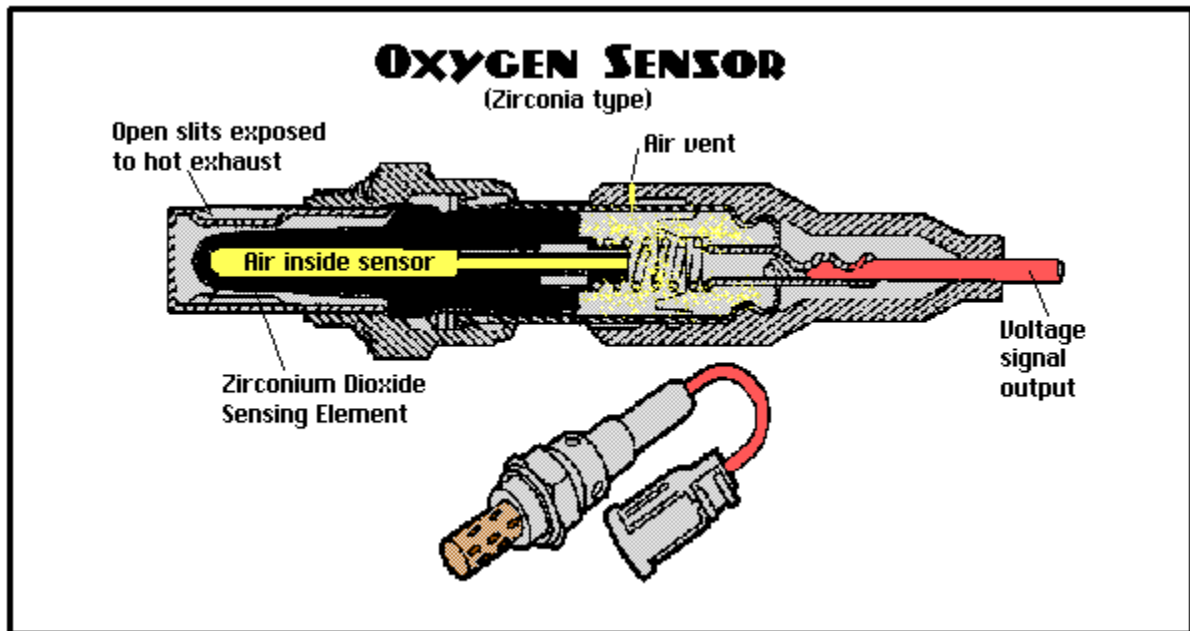


UNDERSTANDING OXYGEN SENSORS



Today's computerized engine control systems rely on inputs from a variety of sensors to regulate engine performance, emissions and other important functions. The sensors must provide accurate information otherwise drivability problems, increased fuel consumption and emission failures can result.

One of the key sensors in this system is the oxygen sensor. It's often referred to as the "O₂" sensor because O₂ is the chemical formula for oxygen (oxygen atoms always travel in pairs, never alone).

The first O₂ sensor was introduced in 1976 on a Volvo 240. California vehicles got them next in 1980 when California's emission rules required lower emissions. Federal emission laws made O₂ sensors virtually mandatory on all cars and light trucks built since 1981. And now that OBD-II regulations are here (1996 and newer vehicles), many vehicles are now equipped with multiple O₂ sensors, some as many as four!

The O₂ sensor is mounted in the exhaust manifold to monitor how much unburned oxygen is in the exhaust as the exhaust exits the engine. Monitoring oxygen levels in the exhaust is a way of gauging the fuel mixture. It tells the computer if the fuel mixture is burning rich (less oxygen) or lean (more oxygen).

A lot of factors can affect the relative richness or leanness of the fuel mixture, including air temperature, engine coolant temperature, barometric pressure, throttle position, air flow and engine load. There are other sensors to monitor these factors, too, but the O₂ sensor is the master monitor for what's happening with the fuel mixture. Consequently, any problems with the O₂ sensor can throw the whole system out of whack.

LOOPS

The computer uses the oxygen sensor's input to regulate the fuel mixture, which is referred to as the fuel "feedback control loop." The computer takes its cues from the O₂ sensor and responds by changing the fuel mixture. This produces a corresponding change in the O₂ sensor reading. This is referred to as "closed loop" operation because the computer is using the O₂ sensor's input to regulate the fuel mixture. The result is a constant flip-flop back and forth from rich to lean which allows the catalytic converter to operate at peak efficiency while keeping the average overall fuel mixture in proper balance to minimize emissions. It's a complicated setup but it works.

When no signal is received from the O₂ sensor, as is the case when a cold engine is first started (or the O₂ sensor fails), the computer orders a fixed (unchanging) rich fuel mixture. This is

referred to as "open loop" operation because no input is used from the O₂ sensor to regulate the fuel mixture.

