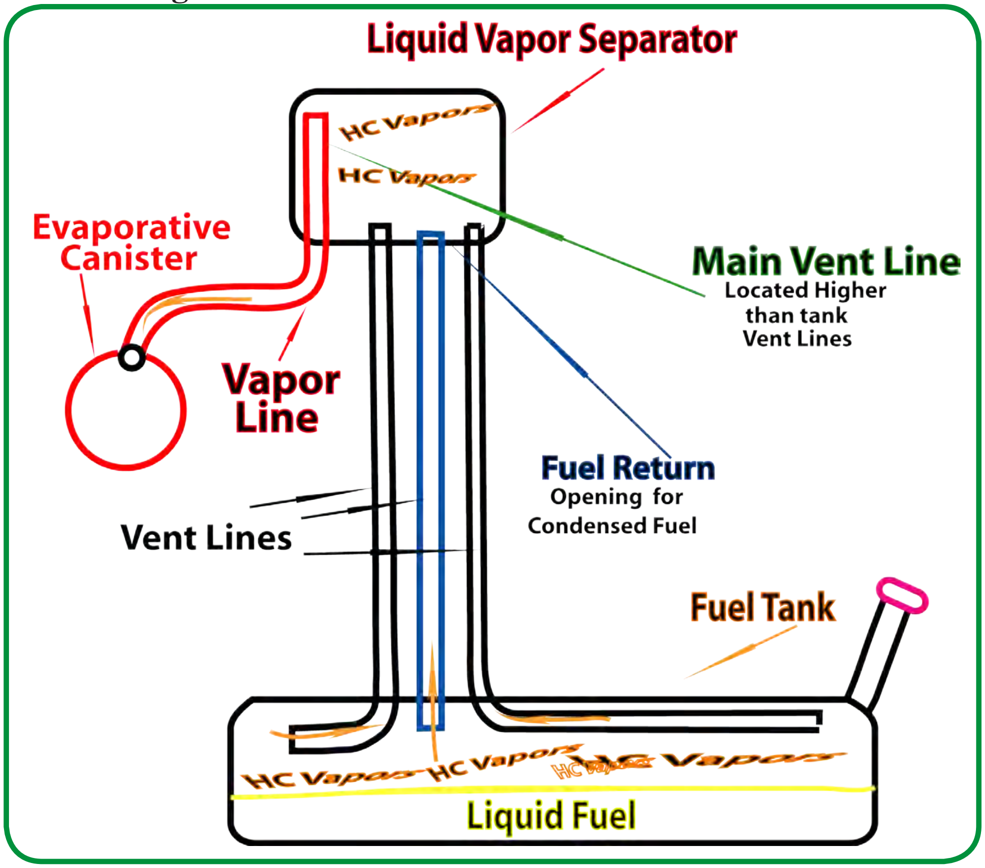


Fig.11-18 is an example of an EVAP system liquid separator.

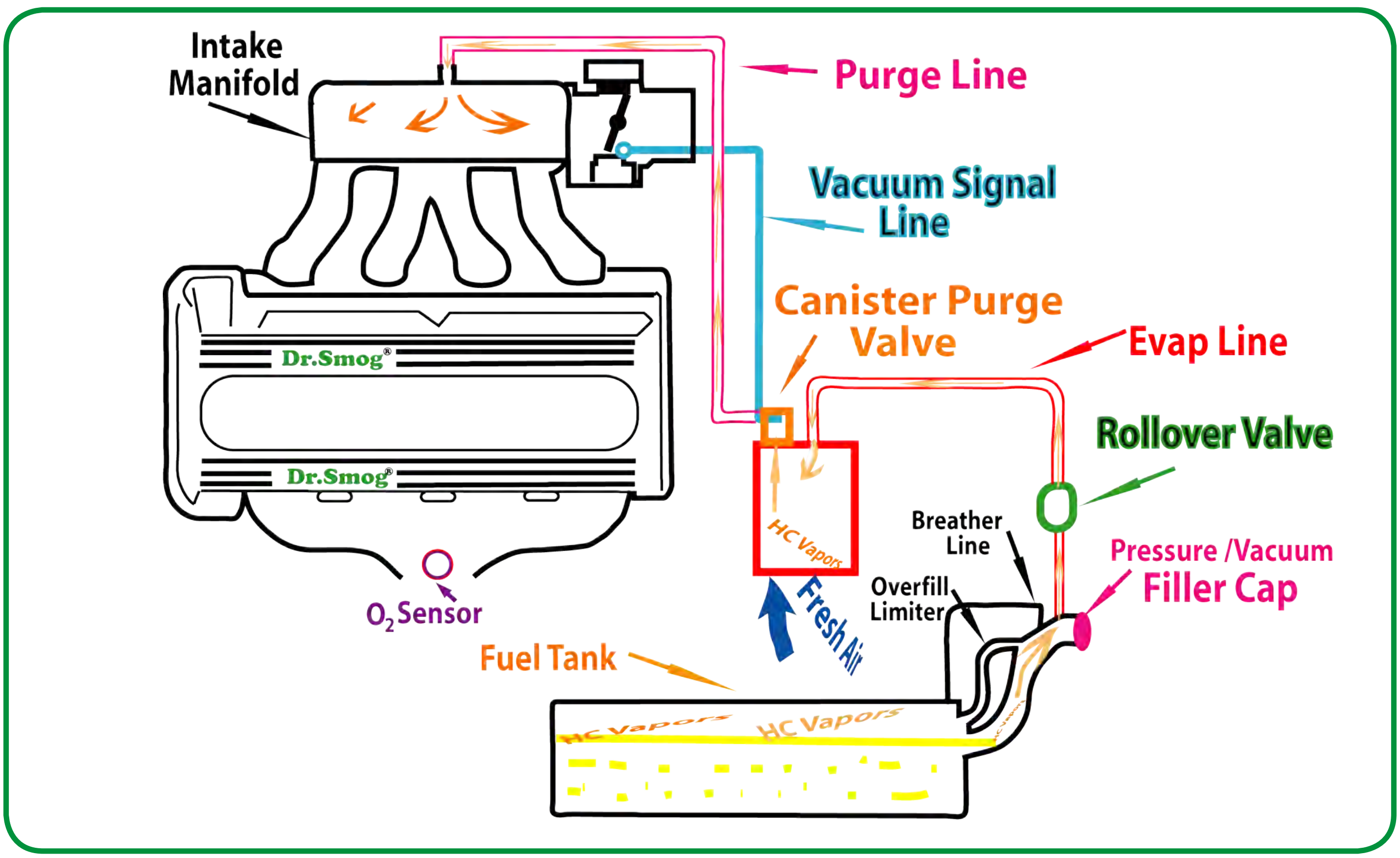


Fig.11-19. Fuel Injection system EVAP diagram

Overfill valve

EVAP systems have an overfill limiting component that prevents the complete filling of the tank. This provides an expansion space allowing the liquid fuel and fuel vapors to expand when temperatures increase.
The device may be one of the following:
a) Two way valve
b) Expansion tank
c) Two way limiting valve
Refer to figure 11-20.

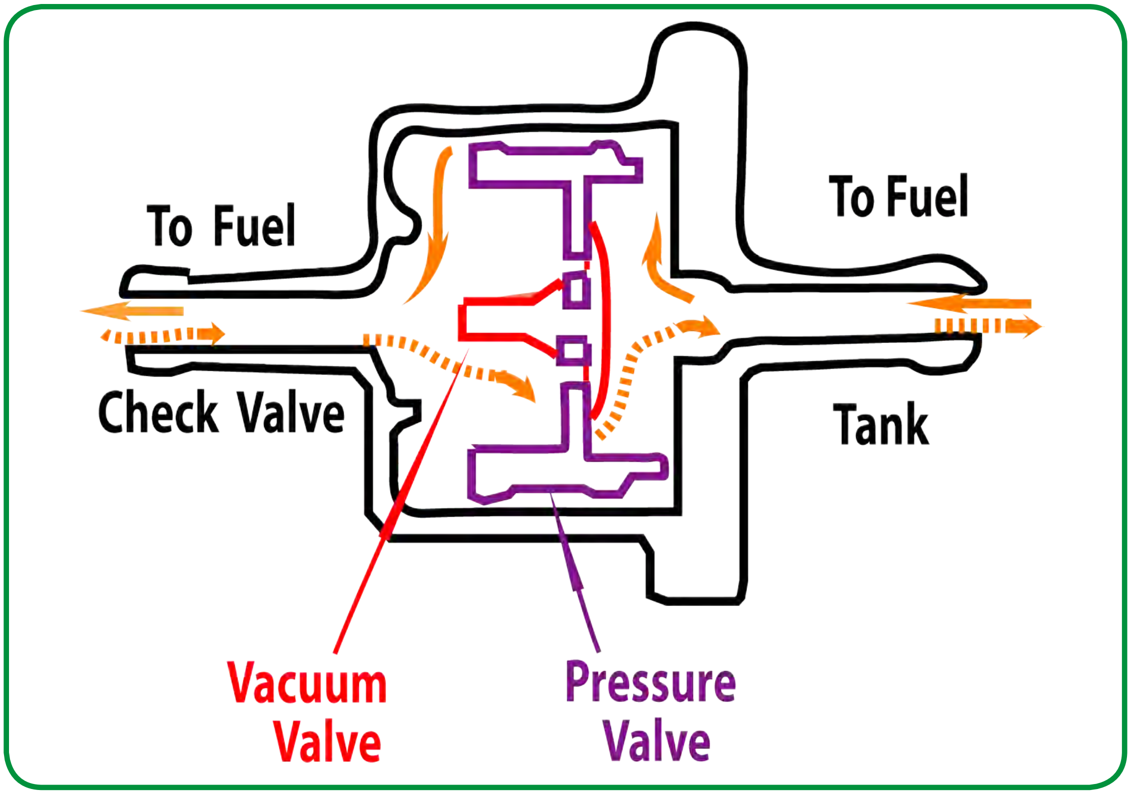
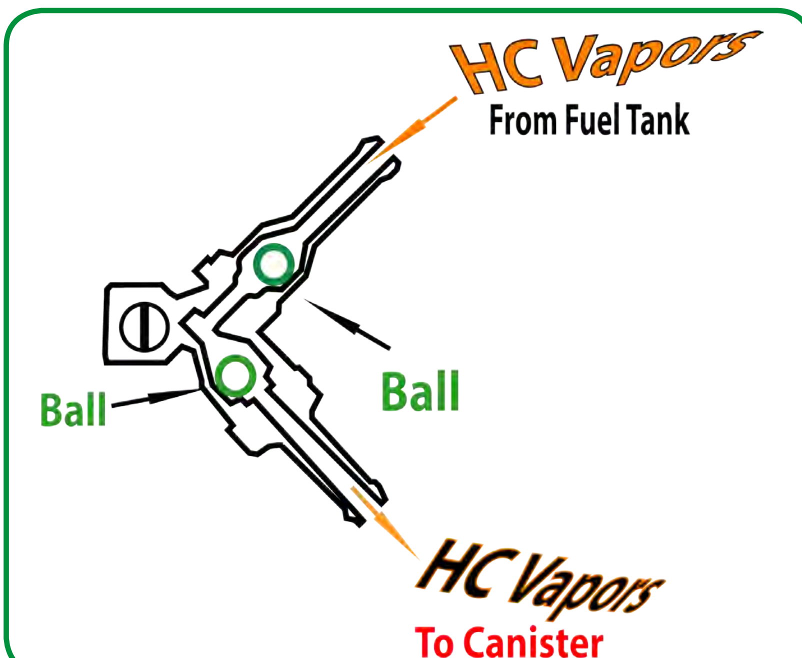


Fig.11-20. EVAP overfill valve. The valve prevents overfilling the fuel tank.

Rollover Valve

See figure 11-21 for a discription of a rollover valve operation.

Fig.11-21. The rollover valve is at the midpoint of the vapor line or incorporated into the liquid separator valve. Under normal conditions, the balls allow vapors to go from the fuel tank to the canister. If the vehicle rolls over in an accident, the passage way is blocked thus preventing liquid fuel from flooding the canister and surrounding area and reducing the risk of fire.



Fuel Tank Caps

1) Vented caps were used before vehicles had EVAP emission controls (pre-1972). HC vapors were vented to the atmosphere.
2) Sealed caps are now used on all post 1972 vehicles and prevent HC vapors from escaping into the atmosphere.

Vacuum/Pressure filler cap

Pressure valve

Late model vehicles use a sealed combination pressure/vacuum valve integrated into the fuel cap that prevents HC vapors from reaching the atmosphere. Refer to figures 11-20, figure 11-21, and figure 11-22. These are safety valves that protect the tank from damage in the event of excess pressure or vacuum. Excessive pressure may develop in the tank due to the thermal expansion of fuel.

Refer to figure 11-20. In this case, the **pressure valve** opens momentarily to release excess pressure in the tank to the atmosphere. This does allow a small quantity of HC vapors into the atmosphere but prevents possible damage or rupture of the tank. This will not occur if the tank has proper ventilation, which is usually through the canister.

Refer to figure 11-21. This is the normal position of the valve.

Refer to figure 11-22. The fuel cap vacuum valve is open. Fuel being drawn out of the tank creates a vacuum inside the tank greater than design specifications. The valve opens letting air into the tank and prevents the tank from collapsing. Many filler caps have tangs. These tangs, which are like the tangs on a radiator filler cap, prevent pressure from pushing liquid gas out of the tank when the cap is opened. When the cap is turned, tank pressure is released slowly. On some systems, there may be a hissing sound when the cap is released due to pressure or vacuum. Always inspect the seal or gasket for a complete compression print. The compression print shows up as a shiny line all the way around the gasket or seal. The seal or gasket should not be damaged in any way. If there is damage, check the cap and filler neck for physical damage.

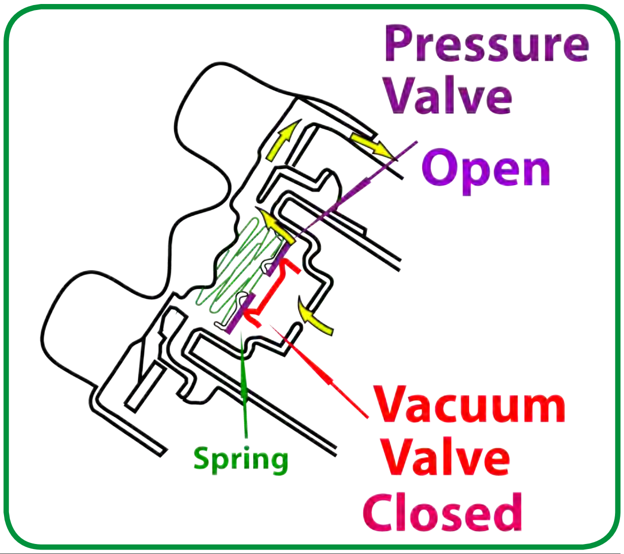


Fig.11-20. Fuel cap pressure valve open.

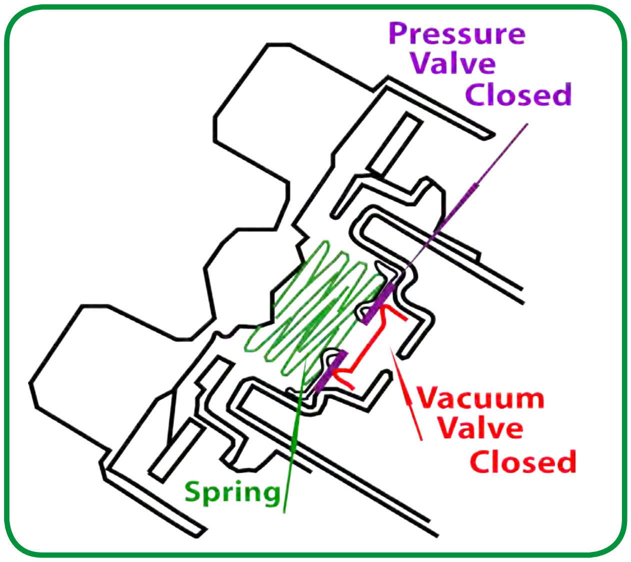


Fig.11-21. Fuel cap vent closed.

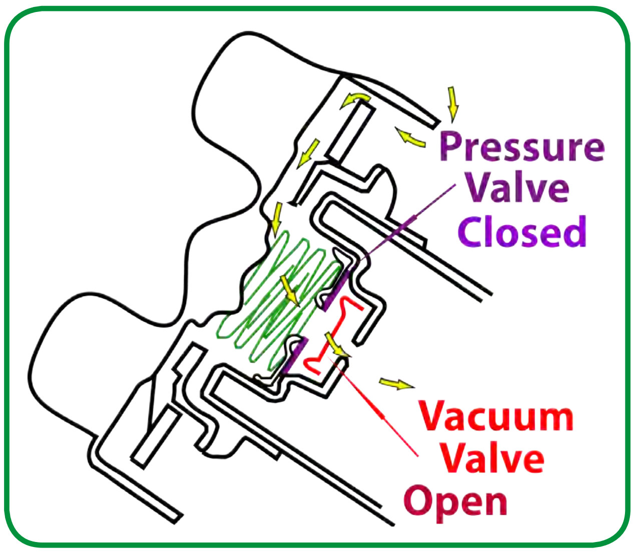


Fig.11-22. Fuel cap vacuum valve open

Air Injection

AI systems inject air into exhaust gasses. The additional oxygen results in the oxidation reaction in the catalyst continuing and intensifying. The additional O_2 also helps unburned fuel to be burnt and helps change HC and CO to CO_2 and H_2O. Secondary air injection systems are used to supply oxygen to the second stage of dual bed catalytic converters.
There are three main types of AI system:

1) Air Pump

Some AI systems use a belt driven pump to supply air into the exhaust system. Refer to figure 11-23.
Some three way catalytic converters have extra air supplied to the reduction section of the catalyst to help reduce HC and CO by adding extra oxygen An air switching or relief valve directs air upstream when the engine is cold and downstream when the engine is warmed up. A Thermo Vacuum Valve (TVV) and/or an air switching solenoid controls the switching upstream or downstream. Manifold vacuum is supplied to the air-switching valve, when the engine is cold. The vacuum supply is cut off when the engine is warmed up, and causes the air to be directed downstream. Continuous operation of upstream air from the pump decreases the efficiency of the reduction catalyst section of a catalytic converter. Refer to Figure 11-24 and figure 11-25

Repair Strategy

Visualy inspect all the hoses and fittings for defects and correct routing. Inspect the pump belt for fraying and tightness. No components should be missing, disconnected, modified, or defective. Remove the output hose from the pump and start the engine. You should be able to hear and feel air pulsating from the pump. Increase engine speed to 1500 rpm. The pump output should increase. If it does, the pump is operating as designed. If not, refer to the appropriate maintenance manual for further diagnostic routines.

Air Switching/Pressue Relief Valve

The air switching/pressue relief valve directs air pump output as follows:
a) Upstream while the engine is cold.
b) Downstream once the engine has warmed up.
The second function of the air switching valve is as a pressure relief safety valve. If excessive pressure builds up in the system, the valve routes this pressure to the atmosphere.

Repair Strategy

To check system operation, let the vehicle idle. If the air supply from the pump is heard or felt continuously dumping air from the top of the valve, it is defective.

Diverter Valve

The diverter valve diverts the air pump output to the atmosphere under certain conditions. For example, when fast deceleration occurs, a large amount of unburned HC/fuel can be released into the exhaust system. (This is usually true on engines with carburetors) PCM operated fuel injected engines switch off the injectors. If the oxygen supplied by the air pump is not diverted away from this fuel, it might ignite causing backfires, which would damage the system.

