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Introduction

This program is a detailed description on the testing and equipment Dr. Norman Nall and Bill Peek use to quickly diagnose the technologies used on new vehicles. Some of new things are refinements of existing technologies and they have refined their techniques but getting more data from Scan Tools to increase the speed and accuracy of repairs. Their approach is to gather and study data before jumping to a conclusion. The approach comes from their experience where they have assisted technicians that are having difficulty correcting a problem. When Doc and Bill start their diagnosis, all the usual quick fixes have been tried without success. These are the diagnostic approaches to use when you need to identify problems that may be missed with other approaches and not loose time trying time consuming tests because you don't know another way to identify the problem.

Doc and Bill work on problem vehicles

Yes we work on vehicle. Certainly not as much as you do, but more than most technicians think two old guys would. We verify the manufacture's information on real world vehicles. We been "driven into a ditch" trying to use overly complex diagrams that are spread over 5 or 6 pages. That is the reason we create our own information and specifications. The Smart Spec product has never really disappeared; we have always used it and updated it as we needed it. We use our own specs and electrical diagrams. It just wasn't being sold. Because technicians have been asking for updates, it is being revived. Not like before though. It is created on certain vehicles only.

Much of the research we do is on vehicles that technicians call us to help with. They come to the limits of their skill, equipment, or information and call us in for help. Any information, diagram, or diagnostic procedure we have created can be used on these real world broken vehicles before we offer the information in a class, training video, or Smart Spec product.

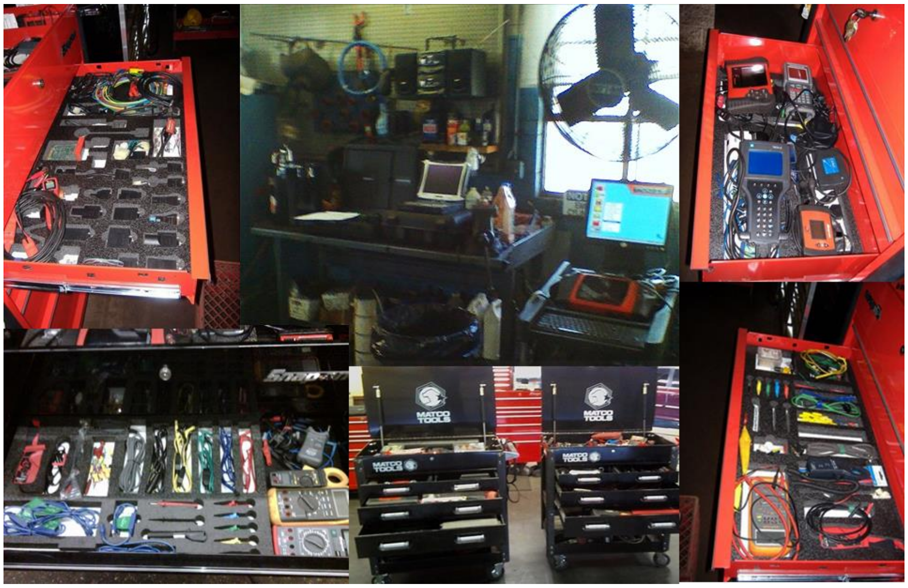
We develop our understanding of new technology by getting the experience of working with it where we can spend hours analyzing the data. Working technicians that have to finish quickly don't have the time we spend looking for the diagnostic data that points to the root cause of the problem. You are getting the advantage of Doc and Bill's "tinkering" with the problem until they see how quickly diagnose the problem.

What are you using?

We are Scan Tool guys. 99% of the time we connect a Scan Tool first in order to get a diagnostic path. This is the modern way to work faster and more accurately, if you take the time to study and analyze the data.

What is a diagnostic path? It is like any path. It leads you to where you need to go. And if you take the wrong path you get lost. You replace components that didn't need replacing. You waste time and effort testing things that don't require

testing. To make matters worse, they keep shoving new technology at us.
This training course is about all that and more.
1. New technology function and operation:



2. Diagnosing new technology:
3. Making sure the technician understands and can use the information:
The class is designed to make the new stuff easy to understand and learn. As well as improving your diagnostics skill.
What's in your Red Cap Box?
We use the tools you use; we try to study them to get the maximum value form the data they provide. The biggest finding is we "see" things in scan data that other technicians miss.

What are we going to do?

This course is packed full of specific details for diagnosing quickly and accurately the first time. It is designed to help you avoid come-backs and losing money on jobs. This information is the missing link for advanced diagnostics. We show you how to be efficient with your digital diagnostic procedures no matter what vehicle is in your service bay. This class doesn't cover how to fix a certain vehicle, it shows you how to diagnose all vehicles. It is a diagnostic class to improve your diagnostic skills. It shows you how to take advantage of the equipment in your shop, not run out and buy new equipment. You probably have the equipment you need. And if you are looking to upgrade come and discover what equipment will fit best in your shop.
What's in the class?
Direct fuel injection operation and diagnostics: Its new, it is here, learn it now! Direct injection isn't diagnosed like the solenoid type injectors. Direct injection requires a different approach and different procedures.
Universal Oxygen Sensors: (Wide bands, Air Fuel Ratio sensors) they made a technician's life easier learn how. Why have the manufactures switched to this sensor, because they offer greater fuel control. The normal oxygen sensor performance test drive that gives a total picture of fuel problems hasn't gone away, it is just different. Come and see the differences.
Coil on Plug Units: There are 2, 3, and 4 wire units. There are engines with multiple ignition modules (up to 8), come and get the latest information about diagnosing them. COP units have been around a long time, now the manufactures have added multiple ignition modules to go along with them. Once a technician knows they're there and how to diagnose them, they become a source of income not a problem he must contend with.
Hydraulic actuated Valve lift: Variable Valve (cam) timing:
This system allows the manufacture to get more power out of a smaller engine. GM has a 260 HP 4 cylinder engine. Ford says this new technology will be showing up on most of their engines and already has several versions on the street. This isn't your Father's VVT. This is new using cam phasing and variable valve lift on intake cams, Exhaust cams, and even all four cams. This technology has already proven itself on the street in the F-150, which has a V-6 giving greater towing capacity then the old V-8.
Functional use of Mode-6: Learn to use Mode-6 information not just learn the theory of it. These test results offer a technician answers to test that he cannot perform himself. There have been many classes about Mode-6.

This isn't a Mode-6 class, it's a simple method on how to take advantage of the information found inside Mode-6. Why aren't you using it?
Air Trim and Fuel Trim: Everyone knows something about Fuel Trim, take time to learn about rear and total fuel trims. There are many fuel trim PIDS, ensure that you know how to evaluate them all. This class discusses Air Trim so that you can have a more complete picture of a problem.

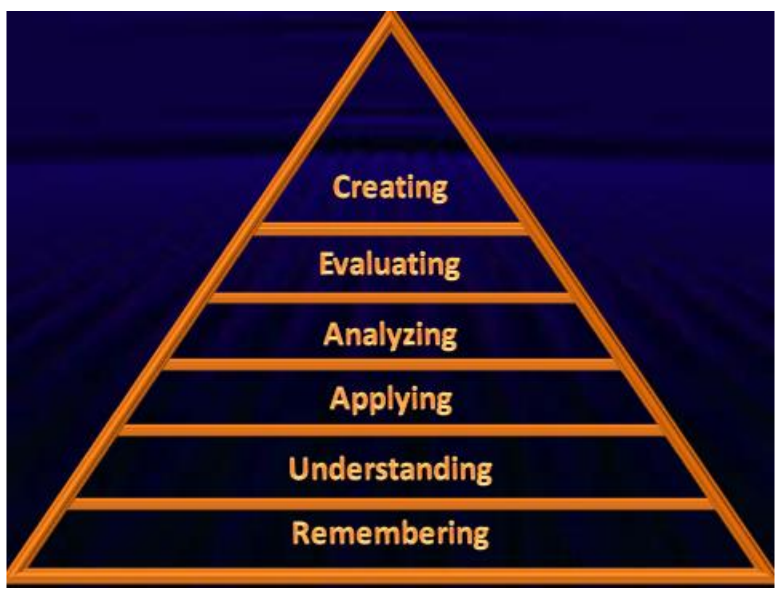
The Truth!

Do enough test and you can figure out anything!
Replace enough parts and you can fix anything!
If you don't run out of time and money, first!
With the right information you will be more productive!
With the right training you can be more efficient and accurate with the diagnostic!
Become Pro-Active to identify potential problems!
Eliminate vehicles going down when they should be in service!

Bloom's Pyramid of Skill:

The pyramid classifies skills from least to most complex.

1. **Remembering**: Remembering lean fuel mixtures can be cause by some sensors and replace a part in hopes of getting it right is not diagnosing. Where do you go when your quick fix does not correct the problem?
2. **Understanding**: You must develop an understanding of how the new complex systems like direct fuel injection work before you can analyze the operation of the system.
3. **Applying**: GDI injectors allow the PCM to command both a stratified and homogeneous air fuel mixture. The benefits are lower emissions, particularly at startup and cold operation. GDI can allow higher compression engines (offers additional horsepower). GDI offers better fuel economy (especially when paired with a turbocharger). These system works together to get more power from a small engine.



4. **Analyzing**: GDI injectors may be diagnosed with Scan Data or a lab scope. Don't just use scan data to look for things that are so far out of range the data can't be valid. Analyze all the data as it relates to other scan data which can give you diagnostic direction to get to the root cause of the problem. Lean fuel mixture is not a diagnostic direction. Lean fuel mixture because of a mass air flow sensor out of calibration is a diagnostic direction. You analyze enough scan data to see the pattern. GDI needs the same type of diagnostics as other fuel injection systems, but now you have additional factors to analyze.
5. **Evaluating**: Scan Data PIDs and Mode 6 information about the injector's performance can be used to evaluate the new GDI injectors. But remember, the new technology is controlled by information from many of the sensors we have used in the past. You must still evaluate the complete control system. New technology may not be the cause of every performance problem just because it new.

6. **<u>Creating</u>**: At this point in the pyramid a technician can create his own diagnostic process that work with his equipment and information system. These are the master technicians that are the high production technicians that help make a shop profitable. These technicians amaze everyone with their expertise. Doc and Bill have to work hard to find ways to try to keep up with these super technicians.