If the engine fails to go into closed loop when the O₂ sensor reaches operating temperature, or drops out of closed loop because the O₂ sensor's signal is lost, the engine will run too rich causing an increase in fuel consumption and emissions. A bad coolant sensor can also prevent the system from going into closed loop because the computer also considers engine coolant temperature when deciding whether or not to go into closed loop.

HOW IT WORKS

The O₂ sensor works like a miniature generator and produces its own voltage when it gets hot. Inside the vented cover on the end of the sensor that screws into the exhaust manifold is a zirconium ceramic bulb. The bulb is coated on the outside with a porous layer of platinum. Inside the bulb are two strips of platinum that serve as electrodes or contacts.

The outside of the bulb is exposed to the hot gases in the exhaust while the inside of the bulb is vented internally through the sensor body to the outside atmosphere. Older style oxygen sensors actually have a small hole in the body shell so air can enter the sensor, but newer style O₂ sensors "breathe" through their wire connectors and have no vent hole. It's hard to believe, but the tiny amount of space between the insulation and wire provides enough room for air to seep into the sensor (for this reason, grease should never be used on O₂ sensor connectors because it can block the flow of air). Venting the sensor through the wires rather than with a hole in the body reduces the risk of dirt or water contamination that could foul the sensor from the inside and cause it to fail.

The difference in oxygen levels between the exhaust and outside air within the sensor causes voltage to flow through the ceramic bulb. The greater the difference, the higher the voltage reading.

An oxygen sensor will typically generate up to about 0.9 volts when the fuel mixture is rich and there is little unburned oxygen in the exhaust. When the mixture is lean, the sensor's output voltage will drop down to about 0.1 volts. When the air/fuel mixture is balanced or at the equilibrium point of about 14.7 to 1, the sensor will read around 4.5 volts.

When the computer receives a rich signal (high voltage) from the O₂ sensor, it leans the fuel mixture to reduce the sensor's reading. When the O₂ sensor reading goes lean (low voltage), the computer reverses again making the fuel mixture go rich. This constant flip-flopping back and forth of the fuel mixture occurs with different speeds depending on the fuel system. The transition rate is slowest on engines with feedback carburetors, typically once per second at 2500 rpm. Engines with throttle body injection are somewhat faster (2 to 3 times per second at 2500 rpm), while engines with multipoint injection are the fastest (5 to 7 times per second at 2500 rpm).

The oxygen sensor must be hot (about 600 degrees or higher) before it will start to generate a voltage signal, so many oxygen sensors have a small heating element inside to help them reach operating temperature more quickly. The heating element can also prevent the sensor from cooling off too much during prolonged idle, which would cause the system to revert to open loop. Heated O₂ sensors are used mostly in newer vehicles and typically have 3 or 4 wires. Older single wire O₂ sensors do not have heaters. When replacing an O₂ sensor, make sure it is the same type as the original (heated or unheated)

A NEW ROLE FOR O₂ SENSORS WITH OBD II

Starting with a few vehicles in 1994 and 1995, and all 1996 and newer vehicles, the number of oxygen sensors per engine has doubled. A second oxygen sensor is now used downstream of the catalytic converter to monitor the converter's operating efficiency. On V6 or V8 engines with dual exhausts, this means up to four O₂ sensors (one for each cylinder bank and one after each converter) may be used.

The OBD II system is designed to monitor the emissions performance of the engine. This includes keeping an eye on anything that might cause emissions to increase. The OBD II system compares the oxygen level readings of the O₂ sensors before and after the converter to see if the converter is reducing the pollutants in the exhaust. If it sees little or no change in oxygen level readings, it means the converter is not working properly. This will cause the Malfunction Indicator Lamp (MIL) to come on.