Repair Strategy

With the engine at operating temperature, raise the rpm to 2500 +/- 300 for 5 seconds. Release the throttle. You should hear the air supply being bypassed by the diverter valve, if it is operating correctly. If not, the valve is defective. Note: Under normal operating conditions, the diverter valve should not divert air.

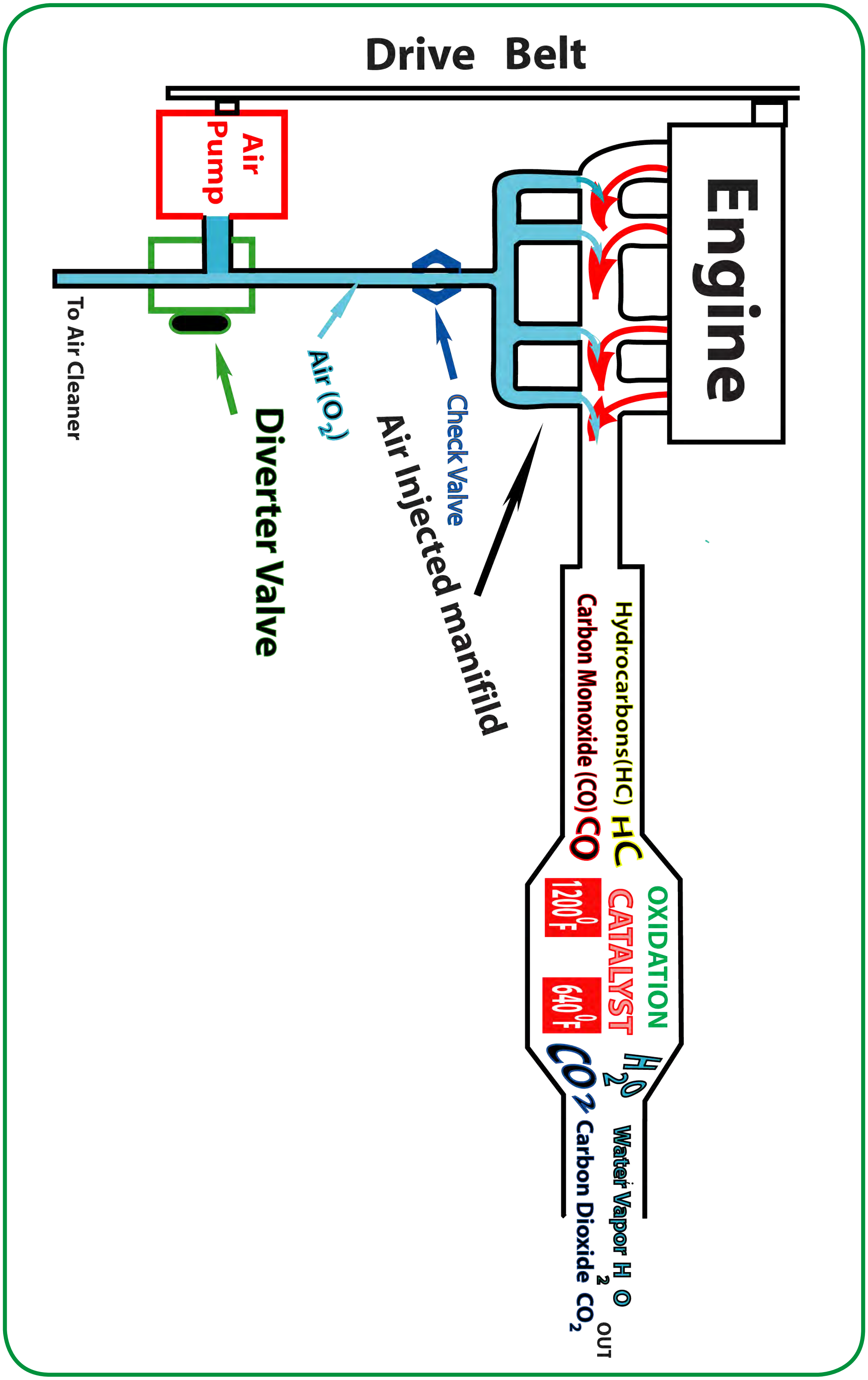


Fig.11-23. Air pump air injection system

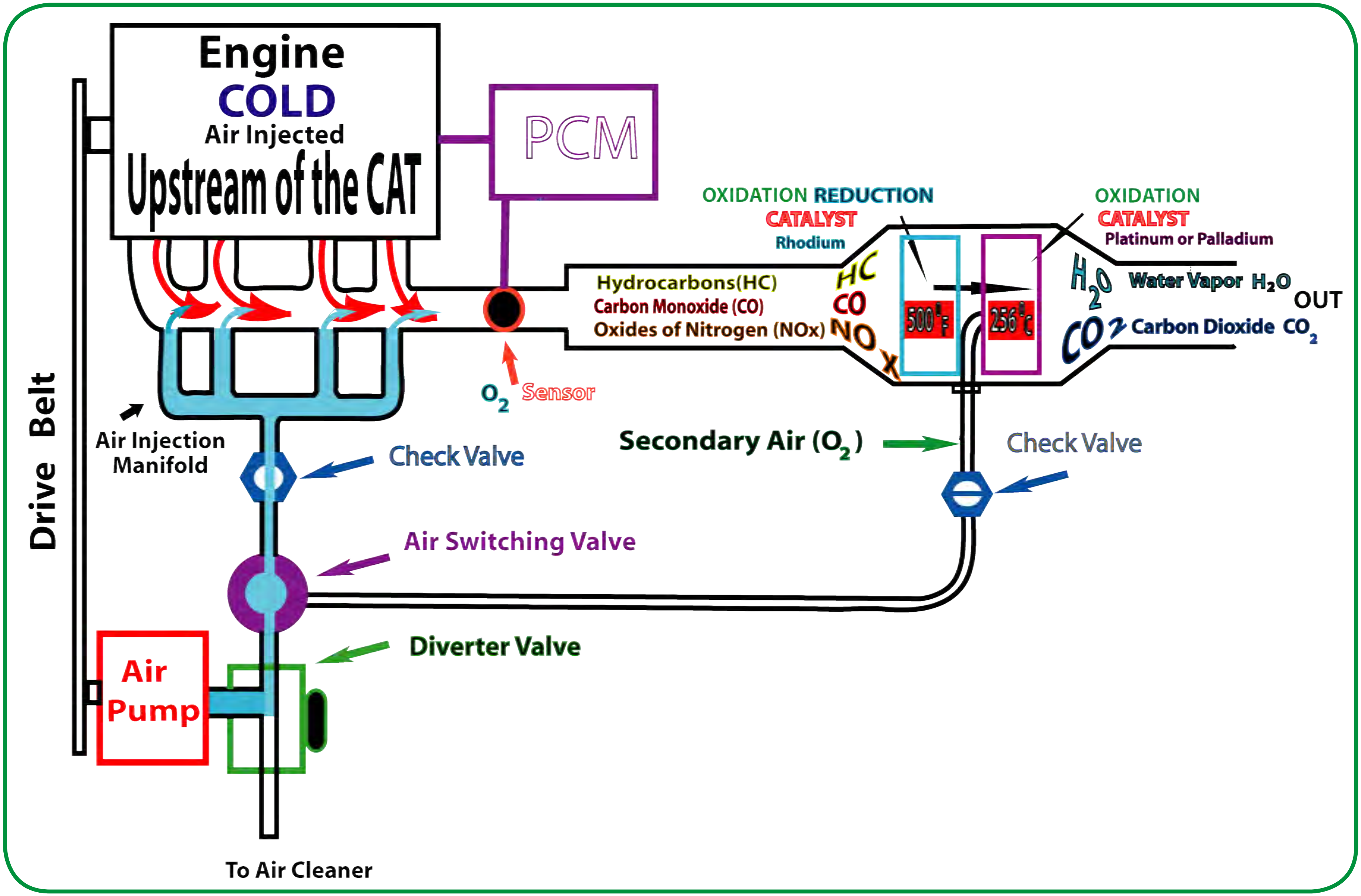


Fig.11-24. Air is injected upstream of the O_2 sensor and CAT, when the engine is cold. The increase in the oxygen in the exhaust results in a longer pulse width/ rich mixture for warm up.

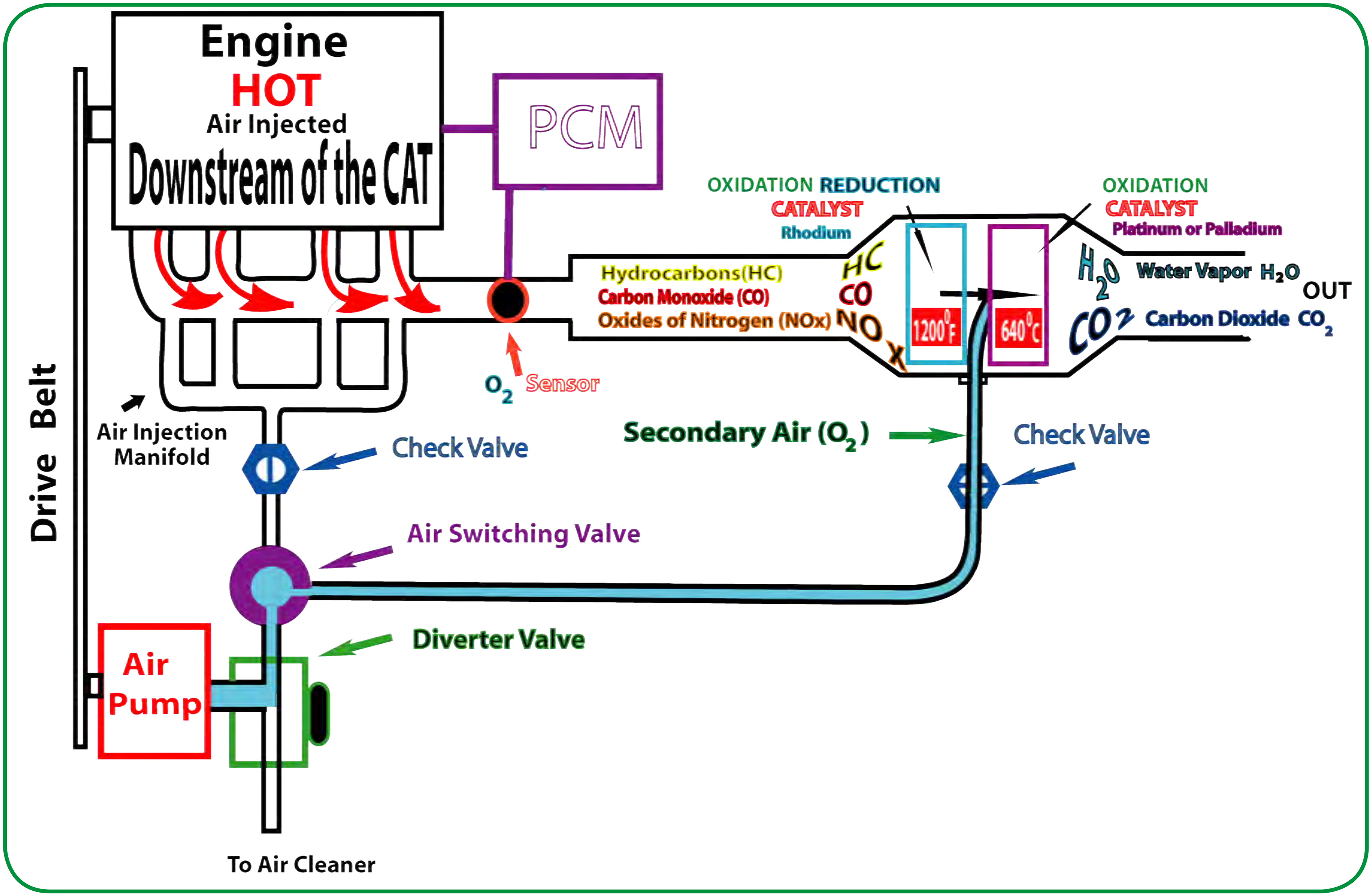


Fig.11-25. When the engine is warmed up air is injected down stream of the O_2 sensor and into the middle of the TWC in front of the Oxidation Catalyst to help reduce HC and CO.

Check Valve

The check valve is a one way valve that allows air to flow from the air pump to the air injection manifold and into the exhaust stream. It prevents exhaust gasses from flowing back into the air injection pump. If the valve fails, hot exhaust gases can damage the rubber hoses and system fittings. A burnt hose going to the check valve is an indication of valve failure.

Repair Strategy

If the hose(s) leading the check valve(s) is burnt, the valve is broken and must be replaced. To check the operation of the check valve(s), remove the rubber hose from the check valve(s). Run the engine at idle. Place a piece of cloth or paper near the check valve. If the valve is leaking, the exhaust gasses will push the cloth or paper away from the valve. If the valve leaks, it must be replaced. Replace any hoses or valves that appear to have any heat damage.

2) Aspirated System

This system uses negative pressure from the exhaust system to pull air into the exhaust system. An aspirated AI system uses the pressure variations that develop in the exhaust system to pull in air, when the engine is running. When the exhaust pressure is negative, it draws air from the air cleaner into the exhaust system. When the exhaust pressure is positive, the flow of exhaust gasses is prevented from flowing in the opposite direction towards the air cleaner by an aspiration valve.

Repair Strategy

Visually inspect all components of the system making sure that all hoses are correctly routed and free from defects. Loud exhaust leaks will be heard, if the system is leaking and has cracked or broken components. Inspect any filters or passages for obstructions. All leaks must be repaired.

Caution: wear gloves to prevent possible burns.

3) Pulse Air System

This system uses engine crankcase pressure acting in a diaphragm to draw air from the air cleaner.

The pulse air AI system uses a two-step process. Air is drawn into the pulse air feeder by crankcase pressures acting on a diaphragm. The pulsating exhaust pressures pull the air from the pulse air feeder into the exhaust system. A main reed valve controlled by the diaphragm and a sub reed valve in turn controlled by exhaust pressures direct the airflow.

Repair Strategy

Visually inspect all hoses and components. Perform a functional check as recommended by the vehicle repair manual for each specific manufacturer.

Air Injection System Quick Check

Visually inspect the AI system to make sure all hoses and valves are correctly connected, and encure the vehicle is at normal operating temperature. Run the engine at 2500 +/-300 rpm for 30 seconds. Allow the vehicle to return to idle and stabilize for 45 seconds. Record the O_2 and CO_2.

Disconnect the air supply at the check valve or plug the intake air port on the air cleaner of aspirated or pulse air systems. If you switch off the engine to perform this task, you must run the engine for at least 2 minutes to warm it up again. Then raise the rpm to 2500 +/- 300 rpm. Allow the vehicle to return to idle and stabilize for 45 seconds. Record the O_2 and CO_2. Compare the two readings. With the air supply connected, the vehicle will have about 2% higher O_2 and about 2-4% lower CO_2. If the readings vary by these amounts or more, the secondary air system is operating correctly, and no further diagnosis is required. If the readings do not change by this amount, refer to the appropriate vehicle repair manual for further diagnostic procedures.

A second method for checking the AI is as follows: With the engine warmed up at normal operating temperature and idling, record the HC, CO, and CO_2. Then pinch off the air injection hose. HC and CO should increase significantly. If they do not, air is not being injected. If the CO_2 did not increase by at least 0.5%, no air is being injected. Check the following:

1) Bad air pump
2) Leaky hoses
3) No signal to the air control valve
4) Malfunctioning air control valve

Caution: The valve will be hot. Use gloves and appropriate tools. As always, refer to the maintenance and repair manual for the vehicle you are working on for the correct test/repair procedures.

Positive Crankcase Ventilation (PCV)

Crankcase emissions are HC vapors and other by-products of combustion that are commonly known as blow-by gasses. Blow-by gasses are the result of gasses escaping past the piston rings on the compression stroke. Refer to figure 11-26.

Blow-by gasses cause three problems: 1) If blow-by gasses in (particular hydrocarbons) are allowed to accumulate in the engine and not controlled, they will enter the crankcase and eventually the atmosphere as pollution. 2) Blow-by gasses contain substances, which are harmful to the engine. For example, hydrocarbons can condense back to liquid form, mix with the engine oil, and reduce its viscosity and lubricating properties. Moisture, which is a by-product of combustion, condenses and enters the crankcase together with dust, soot, and sludge. Water also combines with unburned hydrocarbons, additives, and sulfur from the original crude oil to form carbonic acid, hydrochloric acid, hydrobromic acid, nitric acid, and sulfuric acid. These acids cause engine corrosion, wear, and rusting.

3) The movement of the crankshaft, pistons, and rods in the presence of blow-by gasses causes a positive pressure inside the crankcase. This pressure, if allowed to build up, can result in engine gaskets or seals being blown and resulting oil leaks.

The system has three major benefits:

1. Crankcase vapors, such as HC, that are harmful to life on the planet are prevented from escaping into the atmosphere.
2. The system increases engine life by ventilating the engine and preventing the build up of sludge and other contaminants, which are harmful to the engine.
3. Fuel economy is increased by recirculating all unburned HC to the intake manifold to be burned.

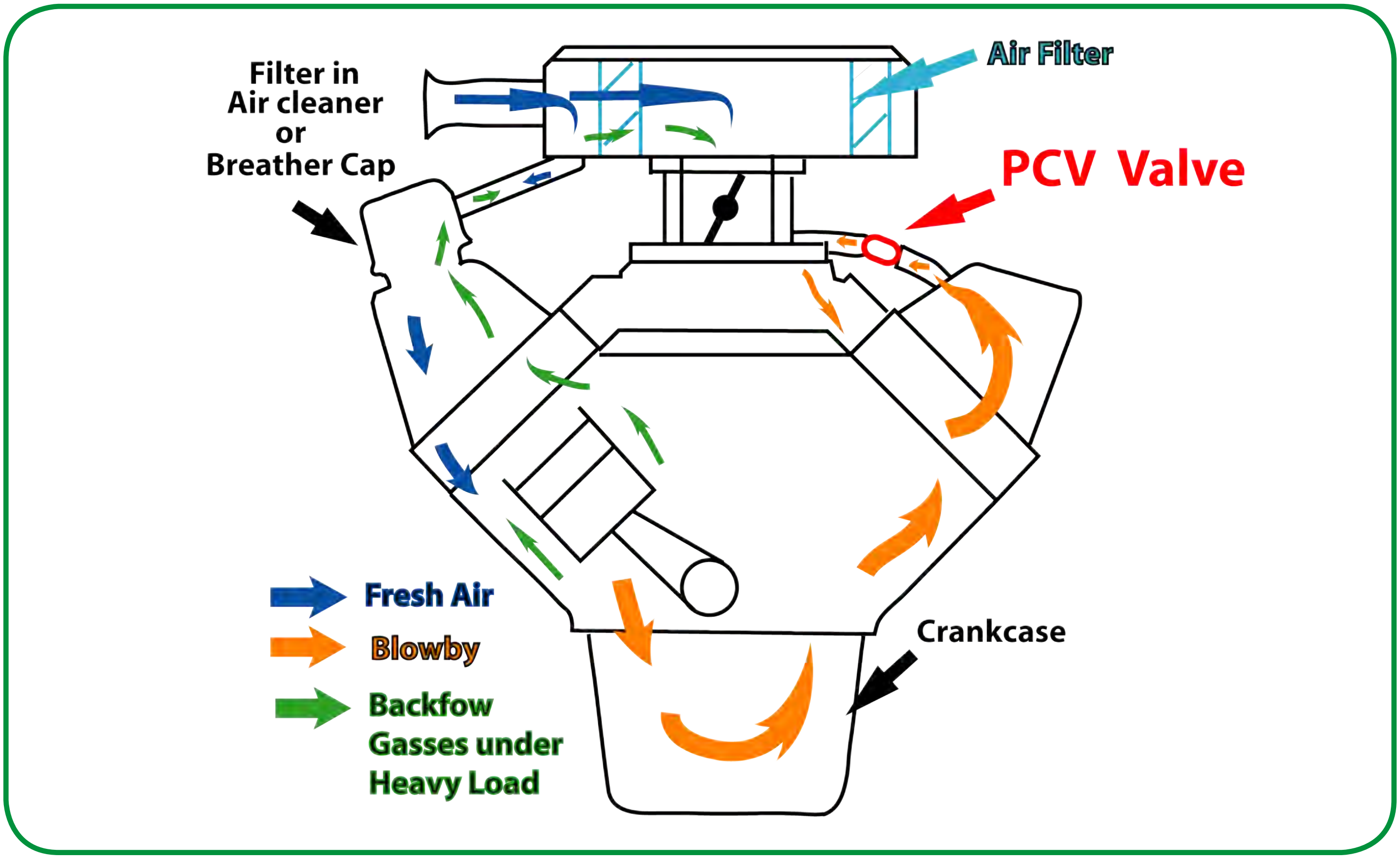


Fig. 11-26. Positive Crankcase Ventilation System (PCV)
Crankcase vapors are continually circulated and burned in the engine.
No vapors reach the atmosphere.