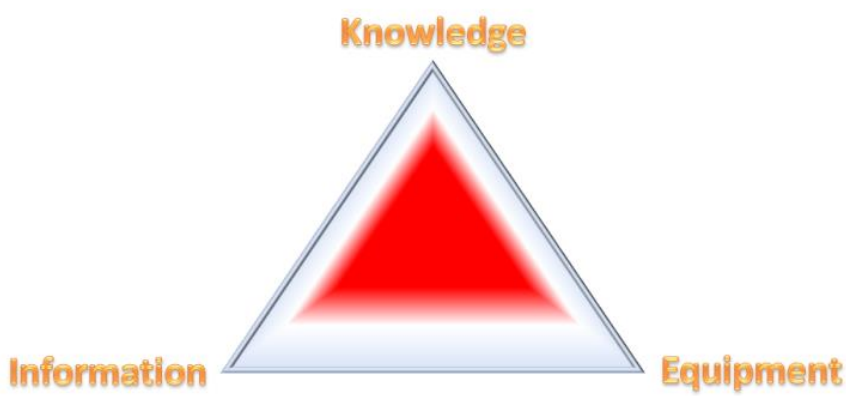
As a technician you attending an advanced training course you are somewhere in the remembering, understanding, and applying part of the pyramid. In this advanced class we will start with remembering and understanding. We will discuss new technology adding it to your knowledge and understanding. Applying and analyzing will be added to each subject. Then we have a discussion on evaluating each system as a whole to the other systems.

Safety

Always **read, understand, and follow the safety procedures posted in your shop and listed is service information.**
Always read, understand, and follow the safety procedures posted in engine compartments and on components and Sub-systems.
A Gasoline Direct Injection system (GDI) may hold dangerous high fuel pressure up to several hours. **<u>Do not disconnect high pressure fuel line without following the manufacturer's instructions.</u>**

Advanced Diagnostics doesn't allow you to overlook the basics

Among automotive technicians the word basic seems to turn them off. No technician would get caught dead in a basic class. We are asked to look at quite a few problem vehicles for students when they can't diagnose the vehicle. More often than not, we find a simple problem that should have been caught by a good basic test procedure. It seems a technician will get caught up in the latest and greatest piece of equipment or test procedure and not see what is right in front of him. If you want to become the sharpest technician in your area become a Master of the Basics.
Remember you are not working on the space shuttle, I's an only a Chevy! (Ford) (Chrysler) (Kia) (Whatever) Yes, these are pictures that technicians have found on vehicles coming in for service. The fuse is special; some fuses made in China corrode causing high circuit resistance while other Chinese fuses have the wrong fuse rating. We are trying to make a point with the two batteries, motorist neglect maintenance



on their vehicles and some of the neglect will not be this easy to identify.

Knowledge, Information and Tools

There are three Critical elements necessary for effective diagnostics. You can arrange them in any order you wish, but it always involves elements of the three elements.

Enhanced Diagnostics

We believe that you perform tests to get a diagnostic path to the root cause of the problem. In most cases one test leads to another. A test result shows you what test to do next. It isn't uncommon to do many tests before finding the root problem.

We also believe that the tests should be easy to perform. <u>There are times you will have to do tests requiring you to use a DSO or another piece of equipment. We are simply suggesting that those tests wait until you're sure they must be done. Use the information in this course before jumping into anything tough or difficult. If you don't have a diagnostic direction, you may make too many unnecessary tests that waste time and find no meaningful results.</u>

This class covers strategies that offer a diagnostic advantage over those tests. We want to take an easy path first. Absorb as much information from the digital data as possible. Why fight to get a test connection on an injector before you determine that is the only way? That's all were saying, work smart.

Where do you want/need to improve? Make sure you ask questions so you get what you came for. Don't sit there like a lump and fail to participate in class. You have invested your time, so take advantage of being here.

There must be a basic understanding of system operation in order to diagnose problems. We understand that in some classes they die on operation, function, and theory. So much, you know how to build a part. That isn't what this class is about. We want to give enough operation so you know what a system should do and what is normal. That way you'll quickly recognize when the system isn't working normally.

Understanding equipment features and functions is a huge part of diagnostics. We offer a Scan Tool class where technicians bring the Scan tool they work with every day in their service bay. We connect equipment to vehicles and cover the features and functions on a vehicle. You must know how the equipment works and how to use it. If you haven't attended a class on the equipment, you must force the person that sold it to you to supply help. Tell them you won't buy anything else until you know all about what you already have. There are tool salesmen that get you into equipment and abandon you. Maybe they send the tech guy around once, who seems he doesn't know much more than the sales guy. And then you buy the next greatest thing from him. That's just not smart. Learn to use what you have first.

Developing diagnostic strategies isn't something you do one time. You can't make a strategy that will work for all problems. The best way to start your strategy is to look at diagnostic trouble code (DTC).

The DTC directs you to a path to follow. As an example, the code is a P0172. The system is too rich on bank 1. What operation do we need to understand? The PCM sets the DTC when it makes attempts to get the oxygen sensor to report a Lambda of 1 or a voltage of .450 on different types of sensors. If the sensor doesn't report that the PCM managed to correct a rich condition the DTC is set.

You have the Scan Tool in your hand reading the DTC. Get out of OBD-II diagnostic test mode 3 and go into test mode 1. Look at the Parameter Identification (PID) Lambda or the oxygen sensor voltage.

Can you verify the condition? Think about what it is you are doing. You are doing what the PCM was doing when it set the code?

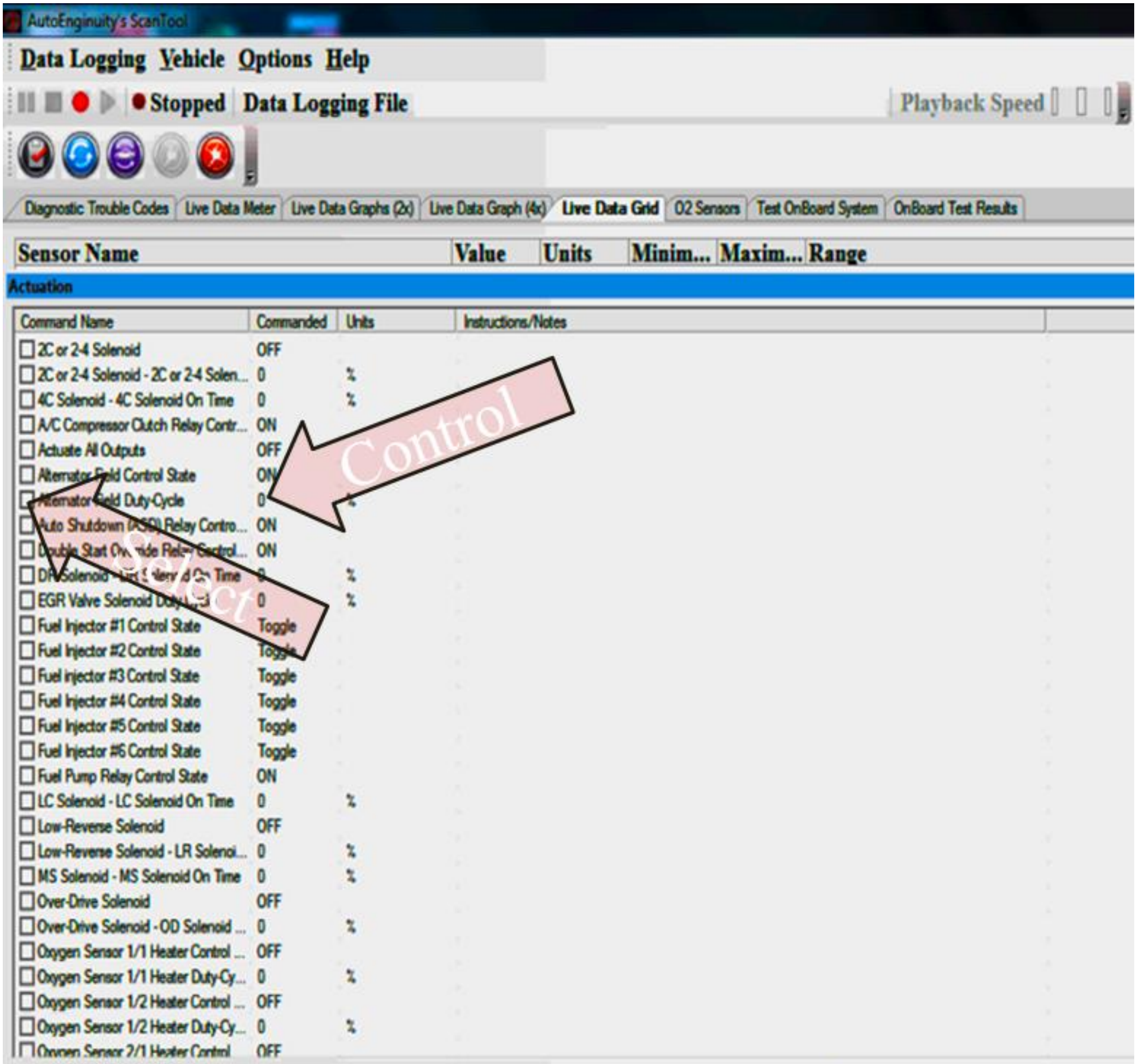
Use the oxygen sensor signal to verify the condition. The next step is to ensure the sensor is working normally. No, we are not talking about connecting a digital storage scope (DSO) to the sensor.

Get out of test mode 1 and go into test mode 6. Without getting out of the front seat; you can verify the oxygen sensor. With a few button pushes on a Scan Tool while sitting in the front seat you have developed a strategy. Identify a direction in which to take the diagnostics.
We believe you perform tests to get a diagnostic path to determine the root cause of the problem
We also believe that the tests should be easy to perform if you are going to be efficient
We don't want to do some new "high tech" test that is hard to do and requires some piece of equipment <u>if it is not required. We get the maximum information from scan tools before we go into the more difficult and time consuming tests</u>
This class covers strategies that offer a diagnostic advantage in time and accuracy.
Where areas do you want/need to improve?