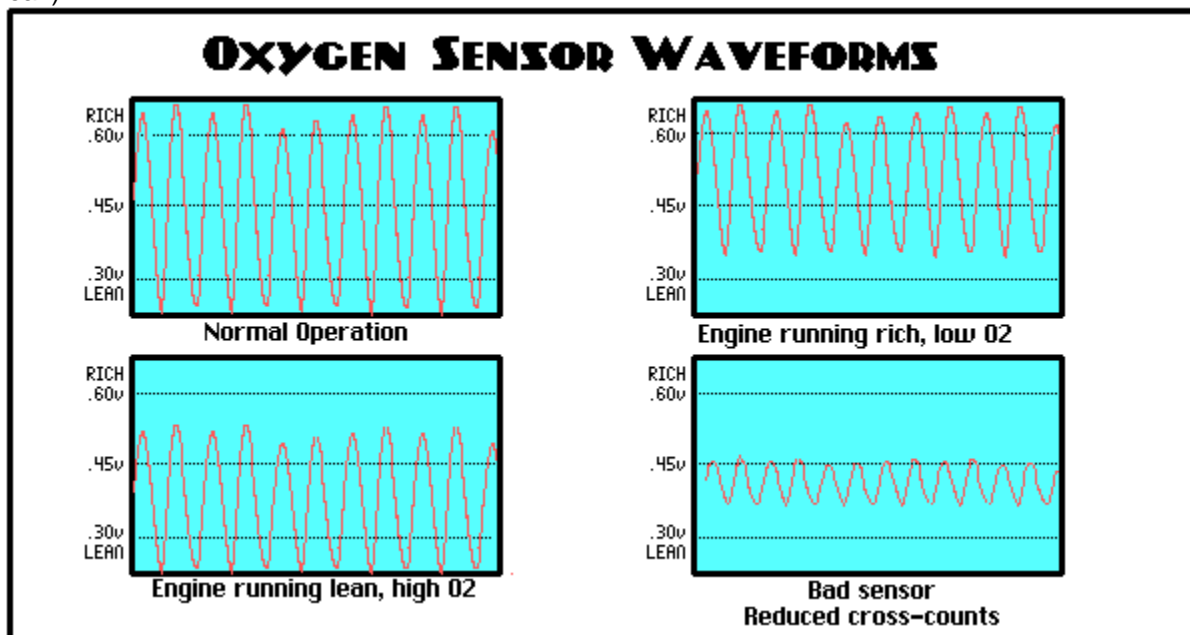
SENSOR DIAGNOSIS

O2 sensors are amazingly rugged considering the operating environment they live in. But O2 sensors do wear out and eventually have to be replaced. The performance of the O2 sensor tends to diminish with age as contaminants accumulate on the sensor tip and gradually reduce its ability to produce voltage. This kind of deterioration can be caused by a variety of substances that find their way into the exhaust such as lead, silicone, sulfur, oil ash and even some fuel additives. The sensor can also be damaged by environmental factors such as water, splash from road salt, oil and dirt. As the sensor ages and becomes sluggish, the time it takes to react to changes in the air/fuel mixture slows down which causes emissions to go up. This happens because the flip-flopping of the fuel mixture is slowed down which reduces converter efficiency. The effect is more noticeable on engines with multiport fuel injection (MFI) than electronic carburetion or throttle body injection because the fuel ratio changes much more rapidly on MFI applications. If the sensor dies altogether, the result can be a fixed, rich fuel mixture. Default on most fuel-injected applications is mid-range after three minutes. This causes a big jump in fuel consumption as well as emissions. And if the converter overheats because of the rich mixture, it may suffer damage.

One EPA study found that 70% of the vehicles that failed an I/M 240 emissions test needed a new O2 sensor.

The only way to know if the O2 sensor is doing its job is to inspect it regularly. That's why some vehicles (mostly imports) have a sensor maintenance reminder light. A good time to check the sensor is when the spark plugs are changed.

You can read the O2 sensor's output with a scan tool or digital voltmeter, but the transitions are hard to see because the numbers jump around so much. An analog voltmeter is better for viewing transitions, but may not respond quickly enough on systems with higher transition rates. So the best instrument for observing the O2 sensor's voltage output is a digital storage oscilloscope (DSO). A scope will display the sensor's voltage output as a wavy line that shows both its amplitude (minimum and maximum voltage) as well as its frequency (transition rate from rich to lean).



A good O2 sensor should produce an oscillating waveform at idle that makes voltage transitions from near minimum (0.1 v) to near maximum (0.9v). Making the fuel mixture artificially rich by feeding propane into the intake manifold should cause the sensor to respond almost immediately (within 100 milliseconds) and go to maximum (0.9v) output. Creating a lean mixture by opening a vacuum line should cause the sensor's output to drop to its minimum (0.1v) value. If the sensor doesn't flip-flop back and forth quickly enough, it may indicate a need for replacement.

If the O2 sensor circuit opens, shorts or goes out of range, it may set a fault code and illuminate the Check Engine or Malfunction Indicator Lamp. If additional diagnosis reveals the sensor is defective, replacement is required. But many O2 sensors that are badly degraded continue to work well enough not to set a fault code—but not well enough to prevent an increase in emissions and fuel consumption. The absence of a fault code or warning lamp, therefore, does not mean the O2 sensor is functioning properly.

SENSOR REPLACEMENT

Any O2 sensor that is defective obviously needs to be replaced. But there may also be benefits to replacing the O2 sensor periodically for preventative maintenance. Replacing an aging O2 sensor that has become sluggish can restore peak fuel efficiency, minimize exhaust emissions and prolong the life of the converter.

Unheated 1 or 2 wire wire O2 sensors on 1976 through early 1990s vehicles can be replaced every 30,000 to 50,000 miles. Heated 3 and 4-wire O2 sensors on mid-1980s through mid-1990s applications can be changed every 60,000 miles. On OBD II equipped vehicles (1996 & up), a replacement interval of 100,000 miles can be recommended.