To prevent the harmful emissions from escaping into the atmosphere, auto manufacturers seal the system. This is called a closed crankcase ventilation system, and crankcase vapors are recirculated and burned in the engine. Fresh air enters the crankcase through a hose connected to the air cleaner. Then it flows through the crankcase, the PCV valve, and into the intake manifold to be burnt. If the system becomes clogged, or the engine is under heavy acceleration, the additional blow-by gasses reverse their direction, and the crankcase gasses flow back up the air inlet PCV hose and into the air cleaner. Where they are sucked into the intake manifold and burnt. Refer to figure 11-27 for PCV valve operation.

PCV Functional Test

The following are procedures to test a PCV valve:

1) Run the engine at idle at normal operating temperature.
2) Remove the PCV valve from the valve cove or crankcase vapor hose as applicable.
3) Making sure there are nor kinks in the hose, place your finger over the PCV valve momentarily.
4) You should feel a strong vacuum, and the valve should "snap closed" indicating that it is functioning correctly.
5) If the valve does not operate correctly, replace it. Make sure the new valve is the correct one, since each valve is calibrated to operate with a particular engine.

Another procedure to test the PCV is as follows:

1). Run the engine at idle at normal operating temperature. Put your gas analyzer probe in the exhaust.
2). Remove the PCV valve from the valve cover or crankcase vapor hose as applicable.
3). Hold the valve away from the engine so it draws in fresh air. If CO goes down and O_2 and CO_2 go up, the system is working.
4). Run the engine at 2000 to 2500 rpm. Place your finger over the PCV valve inlet. If O_2 does-decrease check for a collapsed PCV hose.

Fuel in the Crankcase

Fuel in the crankcase is an emission problem that is related the PCV system. The following are causes of fuel in the crankcase:

1) Engine in poor mechanical condition.
2) Fuel pressure regulator defective.
3) Leaking fuel injector(s).

Fuel in the crankcase will result in a rich mixture. This will cause:

1) Fuel vapors to be drawn into the engine through the PCV valve.
2) The mixture will be rich
3) The O_2 sensor will send a rich mixture signal to the PCM, which will respond with a lean command.

One of the first indications of a problem with the PCV valve may be rough idle. This is because the intake air /fuel calibration is incorrect due to the reduction in flow of crankcase vapors.

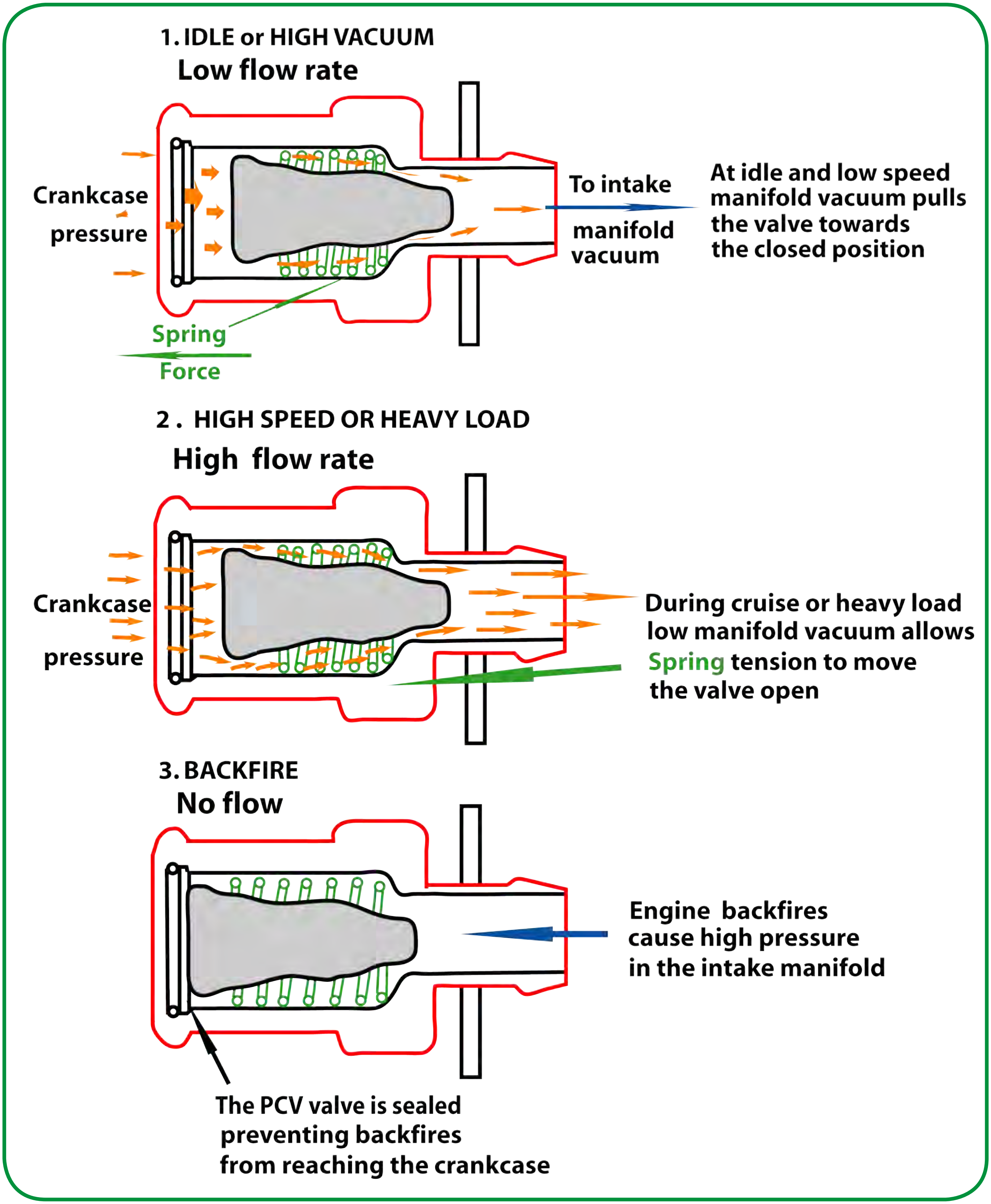


Fig. 11-27. Crankcase ventilation. This is an example of how a PCV valve operates.

SECTION 12
Diesel Emission Controls

Diesel Engines

Diesel engines have fuel economy and durability advantages over gasoline engines for passenger cars. Their major disadvantage is that they emit particulate matter (PM) and oxides of nitrogen (NOx), hydrocarbon (HC), carbon monoxide (CO) and other toxic air pollutants. Particles emitted from diesel engines are very small, less than 2.5 microns in diameter. The particles consist of a carbon core which adsorbs hydrocarbons from engine oil and diesel fuel in addition adsorbs sulfates, water and inorganic materials produced by engine wear. Health experts believe that diesel PM contributes to chronic lung diseases such as asthma, bronchitis, and emphysema. Exposure to diesel PM may increase the risk of cancer in humans. The black color of the black smoke you see coming out of a diesel exhaust is particulate matter.

Mechanical Indirect Injection

The original diesel engines used a mechanical injection system to deliver fuel to the cylinders at the right time and at the right pressure. The maximum fuel pressure generated by these injection systems was not high enough to maintain a well-defined spray pattern of fuel. The pump of the diesel mechanical indirect injection system had to supply not only fuel system pressure, but also act as the timing and delivery device. Mechanical injectors are opened by fuel pressure. The only inputs to help meter their fuel delivery is fuel pump RPMs and throttle position. The result is injection of fuel with a poor spray pattern that is either too rich (which happens most often) or too lean. The rich mixture results in a belch of sooty black smoke, and a lean mixture results in lack of power. The low-pressure fuel had to be injected into a pre-chamber to insure proper atomization of the charge before entering the main combustion chamber for ignition. That is why the system is called an indirect injection system. When the engine is cold and the outside air temperature is low, the engines use glow plugs to help them start. Remember diesel engines have no spark plugs and rely on the compression of air in the cylinders to ignite the fuel.

Electronic Common Rail Direct Injection (CRD)

The main difference between Direct and Indirect Injection is the layout of the injection system. The Indirect Injection System has a small swirl chamber above the cylinder where the fuel is injected The chamber also contains the glow plug, which is needed to start the engine. Direct Injection systems have the injector nozzle actually fixed to the top of the combustion chamber. Pistons of an engine with an indirect injection system have a crown shape in the top to create a swirl effect.

In addition to better fuel economy, engine management and electronic fuel delivery, systems have now increased diesel engine performance and emissions to equal gasoline engines. Refer to figure 12-1.

By using computer controlled electronic injectors and a high-pressure fuel rail, the common rail system fuel pump can raise the high-pressure fuel rail up to 25,000 psi. The fuel quantity and pressure in the rail is independent of engine speed and load and is controlled by the Power Control Module (PCM). Each fuel injector is mounted above a piston in the cylinder head and is connected to the fuel rail by high-pressure metal fuel lines. The high pressure allows the use of fuel injectors with very fine orifices, which facilitate the complete atomization of the diesel fuel. The injectors are controlled by the PCM and can be actuated in rapid succession several times during the injection cycle. Injector actuation is accomplished by a stack of piezo electric crystal wafers that control the fuel spray by moving the injector needle in tiny increments. Piezo crystals function by expanding rapidly when an electric charge is applied to them. This allows precise control over fuel injection by using smaller, staggered quantities of fuel. Sometimes five or more fuel injections are timed over the course of the power stroke to facilitate complete combustion. These short duration, high pressure injections create a spray pattern that support more complete atomization and combustion. This has resulted in a quieter, cleaner and more fuel efficient automobile diesel engine.

The common rail diesel fuel injection engine is quieter, cleaner, more fuel efficient and more powerful than the indirect mechanical injection units they have replaced. It's the high-pressure fuel rail and the computer controlled electronic injectors that make all the difference. In the common rail system, the fuel pump charges the fuel rail at a pressure of up to 25,000 psi, but unlike indirect injection pumps, it is not involved in fuel discharge. Under the control of the onboard computer, fuel quantity and pressure accumulate in the rail independently of engine speed and load.

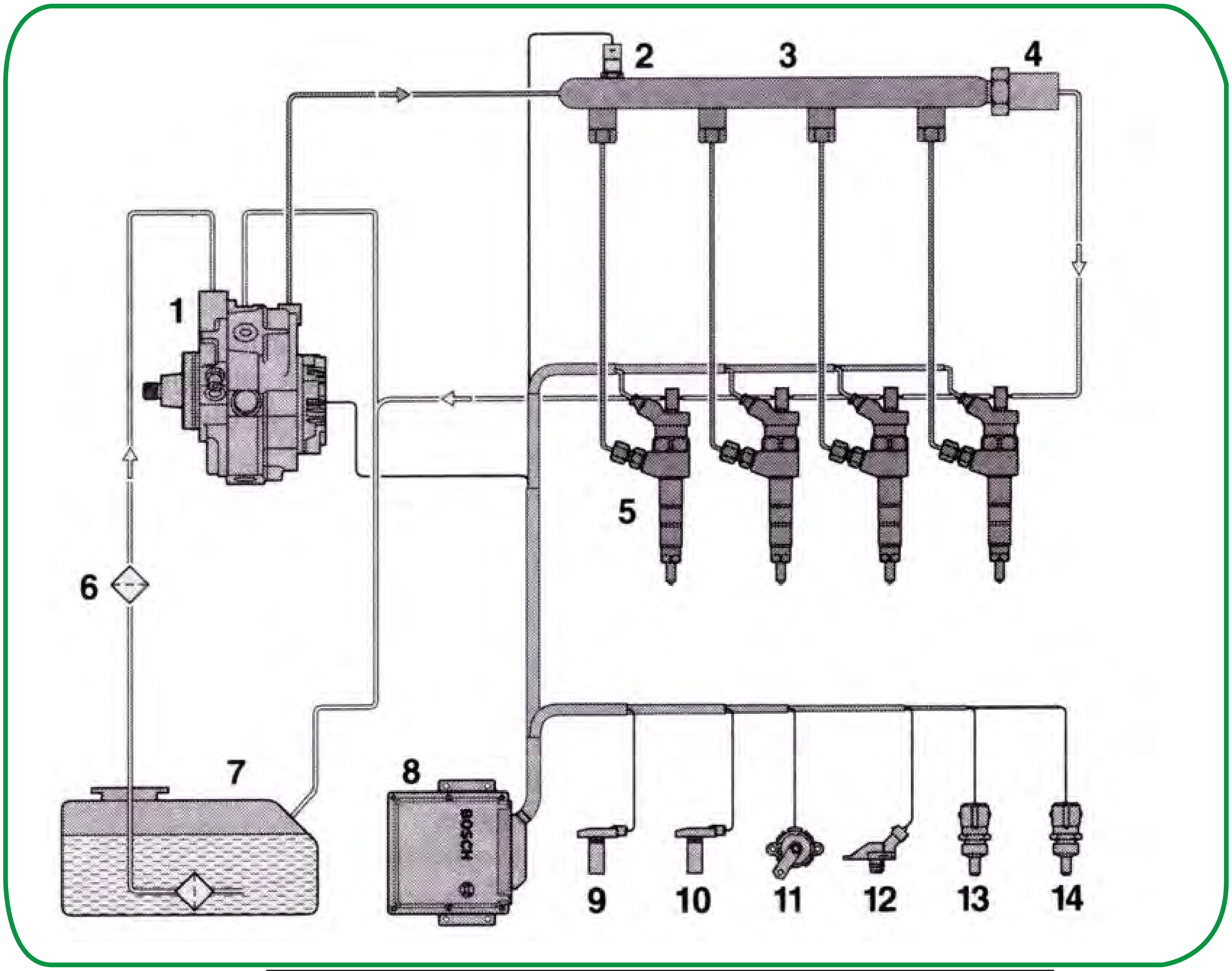


Figure 12-1. Common rail diesel fuel injection system.

How the common rail diesel fuel injection system works. Refer to figure 12-1. A high pressure mechanical pump (1). Pressurizes the fuel which flows to the common rail (3). A fuel control valve (4). Allows the fuel pressue to be maintained at a level set by the Electronic Control Unit (ECU) (8). The common rail feeds the injectors (5). Sensor inputs to the ECU compirse fuel pressure (2). Engine speed (9). Camshaft position (10). Accelerator pedal travel (11). Boost pressure (12). Intake air temperature (13). Engine coolant temperature (14). Numbers (6) and (7) are the fuel filter and fuel tank respectively.

Each fuel injector is mounted directly above the piston within the cylinder head (there is no pre-chamber) and is connected to the fuel rail by rigid steel lines that can withstand the high pressure. This high pressure allows for a very fine injector orifice that completely atomizes the fuel and precludes the need for a pre-chamber. The actuation of the injectors comes via a stack of piezo electric crystal wafers that move the jet needle in tiny increments allowing for the spray of fuel. Piezo crystals function by expanding rapidly when an electric charge is applied to them. Like the fuel pump, the injectors are also controlled by the engine computer and can be fired in rapid succession several times during the injection cycle. With this precise control over injector timing, smaller, staggered quantities of fuel delivery (5 or more) can be timed over the course of the power stroke to promote complete combustion. In addition to timing control, the short duration, high-pressure fuel injections allow a finer and more accurate spray pattern that helps atomization and combustion.

The overall result of the use of the electronic Common Rail Direct injection system (CRD) is a quieter, more fuel efficient, less polluting and more powerful diesel engine than the indirect mechanical injection system.

The following are emission controls used on vehicle diesel engines.

Diesel Emisson Controls

Crankcase Depression Regulator Valve(CDR)

The crankcase depression regulator (CDR) valve is similar to a PCV valve on a gasoline engine. The purpose of the Crankcase Depression Regulator is to recycle engine blow by. Blow by is the exhaust gasses that get past the piston rings into the crankcase.

The Crankcase Depression Regulator (CDR) Valve maintains crankcase pressure. Pressure must be regulated to prevent oil consumption through the intake system and to prevent leaks due to excessive buildup of pressure. Control is accomplished by regulating the blow-by gasses into the intake system to be reburned. The CDR valve has a spring which holds open a valve plate that connects to the CDR valve body with a flexible diaphragm. The valve plate restricts the outlet passage to the turbocharger air inlet duct when airflow pulls it closed against the force of the spring.

The CDR valve controls the pressure/vacuum in the engine crankcase, separates the oil mist from the air and then returns the oil to the crankcase. If pressure builds up because the CDR is stuck closed, the crankcase pressure will increase and force oil past gaskets and seals that could result in leakage.

If the CDR is stuck open oil, mist from the crankcase will be sucked into the engine and be burned as fuel However, it is heavier and thicker than diesel fuel and has a higher BTU heat output. (British Thermal Unit (BTU) is a unit of energy.) This causes excessive heat in the cylinder. Over time, engine and cylinder head temperatures will reach excessively high levels causing the head gasket to fail.

To inspect your CDR valve, remove the air cleaner assembly and look into the air intake with a flashlight. If you see engine oil mist in the intake manifold, use the following text to check the valve or replace it.

Crankcase Pressure Check

Genetic Specifications

Crankcase pressure at idle . . . . .0-1 inch H_2O
Crankcase pressure at 2000 RPM . . . . 2-5 inch H_2O

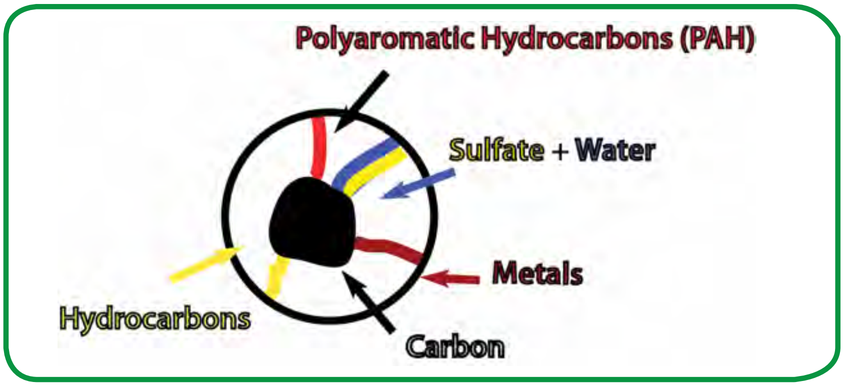
1. Bring the engine to operating temperature.
2. Use a water manometer.
3. Remove the oil dipstick and attach the hose of the water manometer to the dipstick tube.
4. Start the engine, and observe the manometer at idle:
   a) If the reading indicates that the crankcase pressure is 1 inch of H_2O or less go to step 5.
   b) If the reading indicates that crankcase pressure is higher than 1 inch of H_2O, inspect the CDR valve and recheck crankcase pressure.
   c) If the CDR valve is good, check engine compression.
5. Run the engine at 2,000 RPM, observing the manometer.
   d) If the reading indicates crankcase pressure is in a negative state (-4 to -5 inch H_2O), the system is OK.
   e) If the reading indicates crankcase pressure is in a negative state greater than -5 inches of H_2O replace the CDR valve and retest.
   f) If the reading indicates crankcase pressure is in a positive state, review test and results of step 4.