Understanding system operation
Understanding equipment features and functions
Developing diagnostic strategies

Enhanced Scan Data Testing

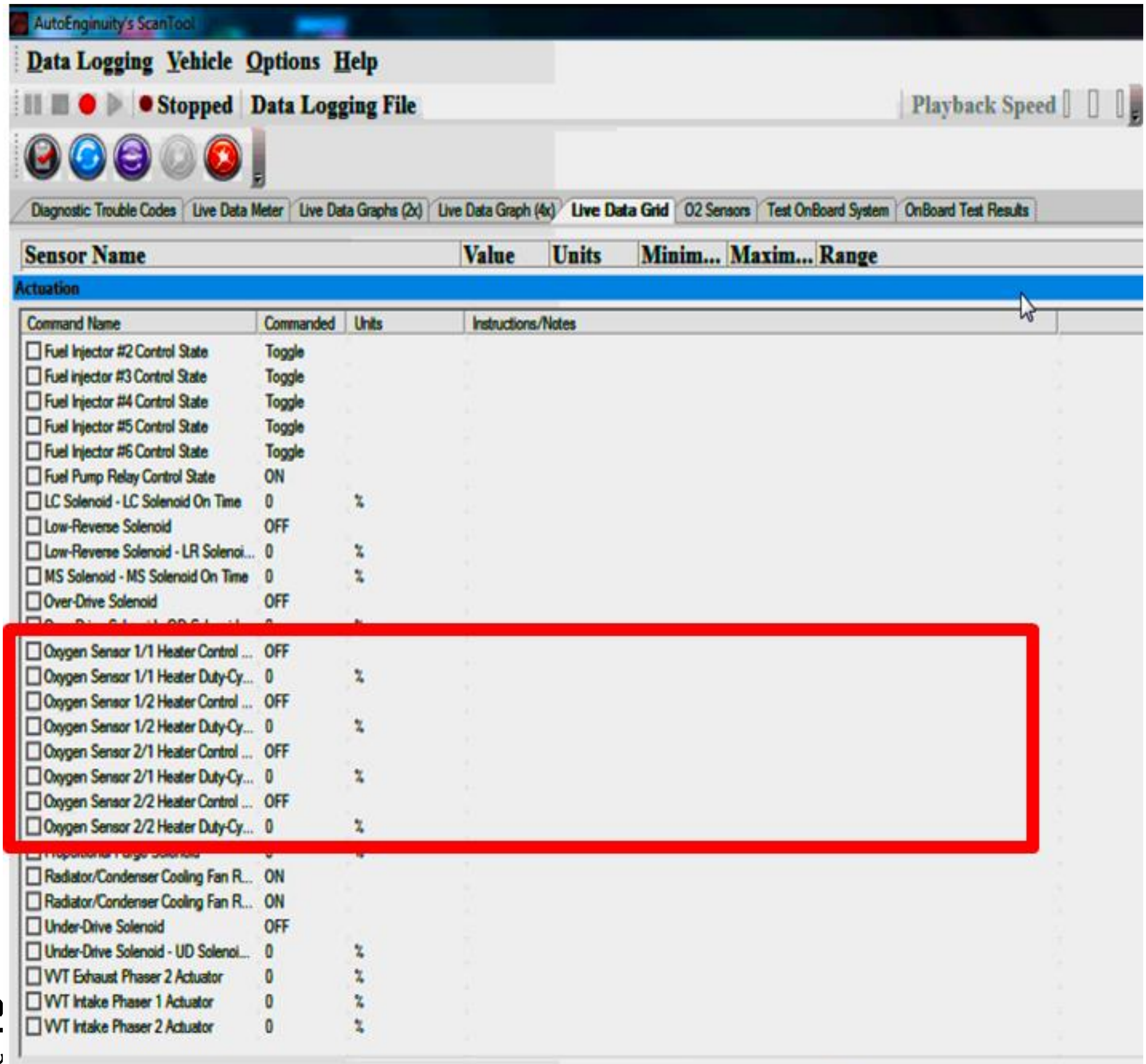
Bi-Directional Testing;
Allows you to take control of a component or system without busting your knuckles



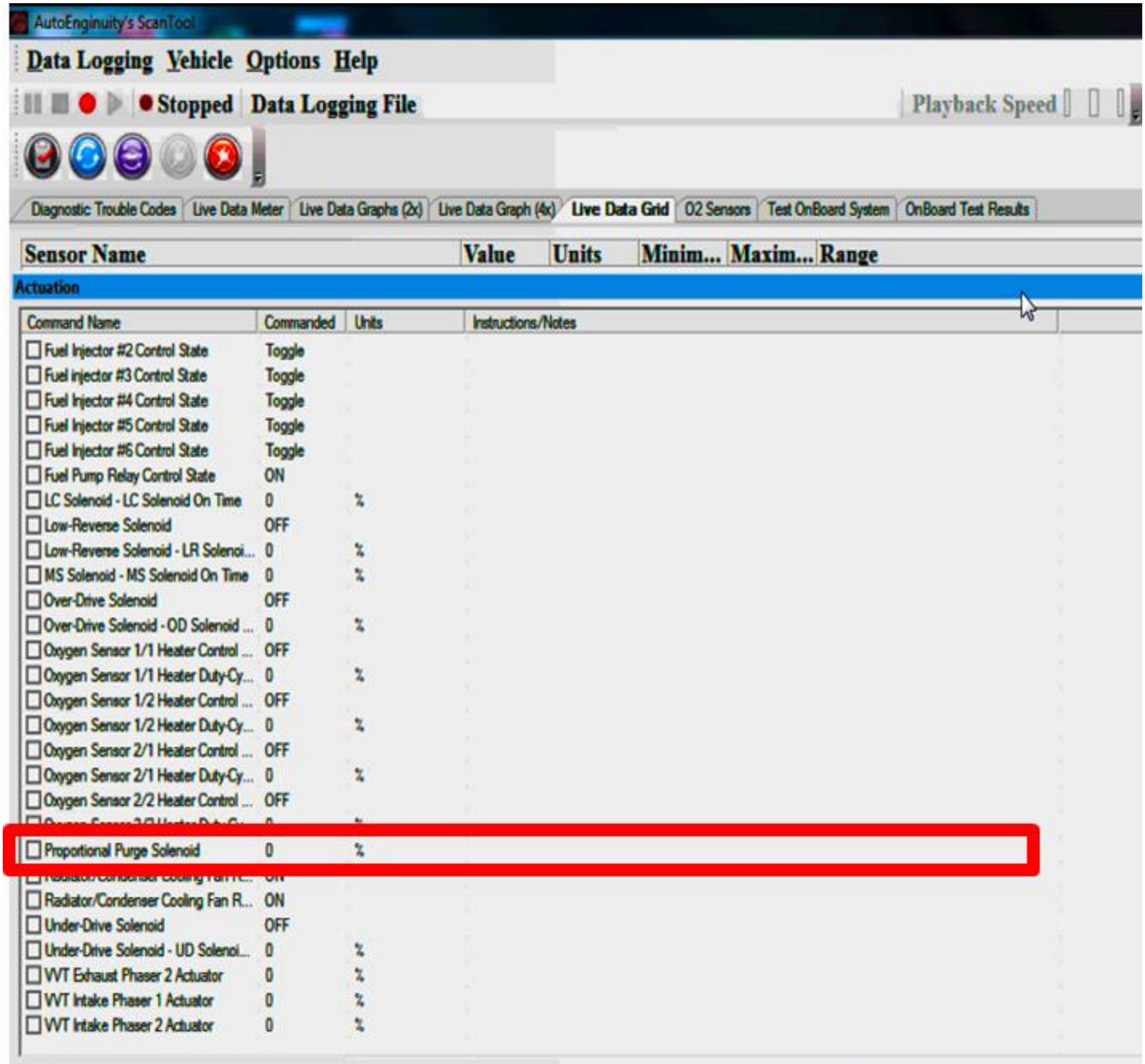
Allows you to run manufactures specific software test programs that give you clear answers to diagnostic questions
Retrieve Diagnostic Trouble Codes (All Modules)
Analyze Scan Data

Bi-Directional Testing

This is a sample screen is a partial list of bi-directional testing where you can control the actions of various components.
The first select the component by checking the square adjacent to the name and then select the action from the drop down menu.
If you need to test things like oxygen sensor heaters, you can control the current by changing the duty cycle and turning the heaters on/off.
Why would be doing this type test?



You would use this to verify the ability of the PCM to control heater current and for have a known value for current flow testing. We will show you mode-6 later where the PCM has performed a current test, but it does not tell you what part of the circuitry is causing the problem. The pin point test will see if the problem is in the wiring, connector or the sensor heater element.



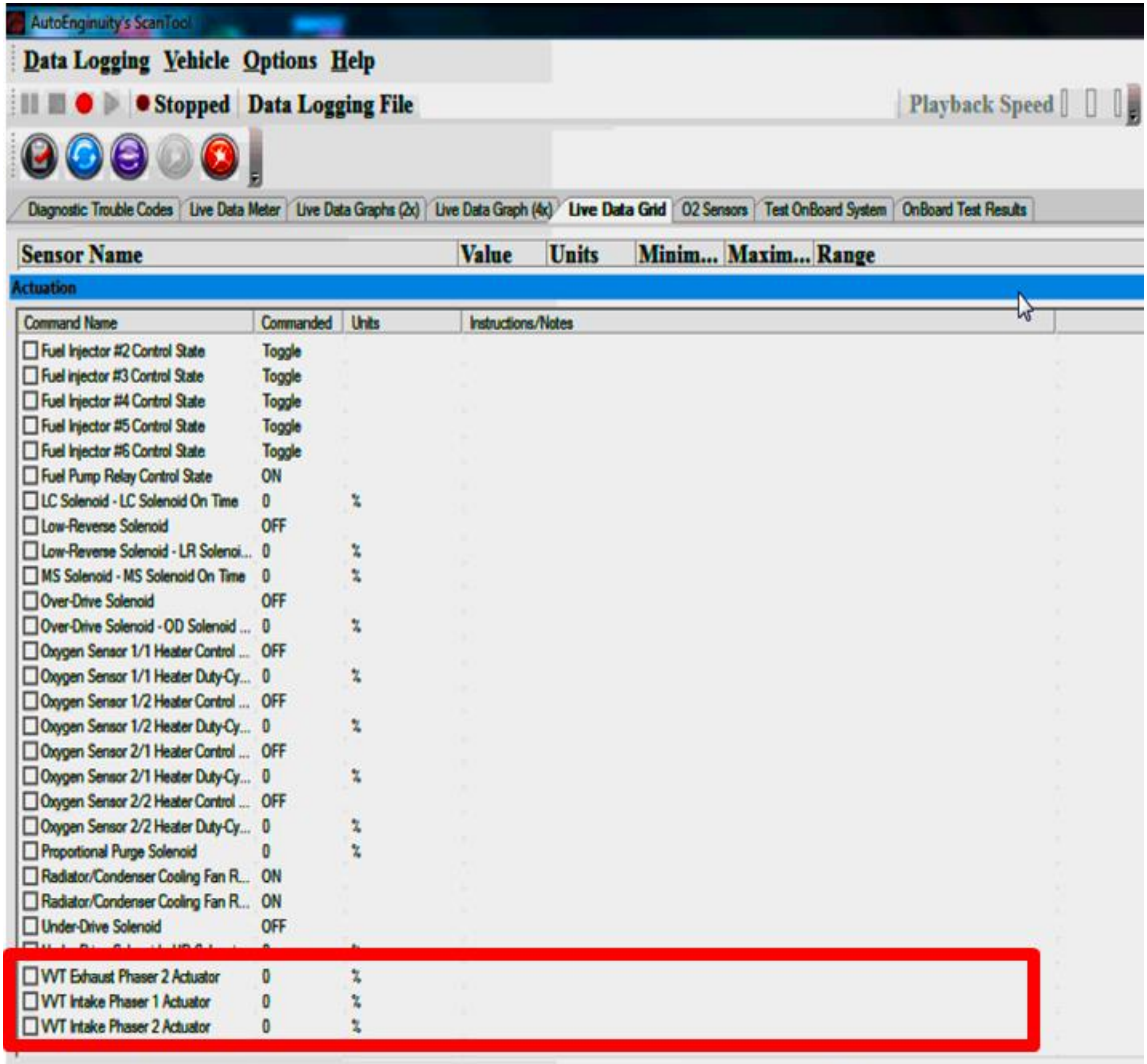
Another example is controlling a solenoid. You could connect a handheld vacuum pump to a vacuum solenoid like the purge solenoid to see if blocks and releases vacuum when you use bi-directional controls to turn the solenoid on/off. You are testing the solenoid action with the computer control working the way it would under normal operating conditions. You answer two questions at one time;

Can the PCM properly control the valve?