Diesel Particulate Filter (DPF)

Diesel particulate consists of small carbon particles that are coated with several compounds that are formed during engine combustion and travel down the exhaust and out into the atmosphere. Diesel engines emit a very large number of particulates that are extremely small (less than 10 microns) consisting of a carbon core. These particules are known to be made up of possible cancer-causing substances (e.g., polyaromatic hydrocarbons) that are carried directly into the lungs where a large fraction remains. Refer to figure 1-12. Diesel particulates are also of concern because they are usually emitted directly into the breathing zone where the urban population lives.

The particles are complex and consist of a carbon core, which adsorbs hydrocarbons from engine oil and diesel fuel as well as adsorbs sulfates, water, and inorganic materials such as those produced by engine wear. Because of their extremely small size and composition, the particles emitted by diesel engines have raised many health concerns. Health experts have expressed concern that diesel Particulate Matter (PM) may contribute to or aggravate chronic lung diseases such as asthma, bronchitis, and emphysema. There is growing evidence that exposure to diesel PM may increase the risk of cancer in humans.

Figure 12-2. Diesel particulate matter consists of small carbon particles that are coated with several compounds, which are formed during the engine combustion and travel down the exhaust and out into the atmosphere.



A DPF works in conjunction with the Oxidation Catalyst (OC) and Exhaust Gas Recirculation (EGR) valve to remove a majority of NO_x, particulate matter (thick, black cough-inducing soot) and unburned hydrocarbons from burned diesel fuel. Soot is a natural byproduct from the combustion of diesel fuel. Inside the DPF is a porous honeycomb structure that catches the soot as it passes through. After the soot builds up over time, the onboard computer controls fuel injection to allow unburned fuel to enter the filter at measured intervals where it flares off and generates increased temperatures that incinerate the accumulated soot. This is called filter regeneration.

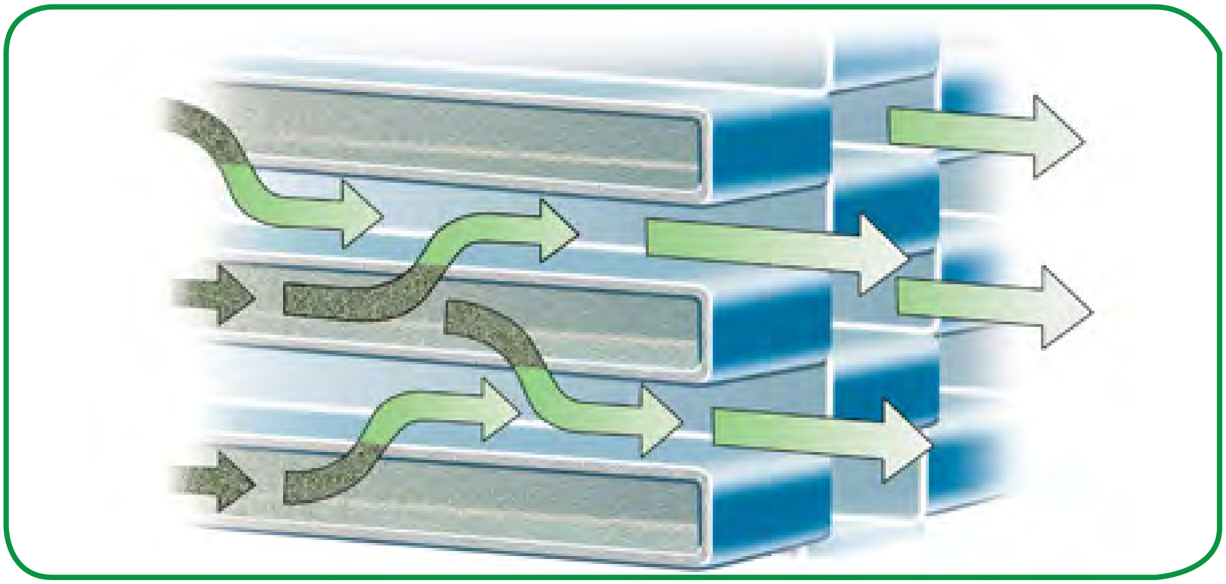


Figure 12-3. Wall flow filters derive their name from the fact that all of the exhaust gasses are required to pass through the porous walls of the filter.

A DPF cleans exhaust gas by forcing the gas to flow through a filter. There are a variety of diesel particulate filter technologies on the market. Each is designed around the same requirements:

1. Fine filtration
2. Minimum pressure drop
3. Low cost
4. Mass production suitability
5. Product durability

As exhaust gasses pass through the filter, particles larger than the pore size are left behind, and filtration efficiencies better than 99% by mass are possible. Wall flow filters are made from a variety of materials with the most common being cordierite, silicon carbide and sintered metal. Refer to Figure 12-3. The filtration efficiency is so high that any filter will rapidly become blocked, unless the accumulated diesel particulate matter is removed by oxidation at regular intervals.

Filter Regeneration

The process known as 'regeneration' is so important that diesel particulate filter systems are usually categorized according to the regeneration principle which they follow. They are designed to burn off the accumulated particulate either passively through the use of a catalyst or by active means such as a fuel burner, which heats the filter to soot combustion temperatures.

Regular scheduled maintenance is required to keep DPF systems in proper working order. Over time all DPF's accumulate non-combustible ash mainly from additives in lube oil burnt by the engine and periodically require removal of this ash to avoid clogging or damage to the filter.

Some filters are single-use, intended for disposal and replacement once full of accumulated ash. Others are designed to burn off the accumulated particulate either passively through the use of a catalyst or by active means such as a fuel burner which heats the filter to soot combustion temperatures. On Board Diagnostic (OBD) systems use a variety of strategies, for example: The OBD system can increase exhaust temperatures by late fuel injection or injection during the exhaust stroke or run a regenertion routine when the filter is full which produces high amounts of NO_x to oxidize the accumulated ash, or through other methods. This is known as "filter regeneration". Cleaning is also required as part of periodic maintenance, and it must be done carefully to avoid damaging the filter. Failure of fuel injectors or turbochargers resulting in contamination of the filter with raw diesel or engine oil can also necessitate cleaning. The regeneration process normally occurs at road speeds higher than can be reached on city streets.

Vehicles only drive at low speeds in urban traffic require periodic trips at higher speeds to clean out the DPF. The driver is warned of the necessary filter cleaning by a dash reminder light. If the driver ignores the warning light and waits too long to operate the vehicle above 40 miles per hour (64 km/h), the DPF may not regenerate properly, and continued operation past that point may destroy the DPF.

Filters will only remain efficient if the trapped soot can be disposed of during normal engine operation. If this is not done regularly, the filter will clog. This increases the backpressure from the exhaust and ultimately stops the engine running

Other filter regeneration methods include:

1) The use of a Fuel Borne Catalyst (FBC). A Fuel Borne Catalyst works by reducing the ignition temperature of the trapped soot.
2) A fuel burner after the turbo to increase the exhaust temperature
3) A catalytic oxidizer to increase the exhaust temperature after injection.
4) Resistive heating coils to increase the exhaust temperature.
5) Microwave energy to increase the particulate temperature

All OBD active systems use fuel, whether through burning to heat the DPF or providing extra power to the DPF's electrical system. A fuel borne catalyst significantly reduces the energy required to perform the regeneration. The PCM monitors one or more sensors that measure backpressure and/or temperature, and based on pre-programmed set points, the PCM makes decisions on when to activate the regeneration cycle. The additional fuel is usually supplied by a metering pump. Running the cycle too often while keeping the backpressure in the exhaust system low will result in high fuel consumption. Not running the regeneration cycle soon enough increases the risk of engine damage and/or uncontrolled regeneration (thermal runaway) and possible DPF failure.

Diesel particulate matter burns at temperatures above 1112^0 F (600^0C). This temperature can be reduced from between 662^0F (350^0C) to 842^0 F (450^0C) by using of a fuel borne catalyst. The actual temperature of soot burnout will depend on the chemistry employed.

Filter Safety

In 2011, Ford recalled 37,400 F-Series trucks with diesel engines after fuel and oil leaks caused fires in the diesel particulate filters of the trucks. There was another recall for the 2005-2007 Jaguar S-Type and XJ diesels; where large amounts of soot became trapped in the DPF. In affected vehicles, smoke and fire came from under the vehicle with flames coming out the exhaust. The heat from the fires like this can cause heating through the transmission tunnel to the interior of the vehicle, melting interior components and possibly setting the vehicle on fire.

Oxidation Catalyst (OC)

The most commonly used catalytic converter for compression-ignition (i.e., diesel engines) is the Diesel Oxidation Catalyst (DOC). This catalyst uses O_2 (oxygen) in the exhaust gas stream to convert CO (carbon monoxide) to CO_2 (carbon dioxide) and HC (hydrocarbons) to H_2O (water) and CO_2. These converters can operate at 90 percent efficiency,virtually eliminating diesel odor and helping to reduce visible particulates (soot). These catalysts do not reduce NO_x because any reducing agent present would react first with the high concentration of O_2 in diesel exhaust gas.

An oxidation catalyst is a flow through exhaust device that contains a honeycomb structure covered with a layer of chemical catalyst. This layer contains small amounts of precious metal (usually platinum or palladium) that interact with and oxidize pollutants in the exhaust stream (CO and unburned HCs), thereby reducing poisonous emissions. Sometimes called an OxyCat when used on a diesel engine. It works together with the DPF and EGR valve to remove the bulk of unburned hydrocarbons, soot and NO_x from diesel exhaust. Reduction in NO_x emissions from compression-ignition engines has been achieved by the addition of exhaust gasses to incoming air charge by an Exhaust Gas Recirculation (EGR) valve. In 2010, most light-duty diesel manufacturers in the U.S. added catalytic systems to their vehicles to meet new federal emissions requirements. There are two techniques that have been developed for the catalytic reduction of NO_x emissions under lean exhaust conditions.

1. Selective Catalytic Reduction (SCR)
2. Lean NO_x trap or NO_x absorber.

Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR) is a method of converting harmful diesel oxides of nitrogen (NO_x) emissions by means of catalytic reaction into benign nitrogen gas and water. SCR can deliver near-zero emissions of NO_x. NO_x from diesel engines is an acid rain and smog-causing pollutant, which also contributes to greenhouse gasess. Refer to figure 12-4.

The SCR system performs emissions after treatment similar to the soot containment achieved by the Diesel Particulate Filter (DPF).

SCR works by injecting Diesel Exhaust Fluid (DEF). Ammonia is supplied to the catalyst system by the injection of urea into the exhaust, which then undergoes thermal decomposition and hydrolysis into ammonia.

One trademark product of urea solution, also referred to as Diesel Emission Fluid (DEF), is AdBlue, which is patented by BASF and used by Mercedes-Benz.

An urea a colorless crystalline compound that is the main nitrogenous breakdown product of protein metabolism in mammals and is excreted in urine.

In the U.S., all on-road light, medium and heavy-duty vehicles powered by diesel and built after January 1,2007 are equipped with a 2-Way catalytic converter and a diesel particulate filter, so they can meet EPA standards. Instead of precious metal-containing NO_x absorbers, most manufacturers selected base-metal SCR systems that use an agent such as ammonia to reduce the NO_x to nitrogen.

Exhaust Gas Recirculation Valve (EGR)

An EGR (Exhaust Gas Recirculation) valve is an emission control device that sits between the exhaust and intake manifolds on a vehicle engine and regulates the amount of spent exhaust gas that is mixed into the intake stream. Its purpose is to cool combustion chamber temperatures to the threshold that reduces the formation of nitrogen oxides (NO_x). The higher the combustion temps, the higher the formation of NO_x. In conjunction with the OxyCAT and DPF, the EGR valve significantly reduces unburned hydrocarbons; soot and NO_x in diesel exhaust emissions.

Diesel Particulate Trap Oxidizers

These systems rely on catalyst fuel additives like cerium, copper and platinum. Catalysts are placed in front of the filter or catalysts are coated directly on the filter in order to initiate the regeneration process.

Diesel particulate trap oxidizers or diesel particulate filters can achieve up to, and in some cases exceed, a 90 percent reduction in particulates. The trap is extremely effective in controlling the carbon core of the particulate and recent evidence indicates it can be very effective in reducing ultrafine PM emissions, which are likely to be the most hazardous to health.

The trap oxidizer system consists of a filter positioned in the exhaust stream designed to collect a significant fraction of the particulate emissions while allowing the exhaust gasses to pass through the system.

Since the volume of particulate matter generated by a diesel engine is sufficient to fill up and plug a reasonably sized filter over time, some means of disposing of this trapped particulate must be provided. The most common means of disposal is to burn or oxidize the particulates in the trap, thus regenerating or cleansing the filter.

A complete trap oxidizer system consists of the filter and the means to facilitate the regeneration.

To protect the filter from overheating and possibly being damaged, some trap systems incorporate a by-pass for exhaust gasses that is triggered and used only when exhaust temperatures reach critical levels in order to slow the regeneration process. The period during which the by-pass is operated is very short and relatively infrequent. Some systems are also designed with dual filters in which one filter collects while the other is being regenerated.

Non-catalyzed trap systems appear to have little or no effect on NO_x, CO, or HC emissions. Experience with the catalyzed trap system indicates that HC and CO emissions have also been reduced to a considerable degree (in the range of 60-90 percent) with no adverse impact on NO_x emissions.

Though difficult to quantify, it has been found that ceramic traps significantly reduce gas phase aromatics and noise. The experience with catalyzed traps indicates that there is a virtually complete elimination of odor and the soluble organic fraction of the particulate.

Trap systems, which replace mufflers in retrofit applications, have achieved sound attenuation equal to a standard muffler.

However, there is a fuel economy penalty with trap oxidizer technology, which is attributable to the backpressure of the system. Some forms of regeneration involve the use of diesel fuel burners, and when these methods are used, there will be an additional consumption of fuel. It is expected that systems can be optimized to minimize or eliminate any noticeable fuel economy penalty. For example, in a demonstration program in Athens, no noticeable fuel penalty was recorded when the trap was regenerated with a cerium fuel additive.

Trap systems do not appear to cause any additional engine wear or affect vehicle maintenance. Concerning maintenance of the trap system itself, manufacturers are designing systems to minimize maintenance requirements during the useful life of the vehicle.

NO_x Adsorbers

NO_x absorbers (also known as NO_x traps or lean NO_x traps) are advanced emission-control technologies that can help diesel vehicles meet stringent EPA nitrogen oxides (NO_x) emissions standards. NO_x absorbers trap and store NO_x present in the lean (i.e. oxygen-rich) exhaust produced by diesel engines. The stored NO_x is transformed into more environmentally benign compounds before these compounds are emitted into the atmosphere. Refer to figure 12-5.

The process starts with ultra-low sulfur diesel (ULSD) fuel combusted in an optimized diesel engine. (Use of ULSD minimizes potential poisoning of the NO_x adsorbed by sulfur compounds.) Lean exhaust from the engine flows into the NO_x adsorbed; in some configurations, the exhaust flows first through other emission control devices. With the aid of a noble metal catalyst, NO_x is captured and stored within the NO_x adsorbed substrate.

When the NO_x adsorbed nears its NO_x storage capacity, it begins "regeneration" by injecting extra diesel fuel into the exhaust stream or late-cycle in-cylinder injection. The engine exhaust is briefly made rich (i.e., fuel rich and oxygen poor). In the presence of this fuel-rich exhaust, the stored NO_x is released and then reduced to carbon dioxide (CO_2), water (H_2O), nitrogen (N_2), and other nitrogen-containing gasses over a noble metal catalyst. These gasses are then emitted out the tailpipe.

NO_x absorbers are not a new technology, but they are just beginning to be seen in vehicle applications. Tests have shown they can reduce automotive NO_x emissions by 80% to 90%.

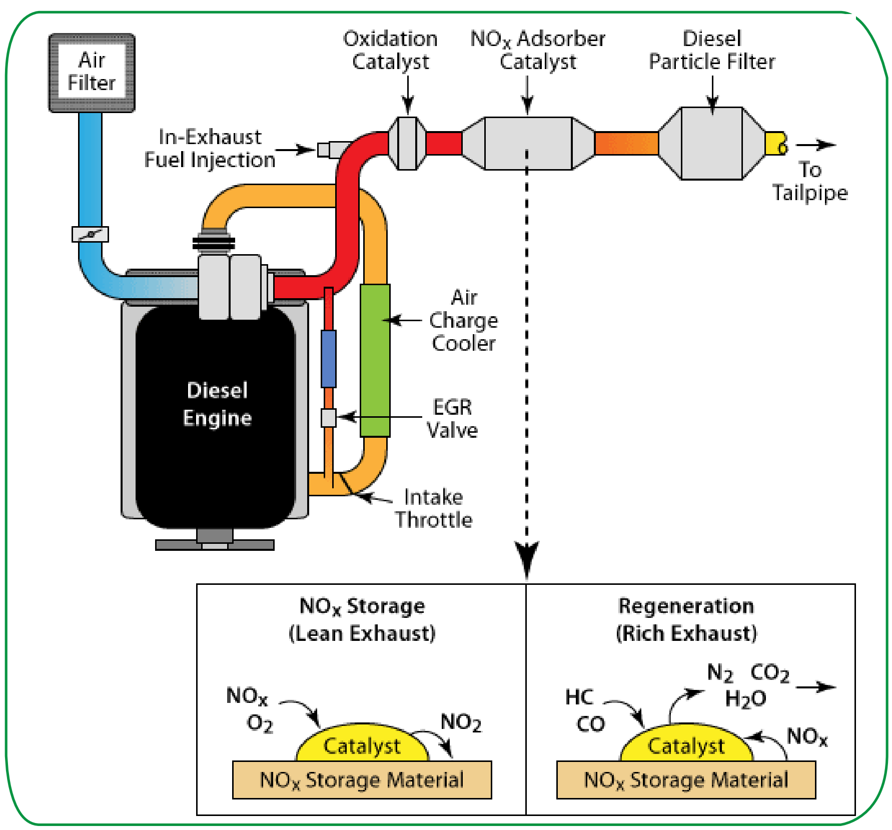


Figure 12-5. Schematic of a NO_x Absorber Configuration.