Does the valve control vacuum properly?

The answers to these two questions give you a diagnostic direction;

Is the problem electrical control?

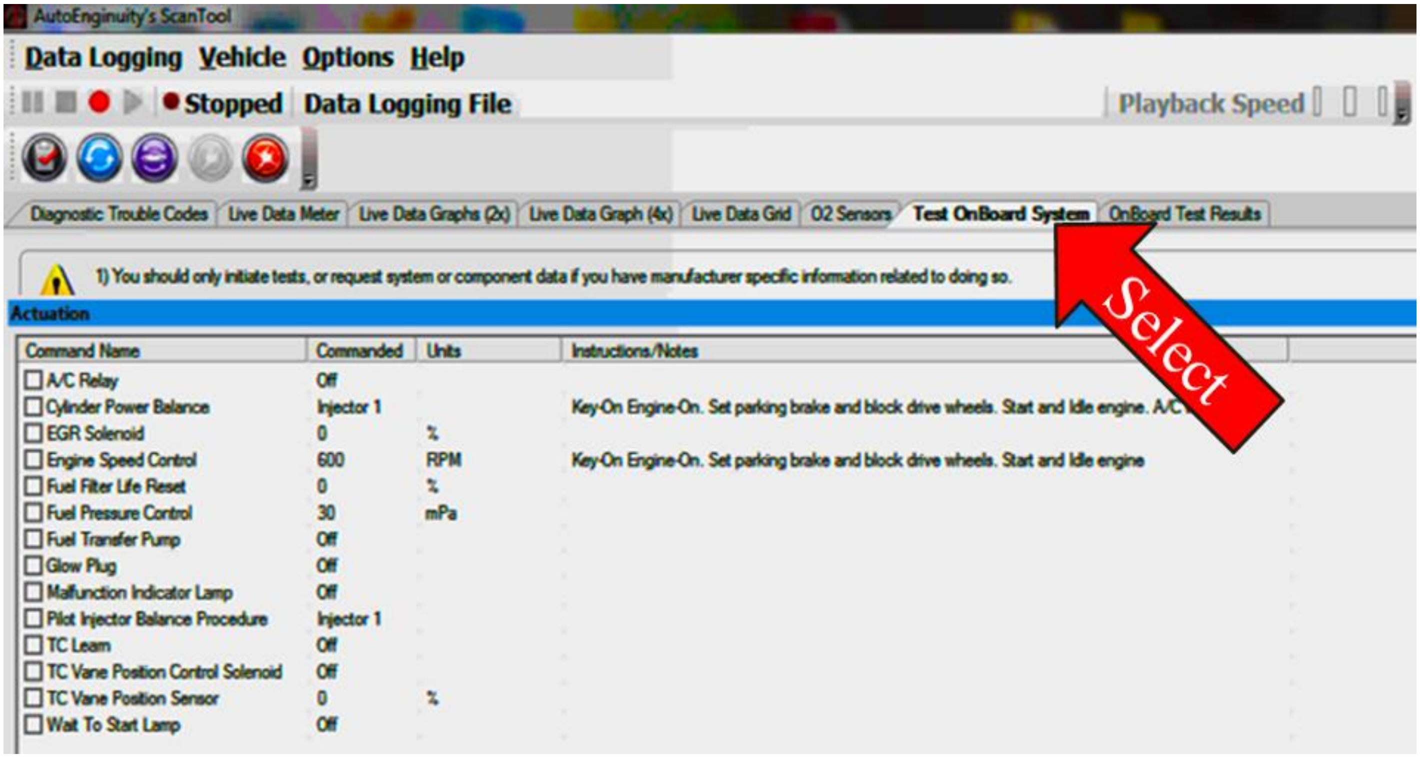


Is the problem vacuum control caused by the valve and any hoses you include in the test?

There are other controls we will discuss later like variable valve timing. This is one of several pages that are available on this vehicle.

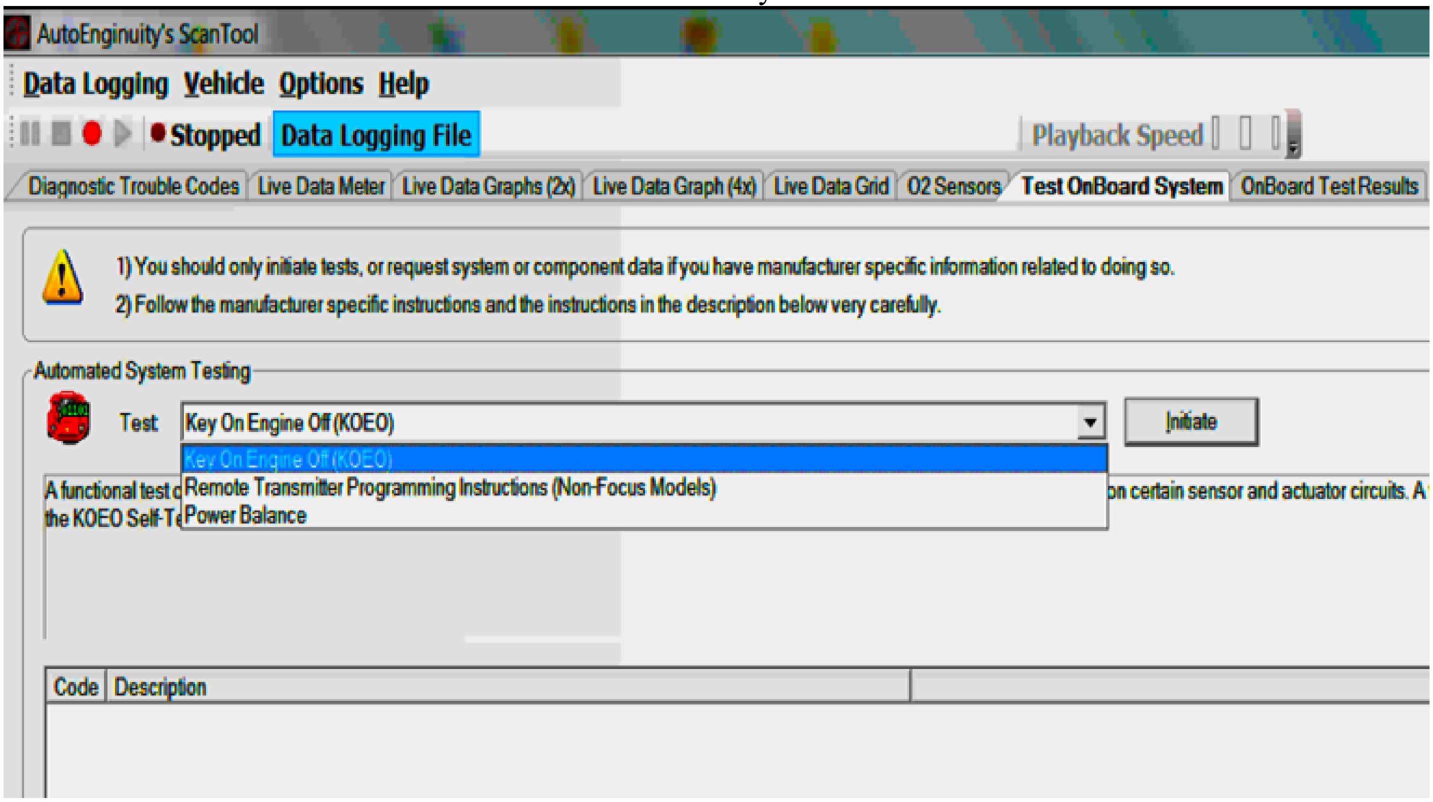
These examples allow the technician to use their choice to create their personal diagnostics. Other Mode 8 bi-directional tests are programmed by the vehicle manufacturer to test systems and provide diagnostic results.

Bi-Directional Testing with Manufacturer's Programs



Manufacturers provide special bi-directional testing for vehicle systems that run the program under PCM control and provide test result for the system being tested. The available tests vary by manufacturer and model years. The AutoEnginuity has a special tab for manufacturer tests.

This vehicle has a short list of test available for this model year.



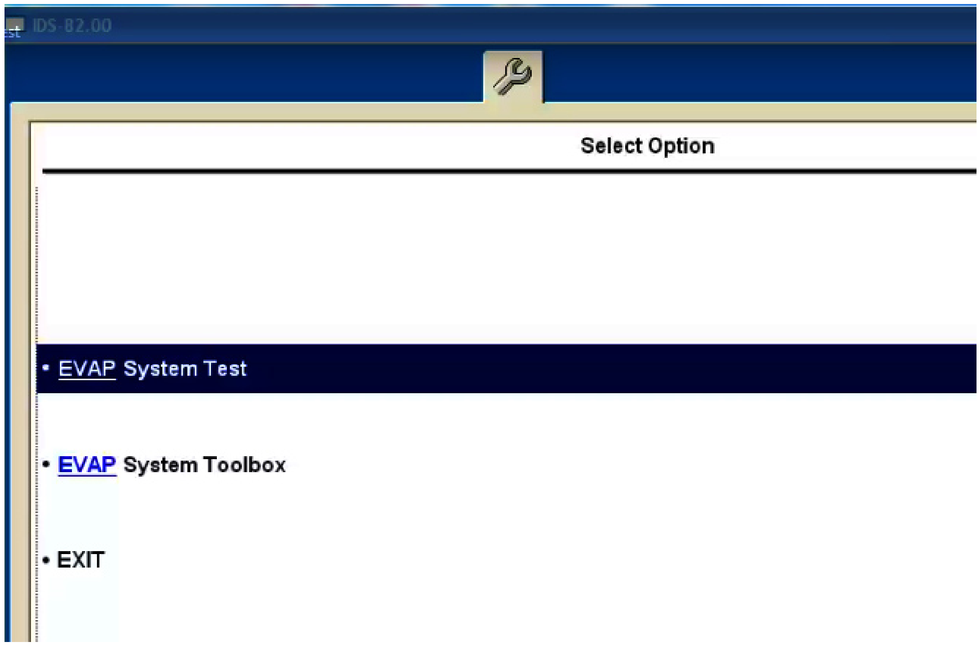
Don’t blame your scan tool if the list is short, they can only display the testing supported the vehicle. Some vehicle manufacturers restrict some of their test as proprietary information and choose not to share it.