SECTION 13
Emissions Causes and Effects - HC CO NO_X CO_2 and O_2

The air we breathe is made up of 78% nitrogen, 21% oxygen, and 1% other gasses. The air an engine intakes has the same composition of gasses. Gasoline consists of hydrogen and carbon molecules, which combine to form hydrocarbon. Together air and hydrocarbons make up the air/fuel ratio that enters an engine. Once inside the engine, each element of the air/fuel ratio is transformed by the heat and pressure of combustion before exiting the engine via the exhaust. There are five exhaust gasses, which are significant, HC, CO, NO_X , CO_2 and O_2. Refer to figure 13-1.
HC, CO, and NO_X are pollutants. CO_2 and O_2 are used for diagnosing combustion efficiency. Exhaust gas analysis is the process of taking readings of HC, CO, NO_X , CO_2, and O_2 using an exhaust gas analyzer and comparing their relationship. Exhaust gas levels, also called cut points, for passing or failing the emissions portion of an I/M test are set by individual states. Depending on the type of test, the standard for exhaust gasses may be expressed in PPM (parts per million), percentage or (gm) grams per mile.
The power of an internal combustion engine comes from the controlled combustion of gasoline (HC). Gasoline engines are heat engines. When the combustion process is perfect, only three things are produced:
1) Carbon dioxide CO_2
2) Heat
3) Water vapor H_2O
Perfect combustion occurs, when one carbon atom from gasoline HC (the C of HC) combines with $O_2$and forms CO_2 (carbon dioxide). No excess fuel remains, and all available O_2 is used up. In other words, there is exactly the right amount of oxygen to burn the existing fuel, and exactly the right amount of fuel to consume the existing O_2. This is called the stoichiometric air/fuel ratio and is expressed as 14.7 to 1. The correct air fuel ratio is critical to low emissions and good driveability. Complete combustion rarely occurs. Even if the fuel ratio is correct, the heat of combustion might not be sufficient, or the spark timing might be may not be correct. The result is incomplete combustion, which results in HC and CO in the exhaust gasses. HC, CO and NO_X can all be a result of an incorrect air/fuel ratio. Therefore, maintaining the correct air/fuel ratio is one of the main goals of PCM emission control systems. NO_X is the result of excessive combustion temperatures, which can be caused by a lean/air fuel ratio.

Air/Fuel ratio

Stoichiometric air/fuel ratio

Refer to figure 13-1. The stoichiometric air/fuel ratio 14.7 to 1 is the ratio at which all three pollutant gasses are at their lowest. This is expressed as 14.7 lbs of air to 1 lb of fuel and is the perfect air/fuel ratio under most conditions. The first number of the air fuel ratio is the air, and the second is the fuel.

Lambda

Lambda is a number used in relation to air/fuel ratio that compares the actual air/fuel ratio to the stoichiometric air/fuel ratio.

$$\text{Lambda} = \frac{\text{Actual ratio}}{\text{Stoichiometric}}$$

Stoichiometric: Lambda =1.

Lean: Lambda >1.

Rich: Lambda <1.

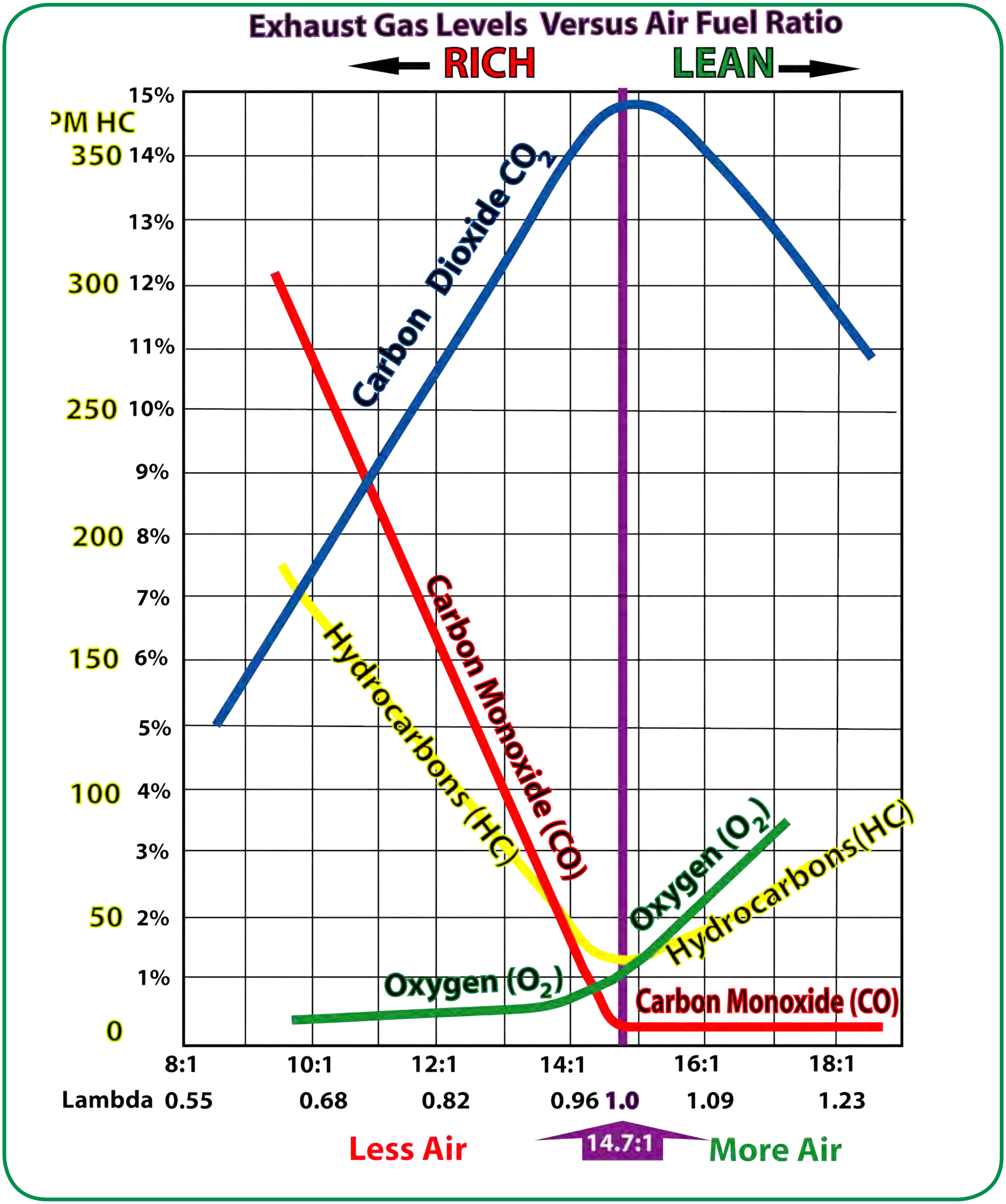


Fig. 13-1. An example of exhaust gas levels versus air/fuel ratio. As the air/fuel ratio moves away from 14.7:1, that is becomes too rich or too lean, driveability and emissions problems occur.

Effects of air fuel ratio on emissions and performance

Air/Fuel Mixture	Effects on Driveability & Emissions
Too Lean **High HC** **Low CO**	Burned Valves Burned Pistons Increased No_X emissions Misfires at cruise Spark knock
Slightly Lean	High gas mileage Low exhaust emissions Reduced engine power May knock or ping
Stoichometric	Best driveabilitay & emission levels
Slightly Rich	High fuel consumption Increased HC Less tendency to knock Maximum engine power
Too Rich **High CO**	Black exhaust smoke Increased HC Misfiring Oil contaminated by fuel

Fig. 13-2. This is an example of how an incorrect air/fuel ratio the effects driveability and emissions.

Typical exhaust gas readings for various A/F ratios

Air/Fuel Mixture	Exhaust Gasses							
Too Lean	HC PPM	250	CO_2	8%	CO	0.4%	O_2	4%
Slightly Lean	HC PPM	150	CO_2	9%	CO	0.8 %	O_2	2%
Stoichometric	HC PPM	20	CO_2	15%	CO	0.5%	O_2	1%
Slightly Rich	HC PPM	160	CO_2	12%	CO	0.5%	O_2	2.7%
Too Rich	HC PPM	390	CO_2	9%	CO	2.3%	O_2	1.0%

Fig. 13-3. Exhaust gas readings at idle of a CAT equipped engine AIR.

Pollutant exhaust gasses

HC-Hydrocarbons

Gasoline is a hydrocarbon fuel and the source of automotive hydrocarbon emissions. HC emissions are caused by partly burned and unburned fuel. Refer to Figure 13-4 for examples of high hydrocarbon emissions of a vehicle at idle and cruise.

Hydrocarbons are :

b) Low at the stoichiometric A/F ratio (14.7:1).
c) Lowest when the mixture is slightly lean.
d) Increase as the mixture gets leaner.

Causes of High HC (lean mixture):

The most common cause of high HC emissions is a misfire.

Anything that causes incomplete or no combustion will result in high HC.

The following will result in high HC emissions:

1) Excessively rich mixture.
2) Ignition system problems due to: Inaccurate spark timing ,inadequate voltage or spark duration,fouled plugs, plug gaps too wide,open or grounded wires, defective cap or rotor, or high resistance in the primary or secondary circuits
3) Air/fuel ratio too lean (>14.7:1).
4) Low or no compression due to worn rings, burnt valves, or a blown head gasket.
5) EGR valve leaking at idle.
6) Very high CO. Problems listed under high CO can cause a misfire. If the mixture becomes too rich to burn, it can cause “rich mixture misfires”.
7) Low fuel pressure possibly due to a plugged fuel filter or fuel lines.
8) Vacuum leaks making the mixture too lean to burn. O_2 will be high since it is not consumed during combustion. This is a lean mixture misfire.
9) Incorrect signals from inputs to the PCM. Incorrect MAP input, for example.
10) Quenching inside the combustion chamber.

Near the cylinder head and engine block, much of the heat of combustion is absorbed by the “cold” metal surface, which causes the combustion flame to extinguish. The result is unburned HC in the exhaust gasses. Refer to figure 13-4 for an example of excessive HC emissions caused by an ignition misfire. Note that HC emissions are high at all speeds. This means that the problem exists at idle and cruise. An EGR valve on at idle is obviously not the problem. Look for a cause which affects idle and cruise. High resistance in the primary or secondary ignition circuit would affect idle and cruise. Use your oscilloscope to check ignition voltage patterns.

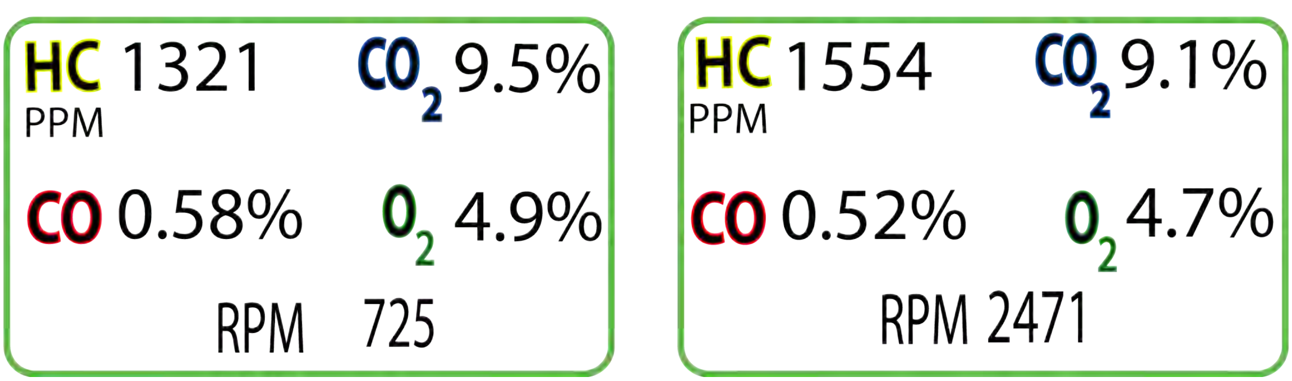


Fig. 13-4. An example of ignition misfires causing high HC emissions at all speeds.

Refer to figure 13 -5. This is a graph of the relationship between HC emissions and fuel air ratio for a CAT and non-CAT equipped engine. On the CAT equipped engine HC is lowest at an air fuel ratio of 14.7 to 1.

HC increase rapidly on the non CAT equipped engine as the mixture becomes leaner.

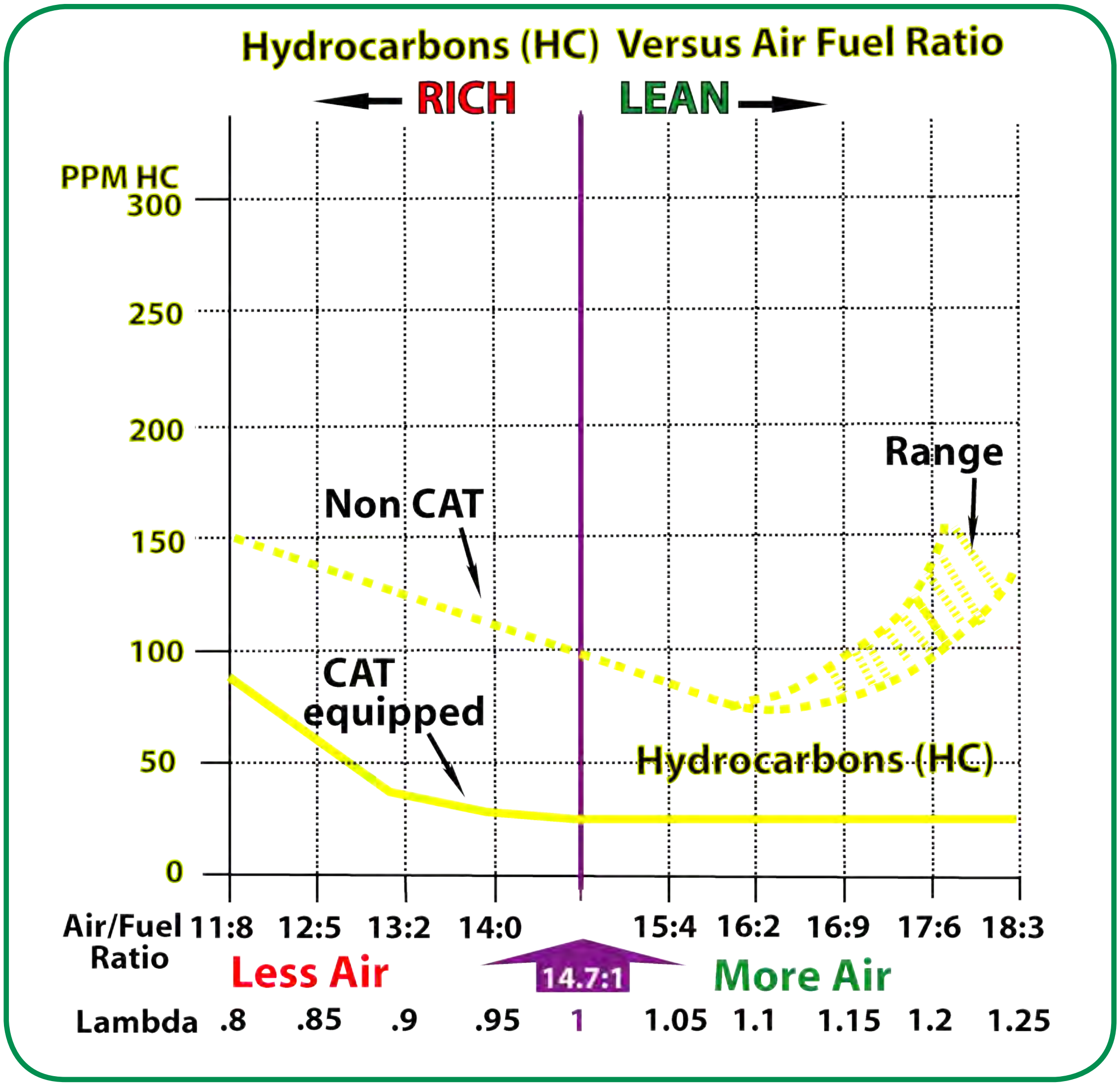


Fig.13-5. HC emissions versus air fuel ratio.

Refer Figure 13-6. This is an example of high HC possibly caused by an EGR valve not completely closing at idle. Note at cruise HC is low.

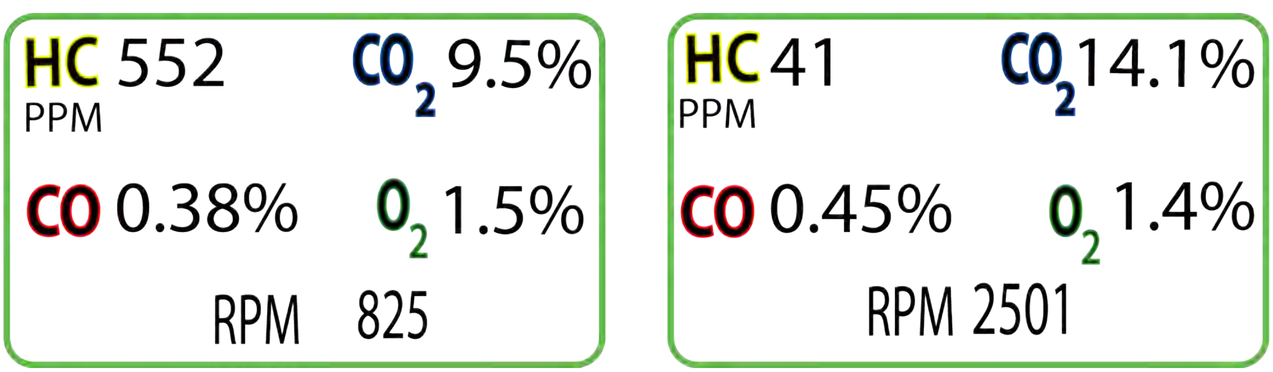


Fig. 13-6. High HC at idle emissions caused by an EGR valve pintle that does not fully close.

CO-Carbon Monoxide

Carbon monoxide is a gas made up of one atom of carbon and one atom of oxygen. It is colorless, odorless, and very poisonous. Refer to figure 13-7.

Caution: When you inhale CO, it takes the place of oxygen in your blood. Carbon monoxide absorbs O_2 ten times faster than blood cells do. Your body being starved of O_2 will result in headaches, reduced intellectual ability (your ability to repair a vehicle, for example), and possibly death.

Always work in a well ventilated area.

When perfect combustion occurs, one atom of carbon (the C from HC) combines with O_2 to produce CO_2. If there is a shortage of O_2 in the combustion chamber, burning of the fuel stops prematurely. When all the O_2 is used up, one atom of carbon (C) combines with one atom of oxygen (O) to produce deadly CO.

Carbon Monoxide is:
a) High when the mixture is rich.
b) Decreases, as the mixture gets leaner.
c) Is close to zero at stoichiometric and stays low as long as the mixture is >14.7:1.

High CO is an indicator of a rich air fuel ratio (<14.7:1).
The lower the CO, the leaner the mixture.
The higher the CO the richer the mixture.
CO is decreased by oxidation. In other words increasing the air/fuel ratio (adding O_2).

Causes of High CO: (rich mixture):

The most common cause of high CO emissions is a rich mixture.
Anything that restricts intake air to the combustion chamber will increase CO.

1) Dirty air filter, which restricts airflow.
2) Restricted induction system.
3) Blocked PCV.
4) Choke closed at normal operating temperature (non-feedback and PCM controlled carburetors) restricting airflow.
5) High fuel pressure.
6) Fuel diluted oil. Fuel vapors are drawn in through the PCV system.
7) Leaking fuel injector's pressure regulator diaphragm.
8) Leaky fuel injector(s) caused by a weak spring.
9) Defective EVAP purge valve.
10) O_2 sensor bias low voltage, lean condition because of an exhaust leak upstream of the O_2 sensor.
11) Open thermostat.
12) Over advanced initial ignition timing.
13) Engine in open loop.
14) Faulty PCM input. For example, the ECT sending an open signal to the PCM (cold engine), which will result in increased injector pulse width (rich mixture) when the engine is at normal operating temperature.

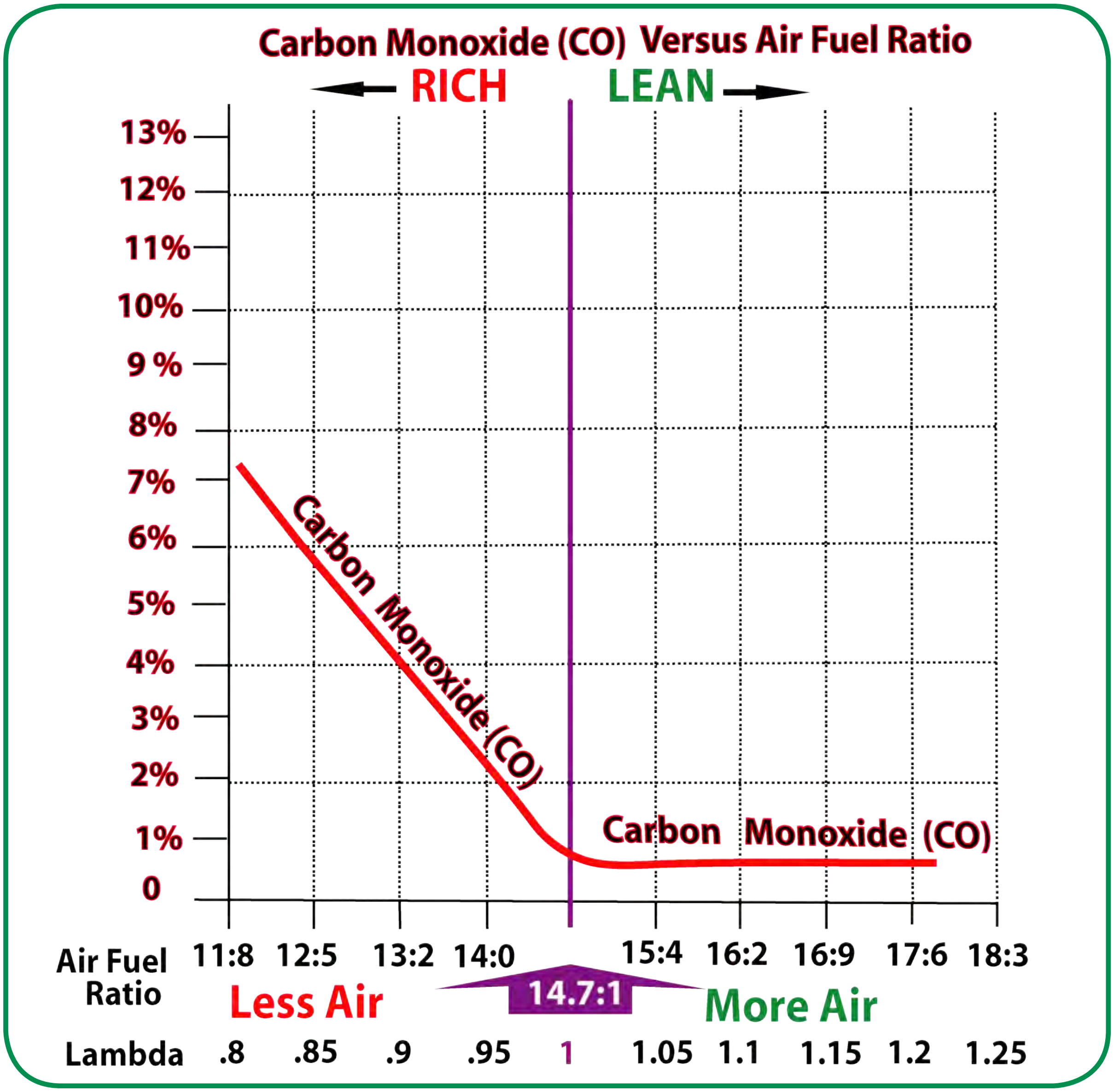


Fig. 13-7. C O emissions versus air/fuel ratio.

Refer to figure 13-8. This is an example of high CO exhaust emissions as you can see, CO is high at both idle and cruise. A dirty air filter will effect CO emissions at idle and cruise, or a weak fuel injector spring will cause the injector to leak.

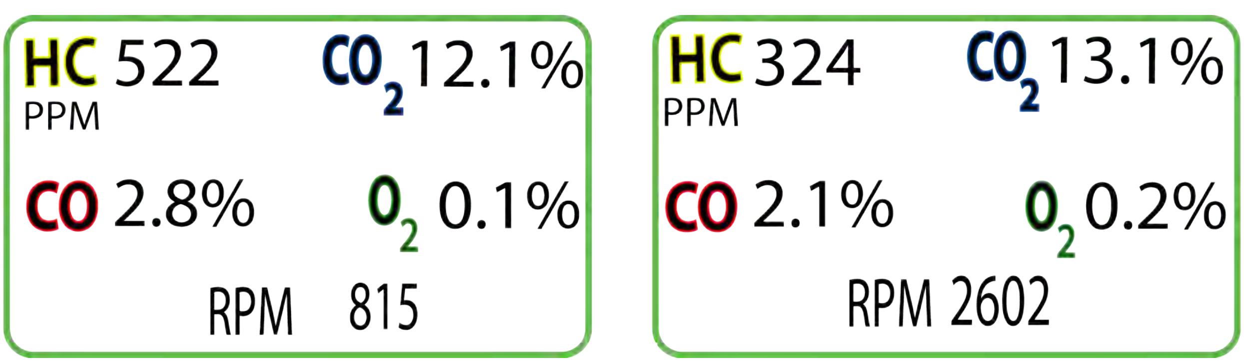


Figure 13-8 is an example of a rich mixture, high C O condition possibly caused by a dirty air cleaner, leaky fuel pressure regulator diaphragm or by a leaky fuel injector. Note the CO is higher at idle. HC is high at idle and cruise because of rich mixture misfires.

NO_x Oxides of Nitrogen

Oxides of nitrogen are gasses that contain a nitrogen atom and a number of oxygen atoms, either one O_1 or two O_2. Because the number varies, X is used to represent the unknown number of oxygen atoms. NO_X is created in the combustion process when oxygen combines with nitrogen. This occurs when combustion temperatures are greater than 2500°F. UV radiation from the sun acts upon a combination of NOx and HC, and the result is photochemical smog. This is the brownish haze that you see in the sky. This smog will cause you respiratory problems and will irritate your eyes. Refer to figure 13-9.

Oxides of nitrogen are:

Lowest when the mixture is a rich <14.7:1 air/fuel ratio.

Moderate at stoichiometric.

Highest at slightly lean mixtures.

Decrease at very lean mixtures.

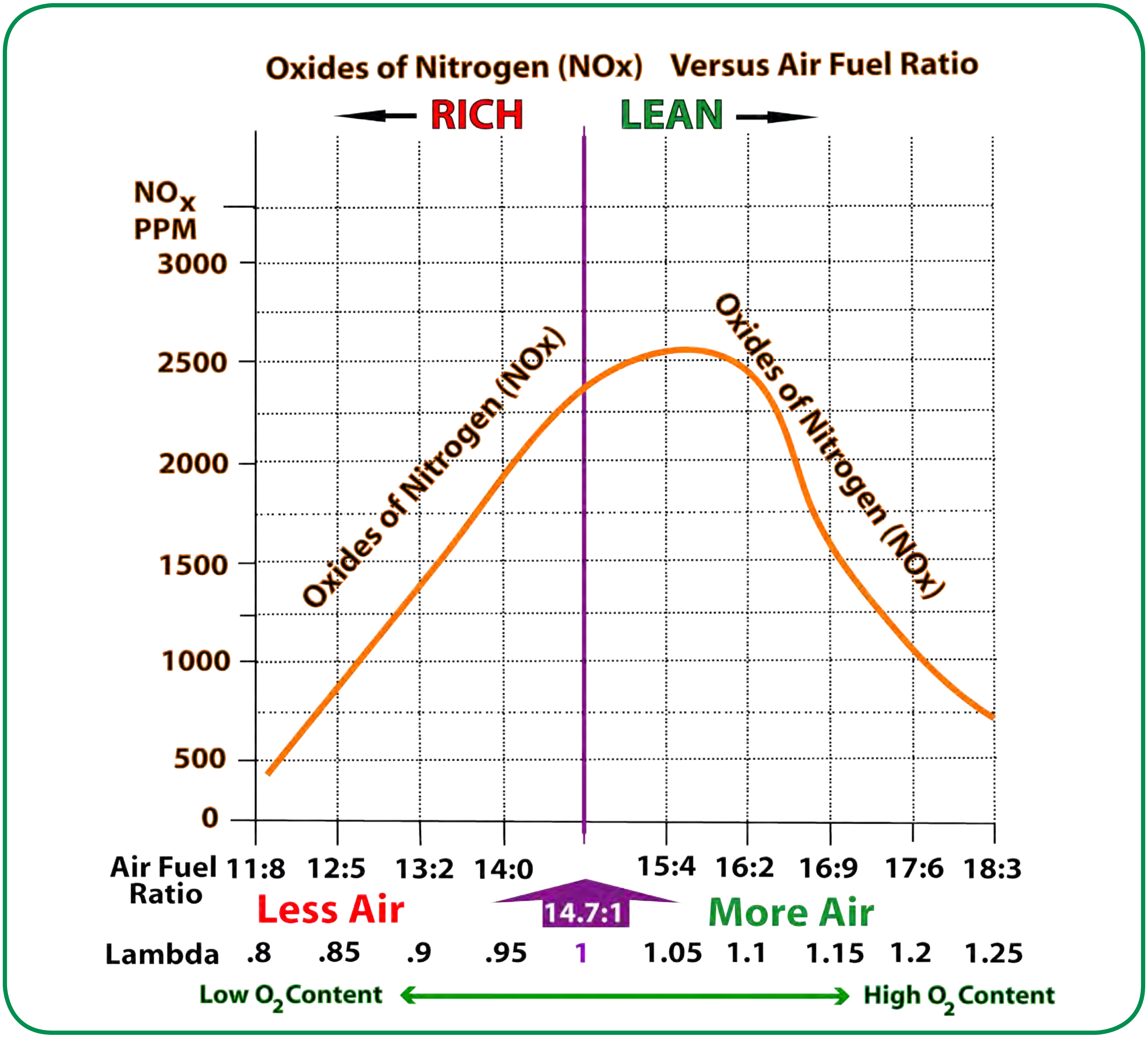


Fig. 13-9 is an example of NO_x emissions versus air/fuel ratio.

NO_x Emissions from gasoline engines are measured under loaded mode conditions. This is because the load on the engine can result in pressures and temperatures conducive to the formation of **NO_x**. Refer to figure 13-10 for an example of normal **NO_x** emissions under loaded mode conditons.

Loaded Mode Emission Test Results

		CO_2 %	O_2 %	HC PPM			CO %			NO_x PPM			
Test	RPM	Meas	Meas	MAX	Ave	Meas	MAX	Ave	Meas	MAX	Ave	Meas	Results
15mph	1970	14.9	0.0	116	12	9	0.47	0.05	0.35	976	74	0	PASS
25mph	1945	15.2	0.0	66	5	7	0.44	0.02	0.02	826	78	2	PASS

Max=Maximun Allowable Emissions
Meas=Amount Measured
Ave=Average Emissions for Passing Vehicles

Fig. 13-10. Normal loaded mode **NO_x** emissions readings

Causes of High NO_x.

The cause of high NO_x emission is excessive combustion temperatures, which may be the result of one or more of the following:

1) Clogged or dirty fuel injectors resulting in a excessively lean air/fuel ratios, which burn and hotter.

2) Ignition timing too far advanced will result in the fuel charge burning hot enough to create NO_x.

3) An EGR malfunction or blocked EGR passages. EGR exhaust gasses are used to lower combustion temperatures and will not be added to the air/fuel charge. Thus allowing temperatures to rise above 2500^{0}F (1371^{0}C), the temperature at which NO_x is formed.

4) Knock sensor malfunction. If the knock sensor malfunctions, the PCM will not receive a signal to retard ignition timing.

5) Low octane fuel. Low octane fuel burns faster, which increases cylinder pressures. Thus increasing combustion chamber temperatures, which will result in an increase in NO_x.

6) Low coolant, a radiator fan not operating, or the thermostat stuck closed will all result in the coolant temperatures increasing to the point where it will not be cool enough to keep the engine at normal operation temperature. The result will be overheating, high combustion temperatures and NO_x formation.

7) Carbon build up in the combustion chamber will increase combustion pressure and temperature.

8) Fuel pressure too low. As the A/F ratio becomes leaner because of the lack of fuel, combustion temperatures increase and NO_x increases up to the point where lean misfires occur. Then NO_x starts to decrease.

9) A TAC stuck in the hot position. The hot air entering the engine combustion chamber once the engine has warmed up, will raise combustion temperatures and hence NO_x emissions.

10) An intake manifold vacuum leak causing a lean mixture and an increase in combustion temperatures will increase NO_x emissions.

11) Incorrect MAP or other input signals to the PCM that result in excessively lean air/fuel ratios,which burn slower and hotter.

12) High compression ratios.

13) TWC contaminated.

CO_2 Carbon dioxide

CO_2 and O_2 are exhaust gasses that are used to diagnose combustion efficiency.
Refer to figure 13-11. Carbon dioxide is a by-product of combustion. Carbon dioxide forms when one atom of carbon from the HC combines with two atoms of oxygen and forms CO_2 in the combustion process. An engine that is running correctly should have a 14% to 16% CO_2exhaust gas reading. CO_2 is also produced when CO is oxidized in an ORC or TWC. CO_2 is not considered a pollutant gas. However, it is believed responsible for the so-called “greenhouse effect” and global warming.

CO_2 level is directly related to the air/fuel ratio.
As the fuel mixture approaches stoichiometric (14.7:1), CO_2 is at it’s highest. It decreases as the mixture becomes richer or leaner. This fact makes CO_2 a good indicator of combustion efficiency. The higher the CO_2, the higher combustion efficiency.

CO_2 is an excellent gas for determining combustion efficiency.
1) CO_2 is low when the mixture is rich (<14.7:1).
2) CO_2 is highest at stoichiometric (14.7:1).
3) CO_2 is low when the mixture is lean (>14.7:1).

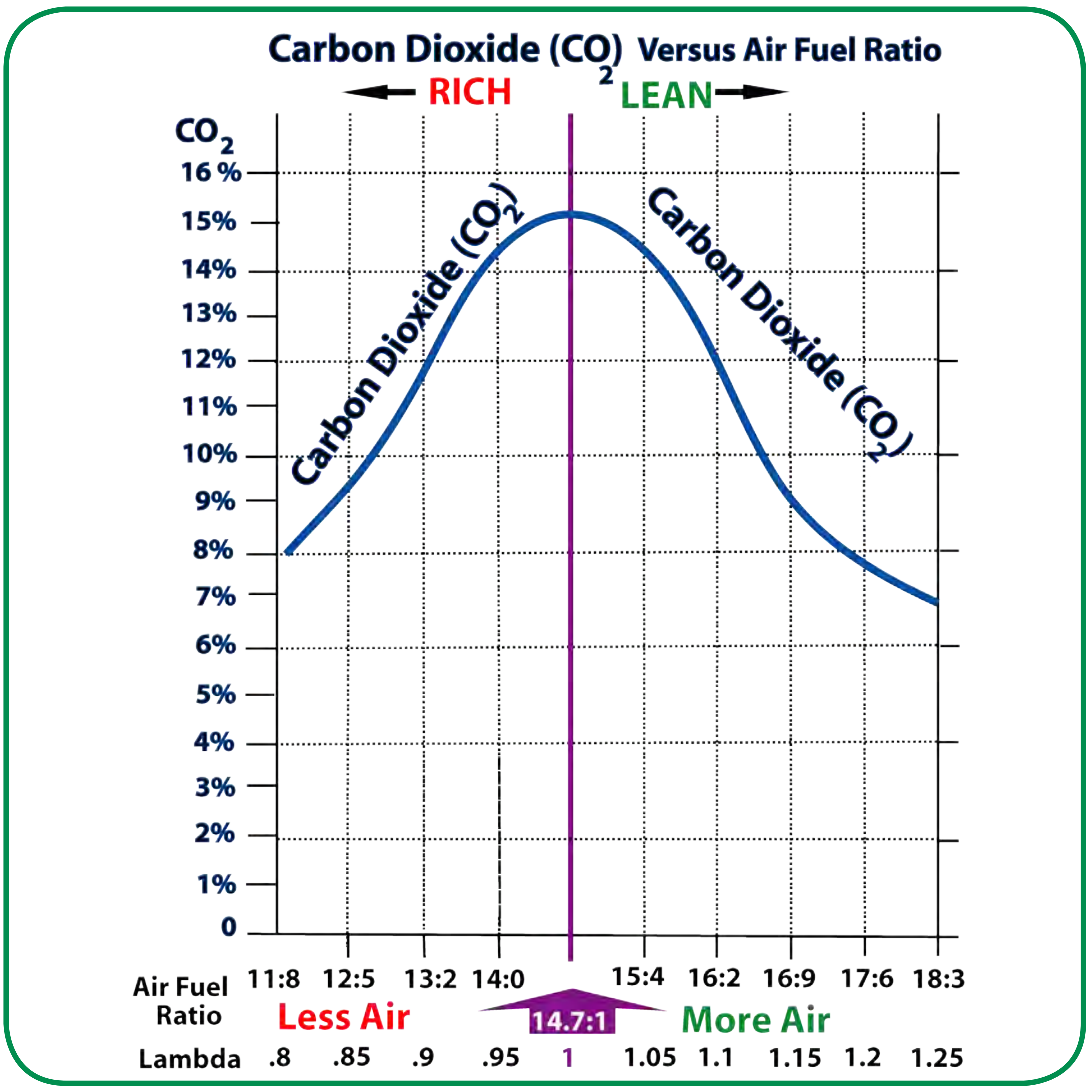


Fig. 13-11. An example of CO_2 emission versus air fuel ratio.

Oxygen O_2

Oxygen makes up about 21% of the earth's atmosphere. Oxygen is mixed with gasoline (HC) in the intake manifold and then enters the cylinders where it is ignited by a spark plug. Oxygen is consumed in the combustion process. When the mixture is rich, almost all the available oxygen gets used up in the combustion process resulting in a low O_2 exhaust content. When there are high levels of O_2 in the exhaust gas, this means that the O_2 did not get consumed in the combustion process, and is an indication of a lean mixture.
Refer to figure 13-12.
Oxygen is:
1) Lowest when the mixture is rich.
2) Slightly high at stoichiometric (about1% to 2%).
3) Highest at lean mixtures.

When the/air fuel ratio is either rich or lean, the levels of carbon monoxide (CO) and oxygen (O_2) will be opposite to each other. When O_2 is high, CO is low, and when CO is low, O_2 will be high.
At the stoichiometric air/fuel ratio, CO and O_2 are approximately equal near zero.