Evap Test

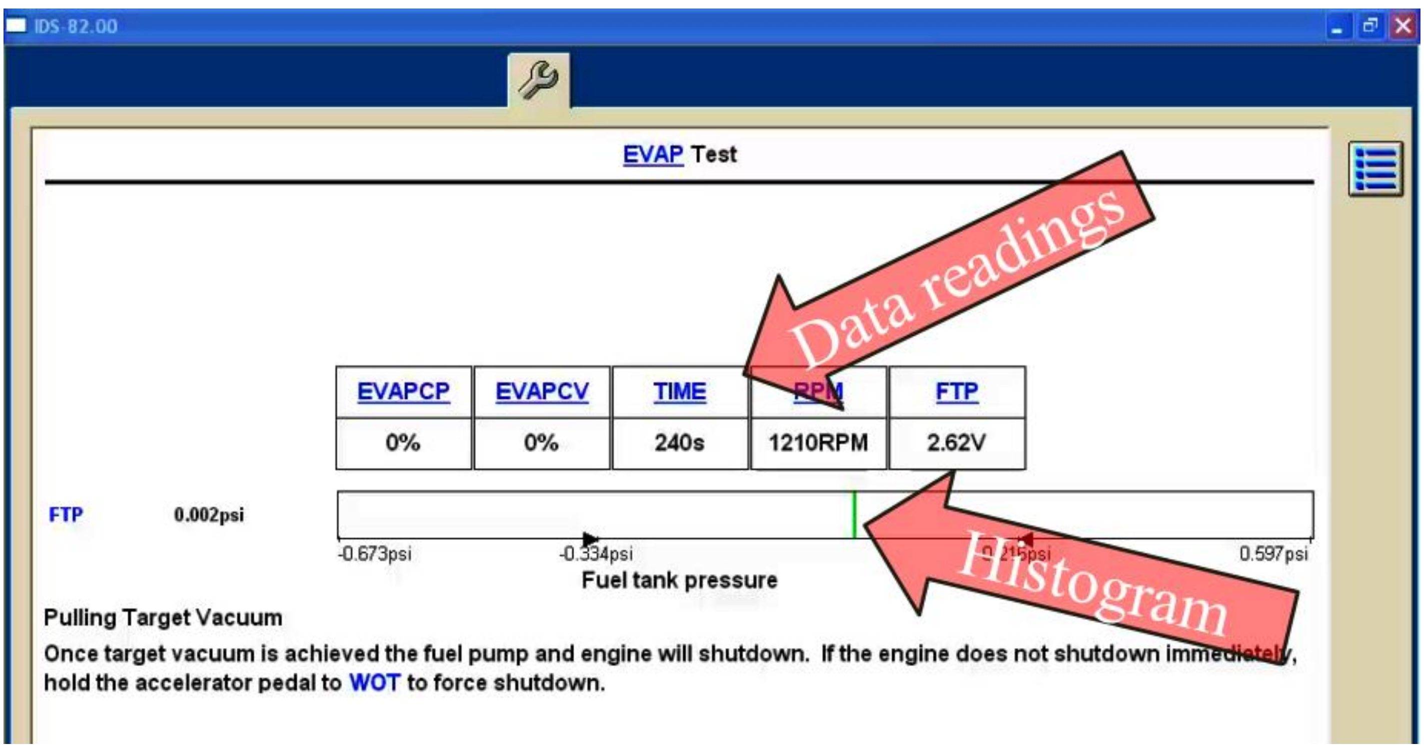
One of our favorite tests is the Evap 0.040" leak test that can be done in the service bay to verify and test repairs.

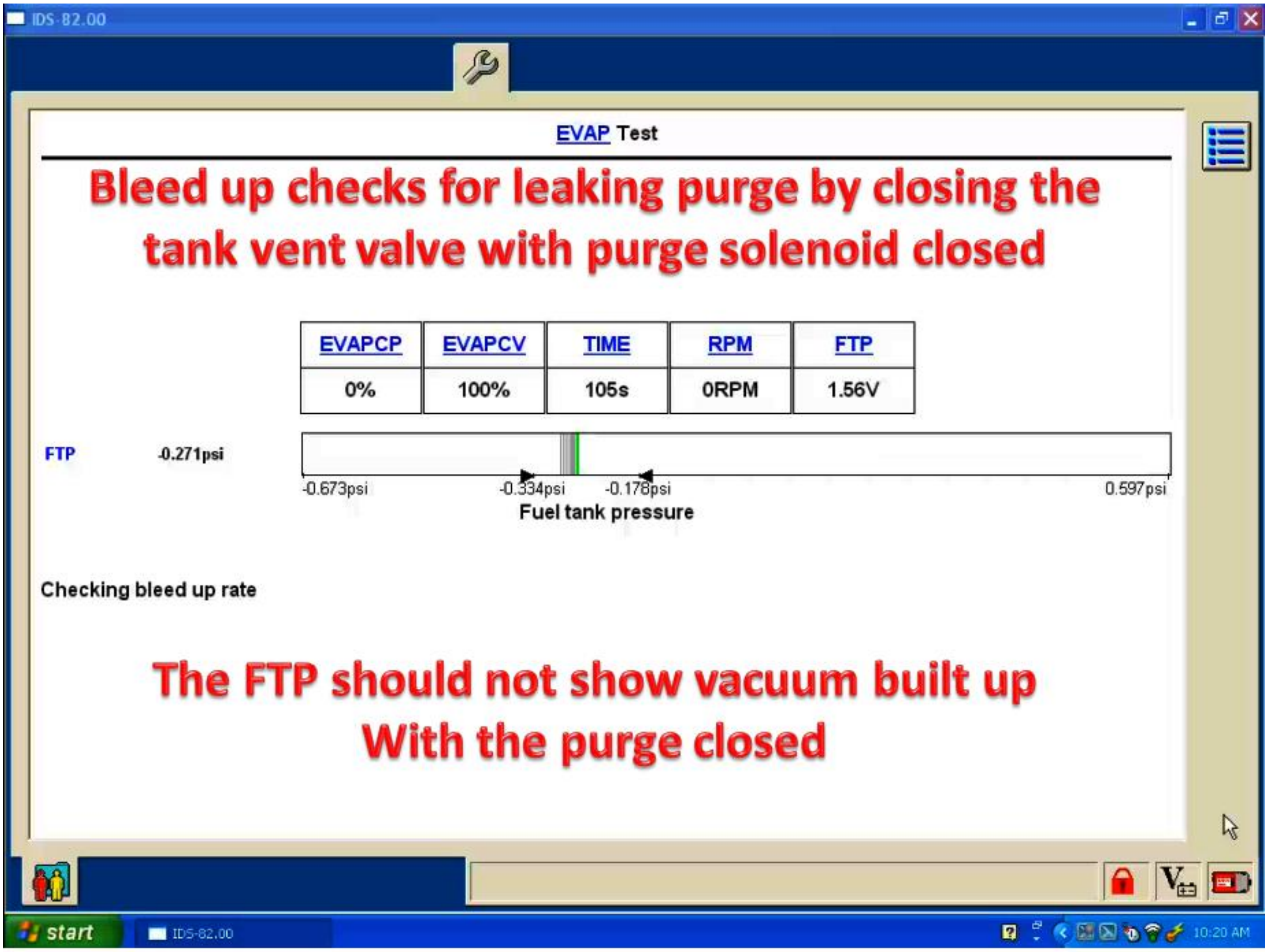
Most enhanced scan tools support this test on newer vehicles. The exact years that specific vehicles included this test in they test programs is difficult to pin point. You can see if vehicle produced earlier that 2005 have the service bay test, but coverage as spotty.

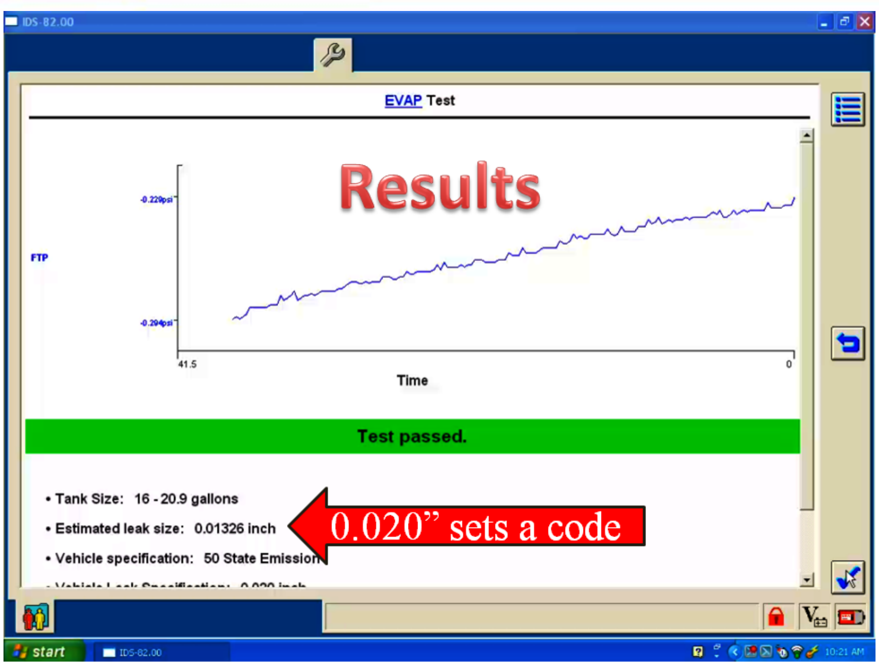
This scan tool allows us to watch the test as it runs.



The first stage of the test is to check for vacuum build up when the purge valve is closed.