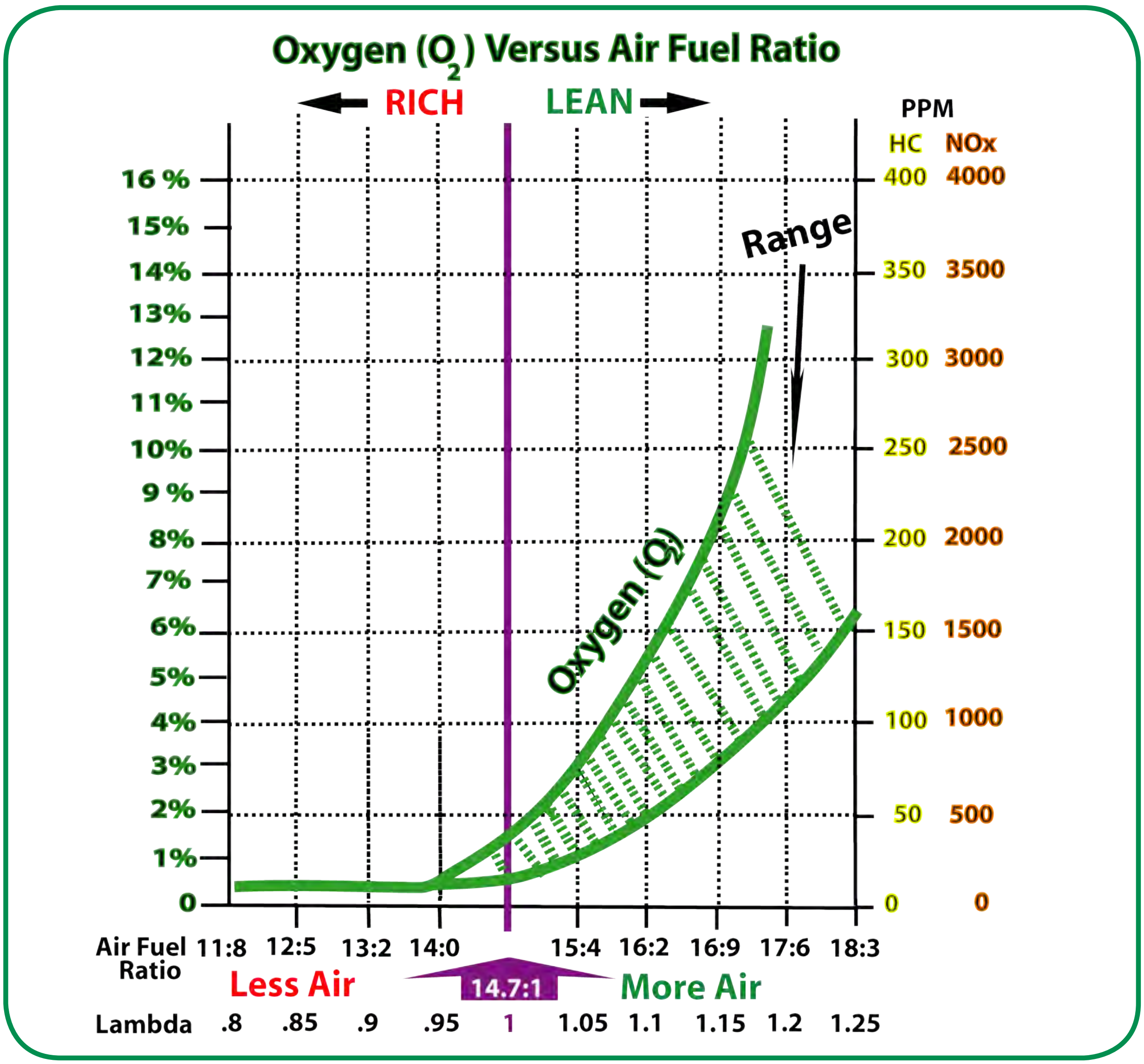


Fig.13-12. This is an example of O_2 emissions versus air/fuel ratio.

Refer to figure 13-13. Study this diagram to better understand four-gas.

Four Gas Analysis

CO	CO_2	HC	O_2	Typical Causes
High	Low	High	High	Rich mixture misfires
High	Low	High	Low	Faulty ECT/IAT
Low	Low	Low	High	Exhaust leak after the CAT
Low	High	Low	High	Injector misfire
High	Low	High/Low	Low	Rich mixture
High	High	High	High	Ignition misfire CAT not working Rich mixture vacuum leak
Low	Low	High	High	Ignition misfires, lean mixture, vacuum or air leak between MAF & throttle body
Low	High	Low	Low	Good Combustion
Low	Low	Low	High/Low	Normal readings

Note: Air injection systems cause the exhaust to have a high level or oxygen because of the additional air being pumped into the exhaust system. When gas analysis is being used for diagnosis, the air injection system must be disconnected. However, when exhaust readings are being taken for emissions testing, all emission system components , including the air injection system must be connected and operational.

Fig. 13-13 is an example of four gas analysis.

Refer to figure 13-14. This is a graph of exhaust gasses versus air/fuel ratio.

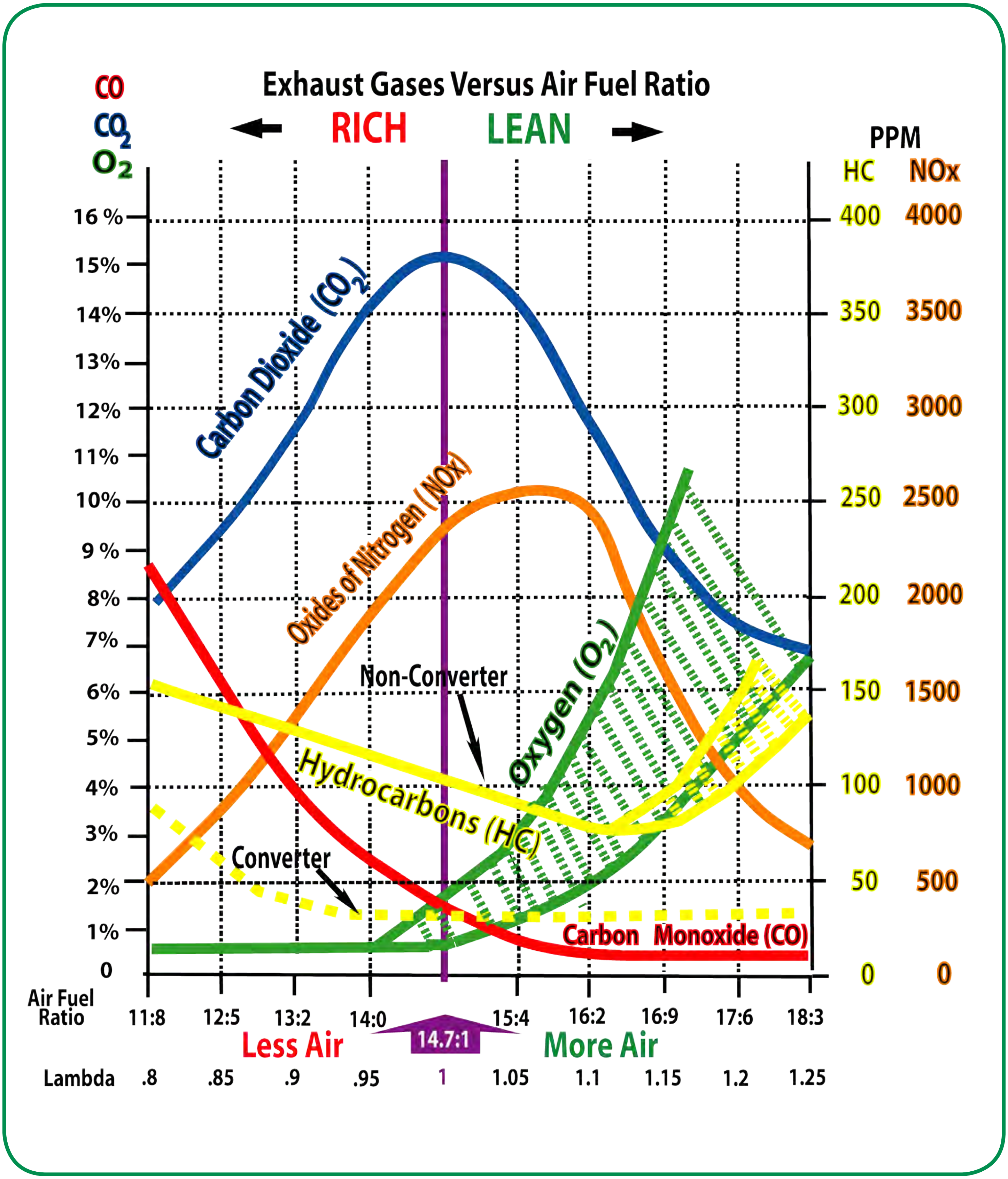


Fig. 13-14. Exhaust gas levels versus air/fuel ratio.

1. What is the function of a regulator on a fuel injection system?
   - a. Accumulates fuel for cold engine start.
   - b. Maintains a constant pressure in the system and returns fuel to the fuel tank.
   - c. Regulates fuel for start up.
   - d. Maintains varying pressure in the fuel rail.

2. Which of the following is correct with respect to the Thermostatic Air Cleaners (TAC)?
   - a. Ensures the engine reaches operating temperature quickly.
   - b. Ensures the engine reaches operating temperature quickly.
   - c. Helps lower HC and CO during engine warm up.
   - d. All of the above.

3. What is the purpose of the fuel bowl vent valve on a carburetor?
   - a. Allows for computer controlled purging.
   - b. Allows fuel ventilation during engine operation.
   - c. Keeps the fuel vapors in the carbon canister under positive pressure.
   - d. Prevents HC ventilation to the canister.

4. The air injection manifold is missing, and there are bolts replacing it. What exhaust gas emission would you expect to be high?
   - a. The O_2 and CO emissions.
   - b. CO_2 and HC emissions.
   - c. HC and CO emissions.
   - d. NO_X and HC emissions.

5. An engine cooling fan has a short and remains constantly on. What effect will this have on emissions?
   - a. There will be no adverse effect on exhaust emissions.
   - b. This will cause inadequate and delayed warm up of the engine.
   - c. The PCM will richen the mixture to compensate for this condition.
   - d. The PCM will lean the mixture to compensate for the short.

6. A knock sensor performs which of the following functions?
   - a. Advances timing at idle, when the engine is hot.
   - b. Increases spark voltage for a cleaner burn.
   - c. Leans the mixture out during hard acceleration.
   - d. Retards timing when it senses detonation.

7. Which of the following is correct with respect to Early Fuel evaporation (EFE) systems.
   - a. EFE system are operated by vacuum or temperature sensitive springs.
   - b. EFE are not actually emission components.
   - c. An EFE helps fuel vaporization for quick engine warm up.
   - d. The EFE stops fuel vapors (HC) from reaching the atmosphere during engine warm up.

8. Most components of an engine controlled by a Power Control Module (PCM) are operated by which of the following?
   a. By being grounded.
   b. By having voltage applied to them.
   c. By high resistance.
   d. Drawing a small current flow from the PCM.

9. What is delivered to the ignition coils of a Direct Ignition System (DIS)?
   a. High amps.
   b. Low voltage and current.

   d. High resistance.

10. What is the main difference between direct and indirect injection systems on a diesel engine?
    a. The direct injection system uses mechanical injectors.
    b. Indirect injectors use Piezo crystals.
    c. The indirect injection system uses short duration, high-pressure injections.
    d. The indirect injection system has a small swirl chamber above each cylinder, where the fuel is injected.

11. The Air Injection (AIR) manifold is missing, and there are bolts replacing it. What exhaust gas emissions would you expect to be high?
    a. The O_2 and CO emissions.
    b. CO_2 and HC emissions.
    c. HC and CO emissions.
    d. NO_X and HC emissions.

12. Which of the following is correct?
    a. Diesel ignition is accomplished by fuel being injected into hot compressed air.
    b. The ignition timing of a diesel engine is controlled by injecting fuel into the combustion chambers.
    c. Each piston stroke rotates the crankshaft 180^0. Therefore, there are 720^0 in a 4-stroke cycle.
    d. All of the above.

13. Why are both diesel and gasoline internal combustion engines cooling systems pressurized?
    a. Raise the coolant boiling temperature.
    b. Help coolant circulation.
    c. Reduce the amount of coolant needed to cool the engine efficiently.
    d. Make sure that hot coolant reaches the heater core.

14. Which of the following is the purpose of a turbocharger?
    a. Reduce detonation in high compression diesel and gasoline engines.
    b. Increase the intake manifold pressure and density.
    c. Increase manifold vacuum.
    d. Reduce acceleration lag.

15. Which of the following is the function of an intercooler on a turbo charged engine?
    a. Intercoolers keep wastegate exhaust gasses cool.
    b. Intercoolers cool intake air to decrease its density, after it has been compressed.
    c. Intercoolers keep turbocharger oil cool.
    d. Intercoolers cool intake air to increase its density, after it has been compressed.

16. Which of the following is correct with respect to diesel engines?
    a. Most turbochargers have a waste gate to limit turbo pressure.
    b. Turbochargers use exhaust gasses to turn the compressor.
    c. The wastegate on PCM controlled engines has a pressure sensor in the intake manifold.
    d. All of the above.

17. Electronic port fuel injectors are usually energized?
    a. All together.
    b. At a fixed pulse width.
    c. Individually in firing order sequence.
    d. Continually.

18. The turbine of a turbocharger is driven by which of the following?
    a. Exhaust gasses.
    b. Electrical motor.
    c. Ram air.
    d. Intake manifold pressure.

19. What is the function of the wastegate on a supercharger?
    a. Increase exhaust back pressure.
    b. Prevent overboost.
    c. Decrease exhaust flow.
    d. Increase exhaust flow.

20. If the O_2 sensor voltage is low and fixed, what mixture solenoid dwell would you expect?
    a. 6-15 degrees.
    b. 22-35 degrees
    c. 45-55 degrees.
    d. Fixed at 30 degrees.

21. Which of the following is correct with respect to a Three-Way Catalyst (TWC)?
    a. NO_X emissions are lowered by a TWC.
    b. A TWC has a heat shield similar to an oxidation reduction catalyst (ORC).
    c. A TWC can overheat and be damaged by misfires.
    d. All of the above.

22. An Oxidation Catalyst (OC) on a diesel engine performs which of the following functions?
    a. Reduces visible particulates.
    b. Uses O_2 in the exhaust stream to convert carbon monoxide (CO) and hydrocarbons (HC) into H_2O and CO_2.
    c. An OC working with a diesel particulate filter (DPF) and an EGR valve can remove most of the unburned HC, soot, and NO_X from the exhaust emissions.
    d. All of the above.

23. Which of the following is correct with respect to a Selective Catalytic Reduction (SCR)?
    a. A SCR helps reduce HC and CO emissions of diesel engines.
    b. Selective Catalytic Reduction (SCR) is a method of converting harmful diesel oxides of nitrogen (NOx) emissions by catalytic reaction into benign nitrogen gas and water.
    c. A SCR is an OBD controlled systems, which reduces HC, CO and NOx exhaust emissions from diesel engines selectively.
    d. SCRs are only found on gasoline engines.

24. Where are NO_X absorbers/traps located in the exhaust system?
    a. Before the turbocharger.
    b. After the Diesel Particulate Filter (DPF).
    c. Before the oxidation catalyst.
    d. Before the oxidation catalyst.

25. The O_2 sensor on PCM controlled vehicles does which of the following?
    a. Generates a voltage between 0.1 and .9 volts.
    b. Monitors the O_2 content of the exhaust gas.
    c. Sends a voltage signal to the PCM.
    d. All of the above.

26. The Electronic Common Rail Direct Injection (CDR) systems used on diesel engines do which of the following?
    a. Allow for low fuel rail pressures.
    b. Allow the use of special injectors with large orifices.
    c. Allow injectors be actuated several times during an injection cycle.
    d. None of the above.

27. Where would you expect to find a Karman Vortex generator on a gasoline powered engine?
    a. On the exhaust manifold.
    b. In front of the throttle valve.
    c. Behind the throttle valve.
    d. None of the above.

28. When and where is ported vacuum available?
    a. Below the throttle valve at cruise.
    b. From the venturi off idle.
    c. Below the throttle valve at idle.
    d. Above the throttle valve off idle.

29. A DTC was set. The fault is corrected. However, the DTC was not cleared from memory by the technician. How long will the DTC remain in memory?
    a. 40 warm-up cycles
    b. Two consecutive trips.
    c. One Drive Cycle.
    d. Three Drive Cycles.

30. When the technician connects a scan tool to the PCM of a vehicle, the readiness status for the EGR system indicates a YES. Which of the following is correct?
    a. The OBD II EGR monitor has diagnosed faults since the last warm-up cycle.
    b. The EGR trip enabling criteria or an OBD II drive cycle has been completed, and the vehicle is ready for an I/M test.
    c. Faults have been found by the EGR system monitor, since the last complete trip.
    d. None of the above.

31. A vehicle comes into your shop for an I/M (Inspection /Maintenance) test. The monitor readiness status indicates that the EVAP monitor has not run. Which of the following is correct?
    a. The engine must be started at a temperature below 86^0F.
    b. The fuel tank must be full.
    c. Maintain 20 MPH for 2 minutes.
    d. An OBD II Drive Cycle will satisfy all the trip criteria.

32. When the technician connects a scan tool to the PCM of the Composite Vehicle, the monitor readiness status for the EGR system indicates NO. Which of the following is correct?
    a. This means that there have been NO faults found by the EGR system monitor, since the last complete trip.
    b. The EGR monitor is not ready to run.
    c. Do not do an I/M test until the EGR monitor trip criteria has been met.
    d. All of the above.

33. The MAP sensor vacuum line is disconnected. Which of the following is your diagnosis?
    a. The PCM will receive voltage from the MAP sensor indicating idle condition high load.
    b. The PCM will receive voltage from the MAP sensor indicating high load.
    c. Replace the MAP sensor and the vacuum hose.
    d. The MAP sensor voltage will indicate absolute pressure by its low voltage signal to the PCM.

34. Closed loop is confirmed by which of the following?
    a. O_2 sensor voltage fixed between 0.2 mvs and 0.8 mvs.
    b. A fixed 0.45 volts (450 mvs) signal.
    c. O_2 sensor voltage varying between .02 volts and .08 volts.
    d. An O_2 sensor voltage signal that is varying rapidly between 0.2 volts](200mvs) and 0.8 volts (800 mvs), when the engine is running at approximately 2500RPM.

35. The EGR system monitor fails. The MIL is illuminated after how many trips?
    a. The first trip of a Drive Cycle is completed.
    b. The second consecutive trip.
    c. Three consecutive trips and 40 warm up cycles.
    d. One Drive Cycle.

36. Refer to exhibit #1. What is the firing order and direction of rotation of the 1987 Toyota 3RC engine?
    a. 1 3 4 2 Clockwise.
    b. 1 4 2 3 No direction.
    c. 1 2 4 3 Clockwise.
    d. 1 5 3 6 2 4 Counter clockwise.

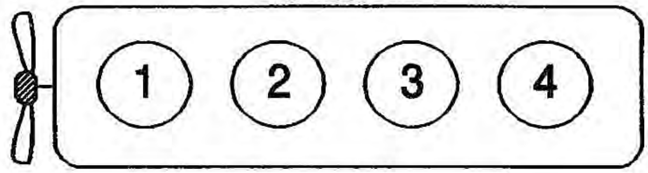
37. During a functional check of the EGR valve, you find that when you disconnect it at idle the engine runs smoothly.
    Which of the following is correct?
    a. A vacuum switch is broken.
    b. The EGR diaphragm is punctured.
    c. The EGR valve is stuck closed.
    d. The EGR passageways are clogged.

38. During you visual inspection you find an evaporative system (EVAP) hose disconnected.
    Which gas would you expect to be escaping into the atmosphere?
    a. Carbon Monoxide (CO).
    b. Carbon Monoxide (CO) and Hydrocarbons (HC).
    c. Oxides of Nitrogen (NO_X) and Hydrocarbons (HC).
    d. Hydrocarbons (HC).