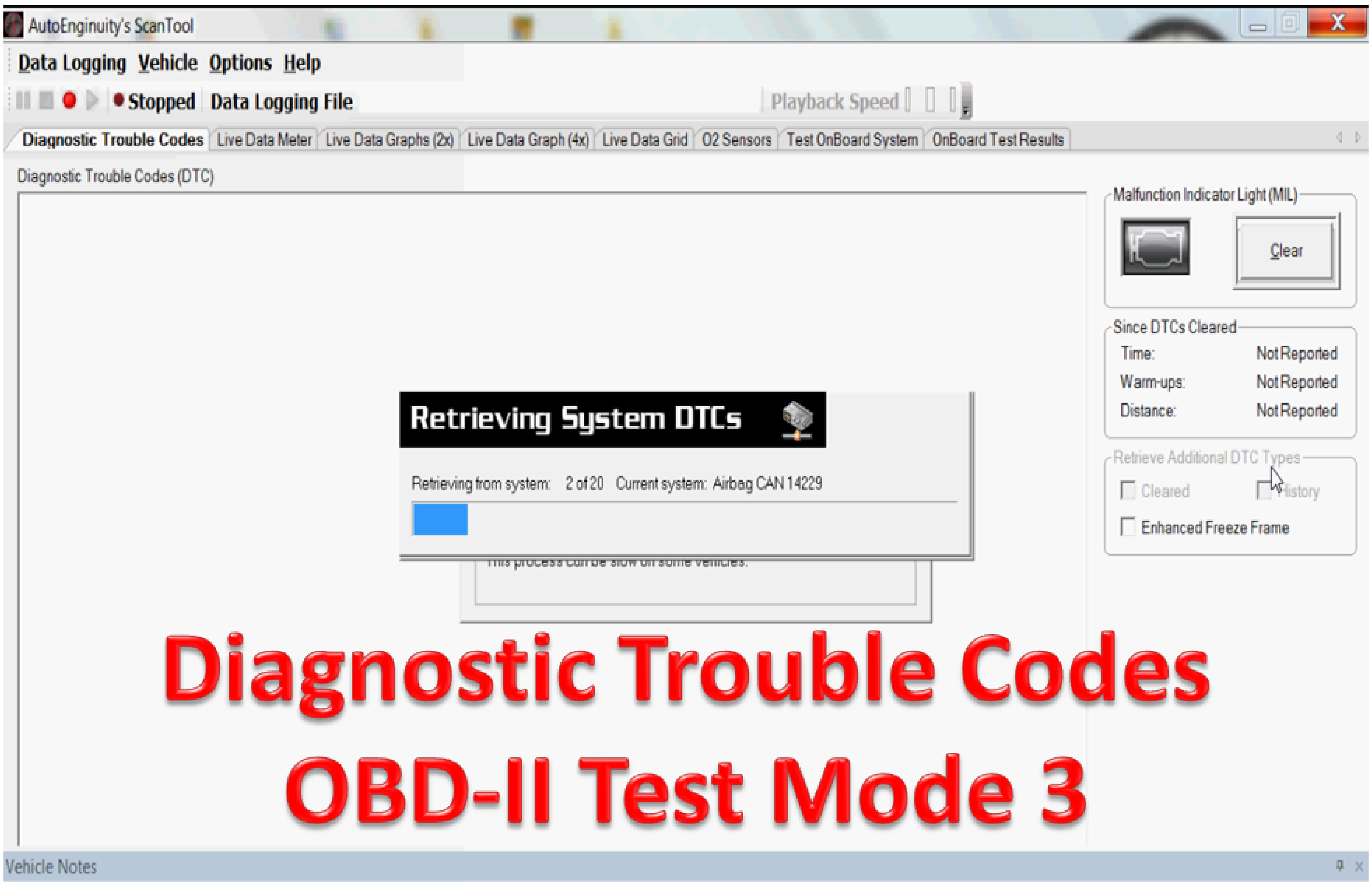
The Evap canister purge duty cycle is 0%, indicating the valve is closed. The canister vent is 100%, indicating the valve is closed. The fuel tank pressure sensor has only minor changes in the histogram, indicating there is no leak in the purge solenoid. You would use the bi-directional testing we describe earlier if you fail this part of the test because you would have a diagnostic direction pointing to toward identifying the leak.

The results page shows the test results. Take note of the test results. The small leak trouble code sets at 0.020". If the test results were 0.019+", you may have an intermittent evap code. You should warn the motorist that there is a possibility of an evap code in the near future. **This is what part of predicting pending failures before a trouble codes sets.**

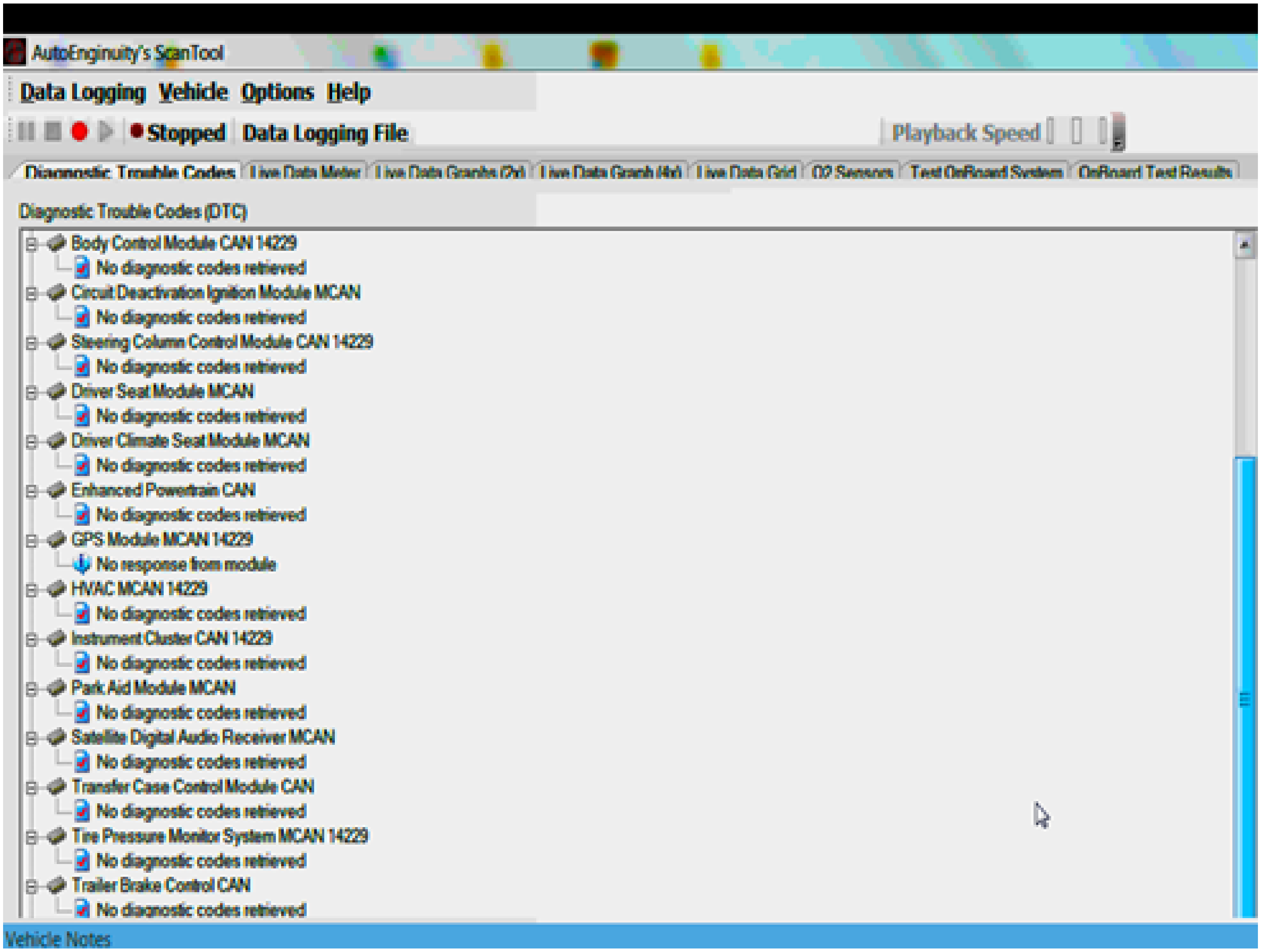
Diagnostic Trouble Codes

We don't want to go too far without checking for trouble codes.
We are looking at this enhanced testing because we had a reason for check a system for a problem. One of the main diagnostic aids is OBDII codes. Later we will look at some enhanced scan data to predict problems that may turn on the MIL lamp in the near future.

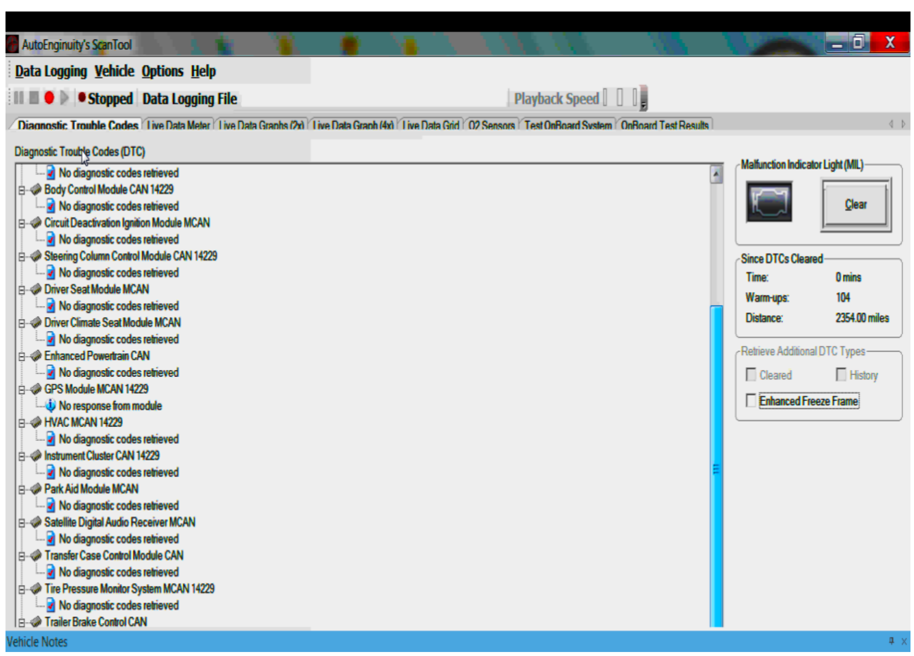
We have had experience where we found problem with engine performance because of codes stored in other modules, the transmission module to be specific. So put codes on all the modules. Here is an example of the procedure to get ALL the codes on a vehicle.