Cylinder Arrangement & Firing Order

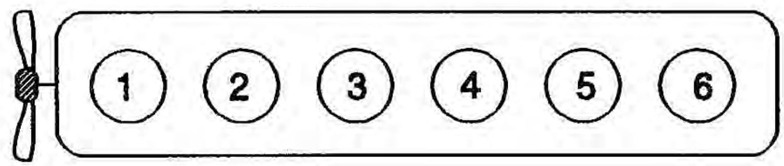
For 1987 and Newer Models

4 Cylinder



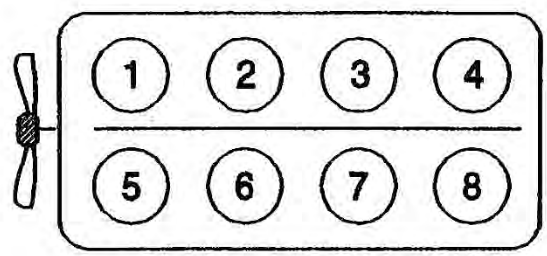
Firing Order	Model	Firing Order
Ford	1600 CC[1]	1 4 3 2
Toyota	3RB, 3RC[2]	1 2 4 3

6 Cylinder



Firing Order	
Chrysler, Ford	1 5 3 6 2 4
Toyota	1 3 5 6 4 2

V-8 Engines



Firing Order	Model	Firing Order
Ford	351, 400[2]	1 3 7 2 6 5 4 8
Ford	272, 292, 368	1 5 4 8 6 3 7 2
Ford	Others	1 5 4 2 6 3 7 8
Mercedes	All	1 5 4 8 6 3 7 2

1 Direction of Rotation Counter Clockwise

2 Direction of Rotation Clockwise

Exhibit #1

39. Refer to exhibit #2. The reference manual instructs you to apply vacuum to line number five (5) while the engine is idling. Which of the following would normally occur?
    a. Nothing.
    b. The timing will be retarded.
    c. RPM will increase.
    d. RPM will decrease.

40. Too high a float bowl level will result in which of the following?
    a. Choke on activating.
    b. A rich mixture.
    c. Misfires.
    d. A lean mixture.

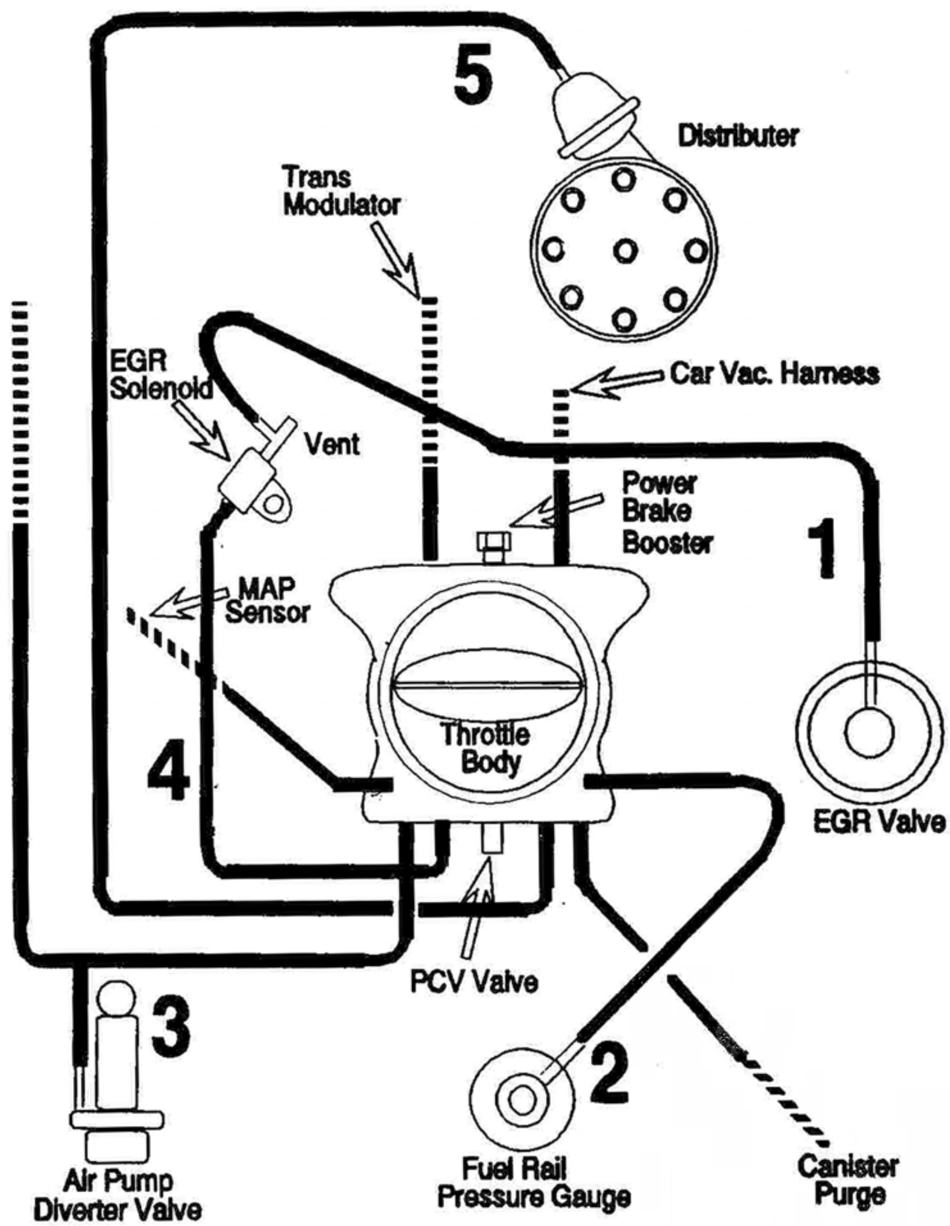


Exhibit #2

41. Which of the following is correct?
    a. Radiator caps have a pressure relief valve and a vacuum relief valve.
    b. When the pressure on water inside a radiator is increased above atmospheric pressure, the boiling point of water is lowered.
    c. A radiator is a heat exchanger with two sets of passages.
    d. All of the above.

42. The desired flow rate of a digital EGR valve is controlled by which of the following?
    a. Positive exhaust back pressure.
    b. Negative exhaust back pressure.
    c. Signal voltage from the potentiometer.
    d. A solenoid energized by the PCM.

43. Which of the following is correct with respect to an electrical circuit?
    a. The sum of the voltage drops in a parallel circuit equals source voltage.
    b. There is more than one path of current to flow in a parallel circuit.
    c. Current is constant in a series circuit.
    d. All of the above.

44. Which of the following is correct with respect to spark advance systems?
    a. Distributorless Ignition Systems (DIS) use crankshaft sensors (CKP) to signal engine RPM and camshaft position sensors (CMP) to control spark advance.
    b. The majority of non-electronic spark advance systems use venturi vacuum.
    c. The trigger wheel of a photoptic distributor controls spark advance.
    d. All of the above.

45. How is blow by controlled on a diesel engine?
    a. Diesel blow by is controlled by the Positive Crankcase Valve (PCV).
    b. The Crankcase Depression Regulator (CDR) controls the blow by of a diesel engine.
    c. The wall flow filter controls blow by on a diesel engine.
    d. A fuel borne catalyst (FBC) controls the blow by of a diesel engine.

46. How many ohms of resistance would be required to produce a pressure of 4 volts, when 2 amps are flowing through the circuit?
    a. 4 ohms.
    b. Half an ohm.
    c. 2 ohms.
    d. 8 ohms

47. In 24 volt circuit, how many amps would flow through a 6 ohm resistor?
    a. 4 amps.
    b. 0.25 amps.
    c. 144 amps.
    d. 8 amps.

48. Exhaust Gas Recirculation (EGR) system is designed to reduce which exhaust emission?
    - a. Carbon Monoxide (CO).
    - b. Oxides of Nitrogen (NO_X).
    - c. Hydrocarbons (HC).
    - d. Carbon Dioxide (CO_2).

49. The most common vacuum used by an Exhaust Gas Recirculation (EGR) valve is which of the following?
    - a. Venturi vacuum.
    - b. Manifold vacuum.
    - c. Amplified vacuum.
    - d. Ported vacuum.

50. The root cause of high Carbon Monoxide (CO) is which of the following?
    - a. Spark plug misfires.
    - b. A rich mixture
    - c. Low fuel pressure.
    - d. High O_2 content in the air fuel mixture.

51. Which of the following is correct with respect to a Karman Vortex generator?
    - a. A Karman Vortex generator is located behind the throttle valve.
    - b. A low frequency signal form the Karman Vortex means high airflow.
    - c. Karman Vortex generators use LEDs.
    - d. The frequency of the signal to the PCM from the Karman Vortex generator is inversely proportional to the airflow.

52. If the A/F ratio were too lean, which of the following would you expect?
    - a. Oil contaminated fuel.
    - b. Maximum engine power.
    - c. High NO_X exhaust emissions.
    - d. Burnt valves.

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ANSWER SHEET

Student Name____
Instructor___________________________ School_________________
Date___________________________ Score_________________

Directions: Darken in the letter of the correct answer. Tear out this page, and give it to your instructor
for credit.

1. A B C D	22. A B C D	43. A B C D	64. A B C D	85. A B C D
2. A B C D	23. A B C D	44. A B C D	65. A B C D	86. A B C D
3. A B C D	24. A B C D	45. A B C D	66. A B C D	87. A B C D
4. A B C D	25. A B C D	46. A B C D	67. A B C D	88. A B C D
5. A B C D	26. A B C D	47. A B C D	68. A B C D	89. A B C D
6. A B C D	27. A B C D	48. A B C D	69. A B C D	90. A B C D
7. A B C D	28. A B C D	49. A B C D	70. A B C D	91. A B C D
8. A B C D	29. A B C D	50. A B C D	71. A B C D	92. A B C D
9. A B C D	30. A B C D	51. A B C D	72. A B C D	93. A B C D
10. A B C D	31. A B C D	52. A B C D	73. A B C D	94. A B C D
11. A B C D	32. A B C D	53. A B C D	74. A B C D	95. A B C D
12. A B C D	33. A B C D	54. A B C D	75. A B C D	96. A B C D
13. A B C D	34. A B C D	55. A B C D	76. A B C D	97. A B C D
14. A B C D	35. A B C D	56. A B C D	77. A B C D	98. A B C D
15. A B C D	36. A B C D	57. A B C D	78. A B C D	99. A B C D
16. A B C D	37. A B C D	58. A B C D	79. A B C D	100. A B C D
17. A B C D	38. A B C D	59. A B C D	80. A B C D	101. A B C D
18. A B C D	39. A B C D	60. A B C D	81. A B C D	102. A B C D
19. A B C D	40. A B C D	61. A B C D	82. A B C D	103. A B C D
20. A B C D	41. A B C D	62. A B C D	83. A B C D	104. A B C D
21. A B C D	42. A B C D	63. A B C D	84. A B C D	105. A B C D

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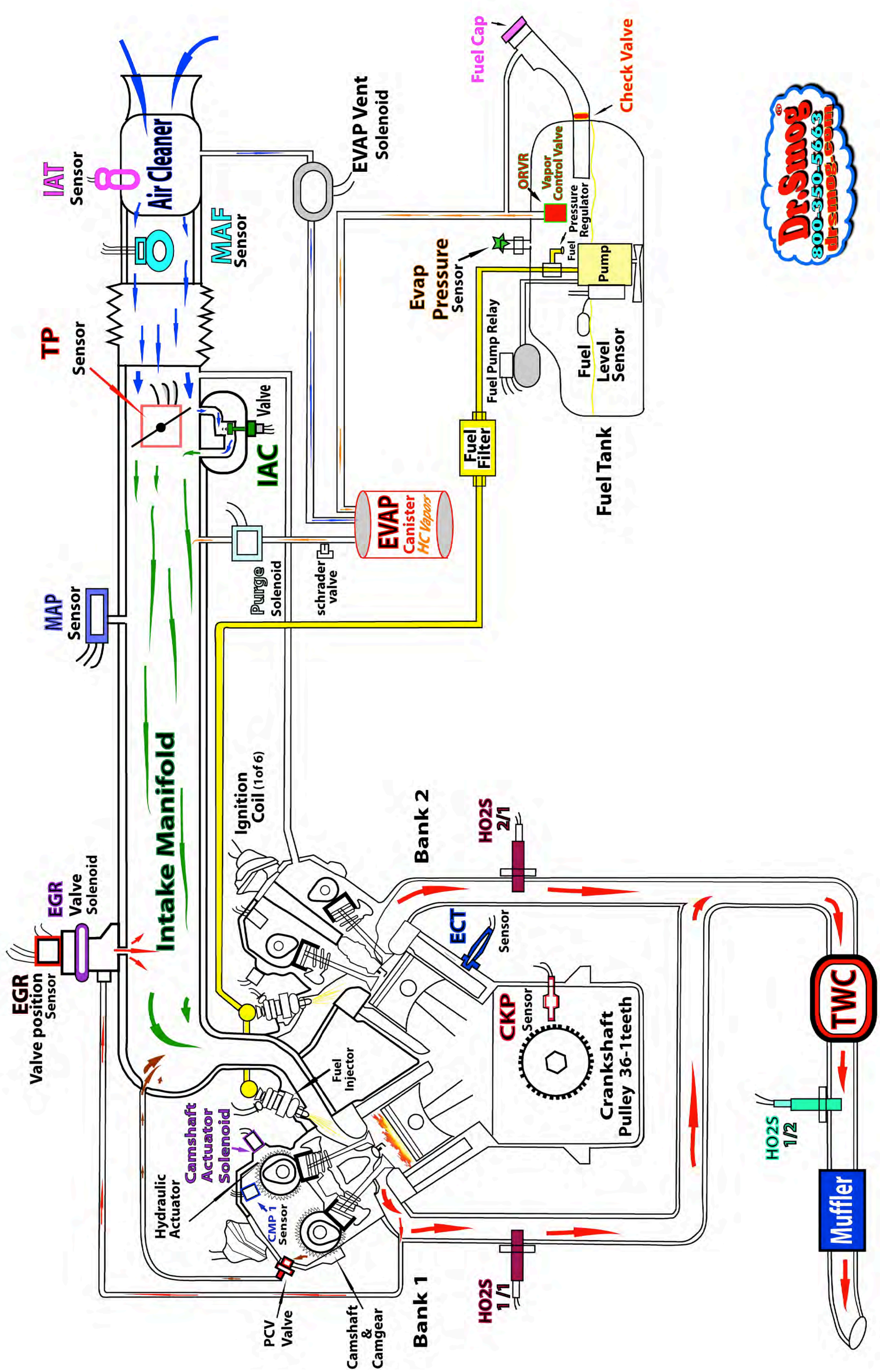
Fuel Cap
Check Valve
EVAP Vent Solenoid
IAT Sensor
Air Cleaner
MAF Sensor
ORVR Vapor Control Valve
Fuel Pressure Regulator
Evap Pressure Sensor
Pump
Fuel Pump Relay
Fuel Level Sensor
Fuel Tank
TP Sensor
IAC Valve
Fuel Filter
EVAP Canister HC Vapors
Purge Solenoid
schrader valve
MAP Sensor
Intake Manifold
Ignition Coil (1of 6)
Bank 2
HO2S 2/1
EGR Valve Solenoid
EGR Valve position Sensor
ECT Sensor
CKP Sensor
Crankshaft Pulley 36-1teeth
TWC
Fuel Injector
Camshaft Actuator Solenoid
Hydraulic Actuator
CMP 1 Sensor
PCV Valve
Camshaft & Camgear
Bank 1
HO2S 1/1
HO2S 1/2
Muffler

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List of Acronym

	Page	Meaning
A/F	81	Air to Fuel ratio
AC	44	Alternating Current
AI	135	Air Injection
ASE	120	Automotive Service Excellence
ATDC	21	After Top Dead Center
B+	94	Battery voltage
BDC	8	Bottom Dead Center
BTDC	21	Before Top Dead Center
BTU	146	British Thermal Unit
CARB	102	California Air Resources Board
Cat	39	Catalytic converter
CDR	146	Crankcase Depression Regulator valve
CIS	81	Continuous Injection System
CKP	61	Crankshaft Position monitor
CMP	61	Camshaft Position monitor
CO	17	Carbon Monoxide
CO2	5	Carbon Dioxide
CRD	144	Electronic Common Rail Direct injection
DC	44	Direct Current
DEF	150	Diesel Exhaust Fluid
DIS	61	Direct Ignition System
DLC	103	Data Link Connector (standardized, keyed 16-pin connector for OBD II scan tool access)
DOC	150	Diesel Oxidation Catalyst
DPF	147	Diesel Particulate Filter
DPFE	110	Delta (or Dual) Pressure Feedback sensor
DSO	95	Digital Storage Oscilloscope
DTC	103	Diagnostic Trouble Code
DVOM	54	Digital Volt Ohm Meter
E	46	Voltage (Volts)
ECT	91	Engine Coolant Temperature sensor (thermistor)
ECU	58	Engine Control Unit
EFE	74	Early Fuel Evaporation
EFI	17	Electronic Fuel Injection
EGR	33	Exhaust Gas Recirculation
EMF	54	Electromotive Force
EPA	60	Environmental Protection Agency (Federal) (also p 102)
EVAP	111	Evaporative Emission Control System
EVR	110	Electronic Vacuum Regulator
FBC	149	Fuel Borne Catalyst
FTP	106	Federal Test Procedure
gm	153	Gram (weight)
HC	15	Hydrocarbons
HO2S1/1	110	Heated Oxygen Sensor (bank#1) 1 upstream
HO2S1/2	110	Heated Oxygen Sensor (bank#1) 1 downstream
HP	23	Horsepower

List of Acronym

	Page	Meaning
I	46	Current (Amps)
I/M	109	Inspection/ Maintenance
IAC	93	Idle Air Control valve
IAT	78	Intake Air Temperature sensor (also p 92)
IC	78	Integrated Circuit
ICM	22	Ignition Control Module
Karman-vortex	94	A Mass Air Flow (MAF) sensor with proportional-frequency output
K-Jetronic	82	Bosch CIS system with airflow sensor plate
Lambda	81	Actual A/F ration / stoichiometric ratio (14 air / 1 fuel) At stoichiometric, Lambda = 1; for leaner, Lambda > 1; for richer, Lambda < 1
LED	58	Light Emitting Diode
LH-Jetronic	87	Bosch MPFI with Mass Air Flow (MAF) sensor
L-Jetronic	87	Bosch MPFI with Vane Air Flow (VAF) sensor
MAF	78	Mass Air Flow sensor (ex.: hot wire)
MAP	78	Manifold Absolute Pressure sensor
MFI	17	Multiport Fuel Injection
MIL	103	Malfunction Indicator Light (on dashboard; labeled "Check Engine")
MPFI	87	Multiport Fuel Injection
ms	90	Millisecond (= 1/1000th of a second)
NOx	19	Nitrogen Oxides
NTC	91	Negative Temperature Coefficient (engine cold > ECT resistance high; hot > low)
O2	19	Oxygen
OBD I	102	On Board Diagnostics (1st version: 19xx - 1996)
OBD II	102	On Board Diagnostics (2nd version: 1996 - current)
OC	124	Oxidation Catalyst
OC	148	Oxygen Catalyst
OHC	10	Overhead Cam
OHV	10	Overhead Valve
ORC	125	Oxygen Reduction Catalyst
OSS	111	Oxygen Sensor System
PCM	17	Power Control Module
PCV	141	Positive Crankcase Ventilation
PM	144	Particulate Matter
PPM	153	Parts per million
psi	89	Pounds per square inch
R	46	Resistance (Ohms)
RPM	21	Revolutions Per Minute
SAE	102	Society of Automotive Engineers (United States, national)
SCR	150	Selective Catalytic Reduction

List of Acronym

	Page	**Meaning**
TAC	39	Thermostatic Air Cleaner
TBI	17	Throttle Body (fuel) Injection
TCC	91	Torque Converter Clutch
TDC	8	Top Dead Center
TPS	78	Throttle Position Sensor
TVS	116	Thermostatic Vacuum Switch
TVV	33	Temperature Vacuum Valve
TWC	39	Three Way Catalyst
ULSD	152	Ultra-Low Sulfur Diesel
VAF	87	Vane Airflow sensor

Notes