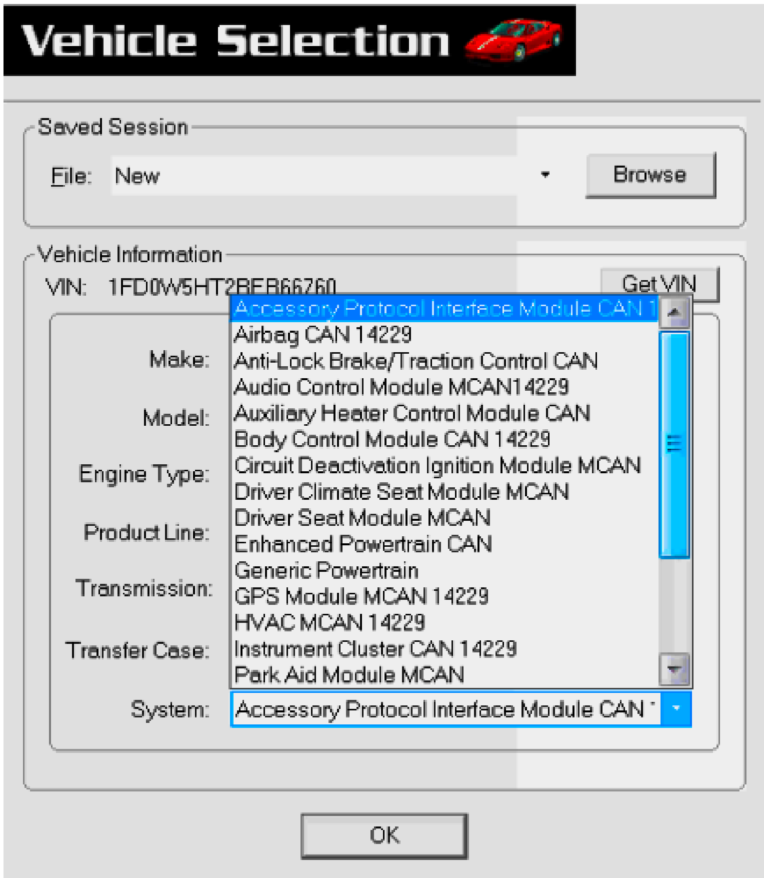


Note; we are pulling codes for 20 possible modules. The AutoEnginuity pulls all possible modules that were used on this model vehicle, so some modules will not respond. If you thing the vehicle is equipped with this specific module, you have a communications problem. New vehicles require communications for too many things to ignore any communication problem.



Notice that there are 19 modules reporting no code and the GPS module has no response. This list is long than one page.



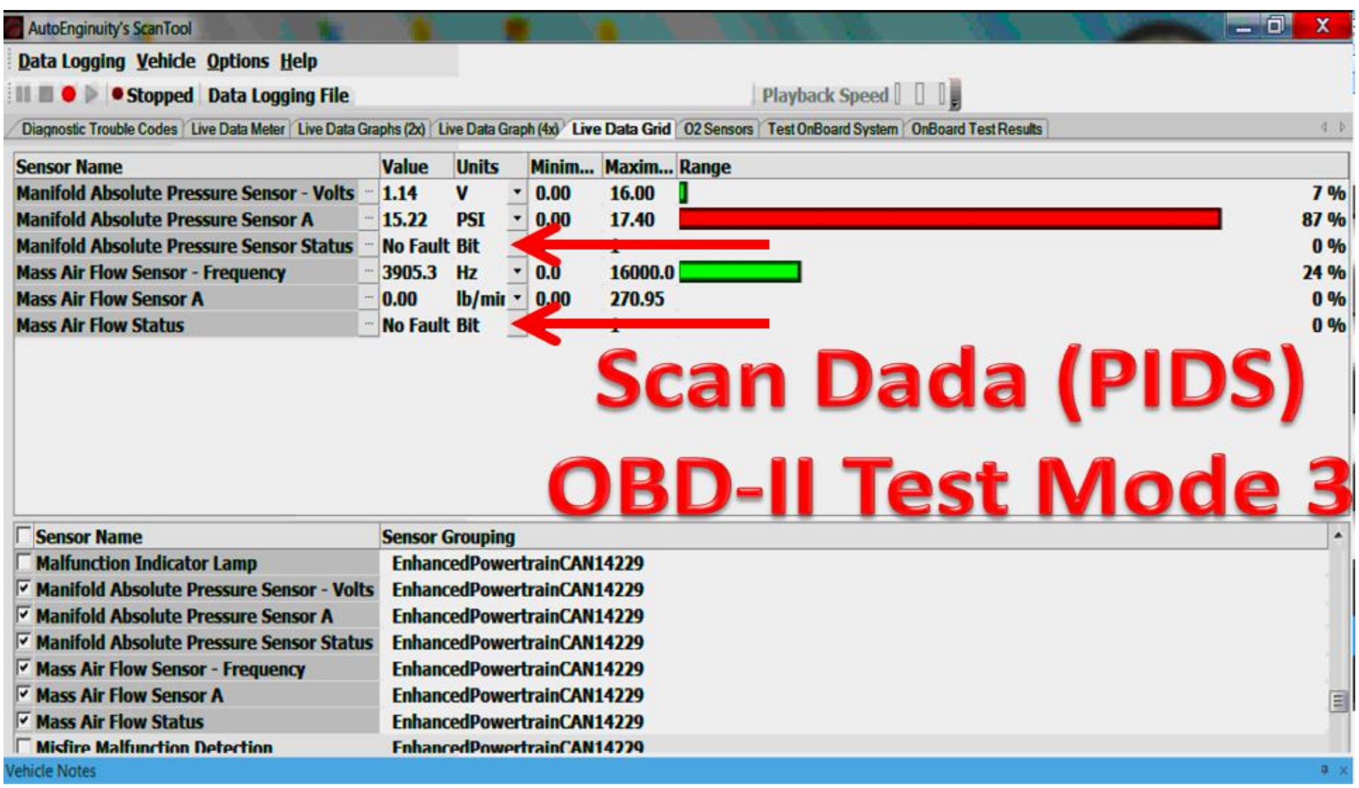


Enhanced Scan Data

We have scan data from most of these modules, which can make testing more efficient. In future classes we are going to go through the extra modules and diagnostics for each module in a vehicle specific class.

As you can tell by the slider bar on the right this list of modules with scan data are also over two pages.

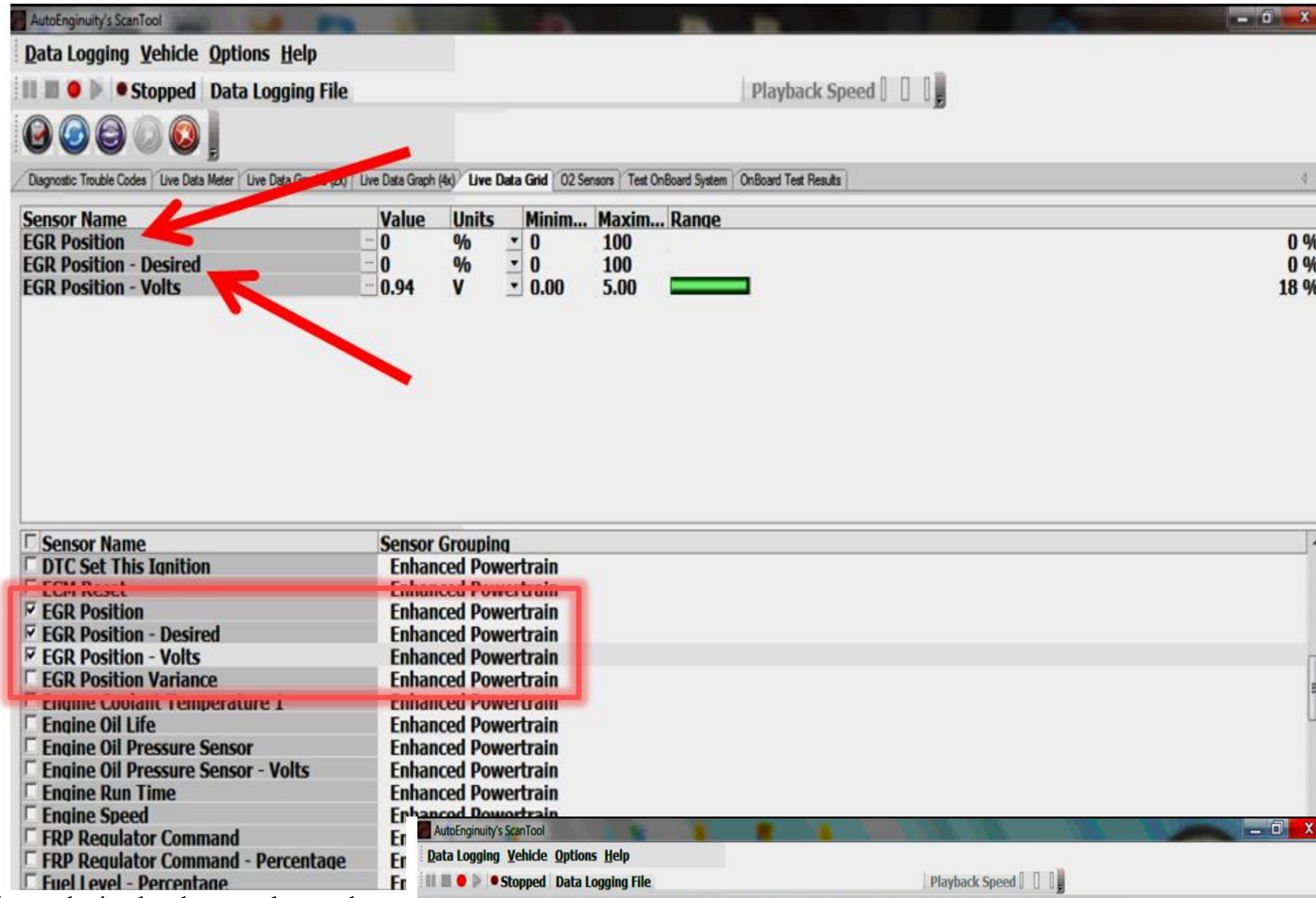
We will work with enhanced powertrain control module functions in this program. We sometimes find our

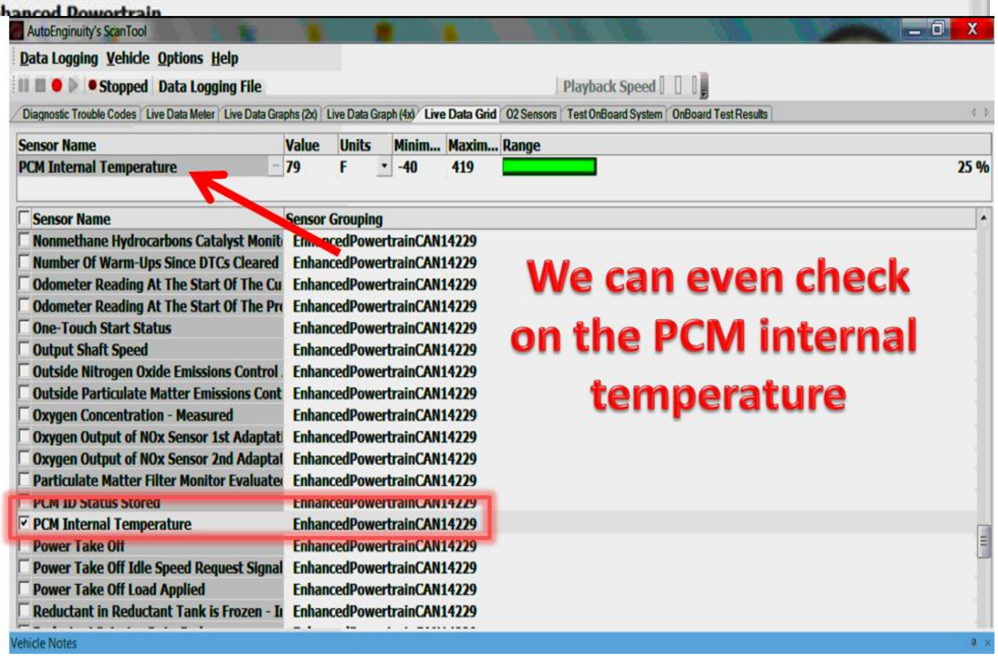


diagnostic direction by studying the details that available nob the newer vehicles. It saves us time making manual checks.

Desired Versus Actual Vlaues

Actuators have scan data that can improve your diagnostic process with a minimum of effort. Some actuators





have desired values and actual values to help you see the difference in command and actual.

We selected the information on EGR that we are going to watch during a test drive to check EGR operation. It take two technician unless you graph or record the data.

We can check on the PCM internal temperature on newer vehicles.

Analyzing Scan Data is the Key

We are going to breakdown each cycle of engine performance to think about what we should be looking for in that area. We are trying to think like the PCM thinks about engine operation.

Intake Stroke

What are we diagnosing here?

- Mechanical engine components
- Load sensor input (MAP/MAF)
- Temperature sensor input
- Variable Cam Timing System
- Turbocharger operation and Boost Pressure
- Fuel Delivery

What will scan data show if this is wrong?

Compression Stroke

What are we diagnosing here?

Mechanical engine component Tests

- Power Balance
- Relative Compression
- Variable valve timing on some vehicles

What will scan data show if this is wrong?

Compression Stroke

What are we diagnosing here?

- Mechanical engine components
- Fuel Injection (strategies)
- Ignition/combustion Event
- Power Contribution
- Crankshaft and Camshaft Position

What will scan data show if this is wrong?

Exhaust Stroke

What are we diagnosing here?
Mechanical engine components

- Exhaust system integrity
- Variable Cam Timing System
- Turbocharger operation

What will scan data show if this is wrong?

Most technicians have an understanding of the four cycles of an engine. Thinking them through as you diagnose will help divide the tasks.

1. Intake cycle;
   It draws the air fuel mixture into the cylinder. What does the PCM do during the intake cycle? It measures engine load and the temperature of the air and the engine. The PCM doesn't do the measuring, the sensors do that. The PCM interrupts the measurements. It does so to command the correct amount of fuel matching the air. The purpose of this is to control Air/Fuel ratio to match operating conditions. Depending on the load and temperatures the A/F ration may need to be rich, lean, or stoichiometry. There are other sub-systems involved in the intake cycle. Variable Cam Timing Systems are a common sight on engines now. They have gone from simple one camshaft controlled to independent twin camshaft control, where all four cams on a V-engine are computer controlled independently. The PCM uses camshaft position sensors, load sensors, and engine RPM to control the system. Turbocharger operation and Boost Pressure is an important sub-system involved with the intake cycle. The PCM uses manifold absolute pressure and exhaust back pressure sensors to control the waist gate or the variable geometry solenoid that controls the amount of boost.
2. Compression cycle;
   This is a mechanical cycle that depends on the valves being closed at the right time. The Variable cam timing sub-system is what makes this happen. Compression testing is common for ensuring that the valves are not leaking. Many of the new systems for OBD-II diagnostic Test Mode 8 or bi-directional testing is built into the Scan Tool.
3. Power cycle;
   For the engine to produce normal power, the Fuel Injection strategies, Ignition Events, as well as the crankshaft and camshaft Position plays a huge part. Once again the test modes can offer information for all of these.
4. Exhaust cycle;
   We sometimes take exhaust the exhaust system for granted if it is not too loud, but is part of the closed loop fuel control system. Small air leaks into the exhaust can offset the oxygen sensor readings and throw off the fuel control system. The exhaust but also be free flowing to allow the engine to breathe.

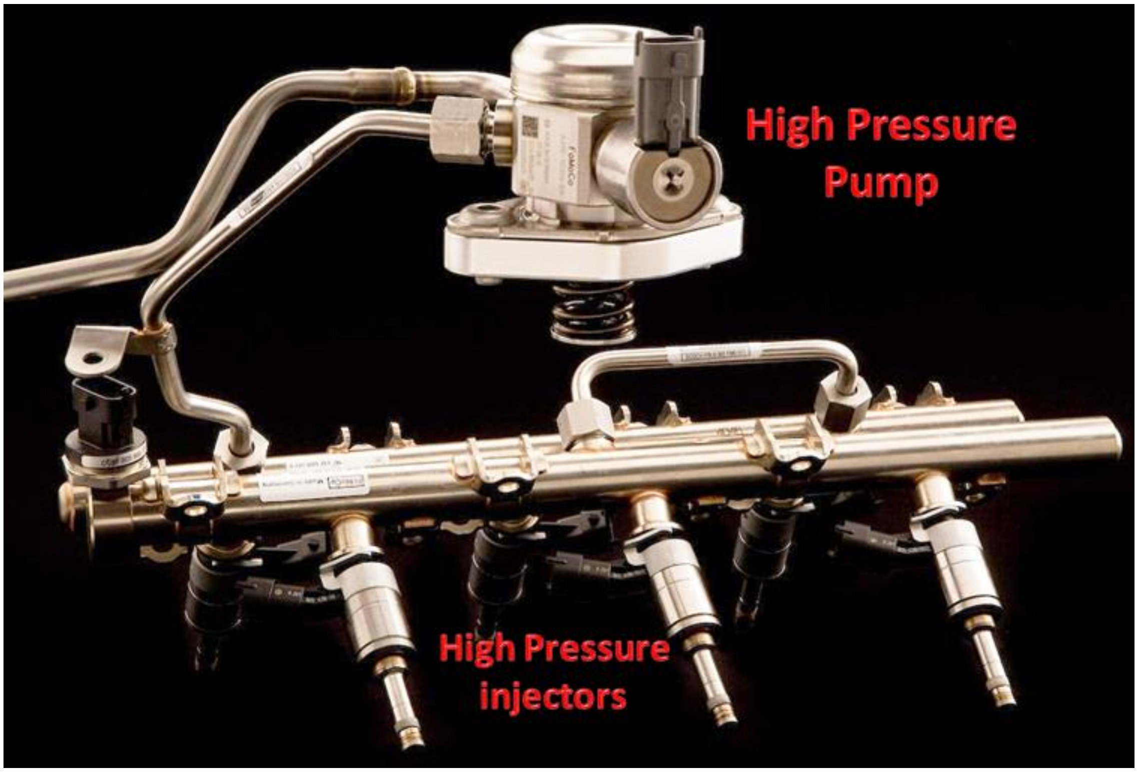
The reason for all this basic review is we sometimes locate difficult problems by looking into overlooked aspects of engine operation. We use this factor to try and determine a diagnostic direction.

3 Major Challenges for Technology

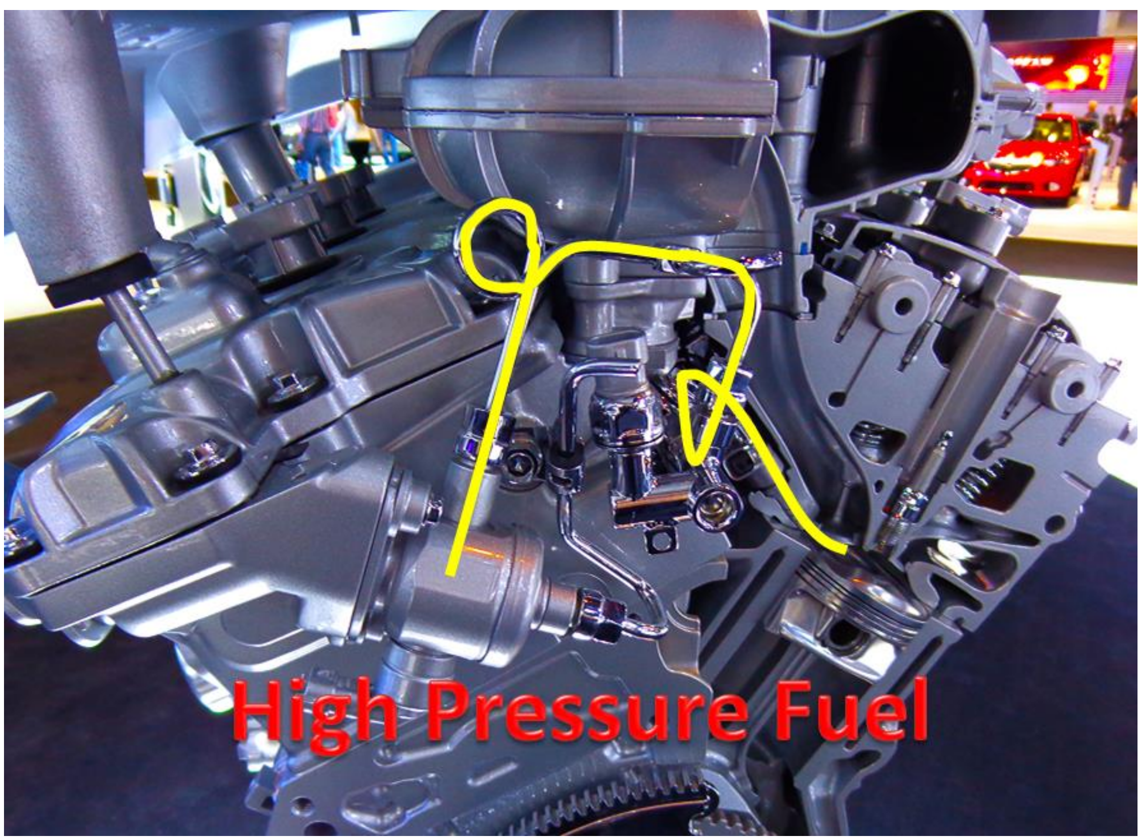
All the new systems are employed to address three issues

- Performance
- Fuel economy
- Emission control
- You can't change one of these and not change the others, but the new technology is bending the "old" rules.

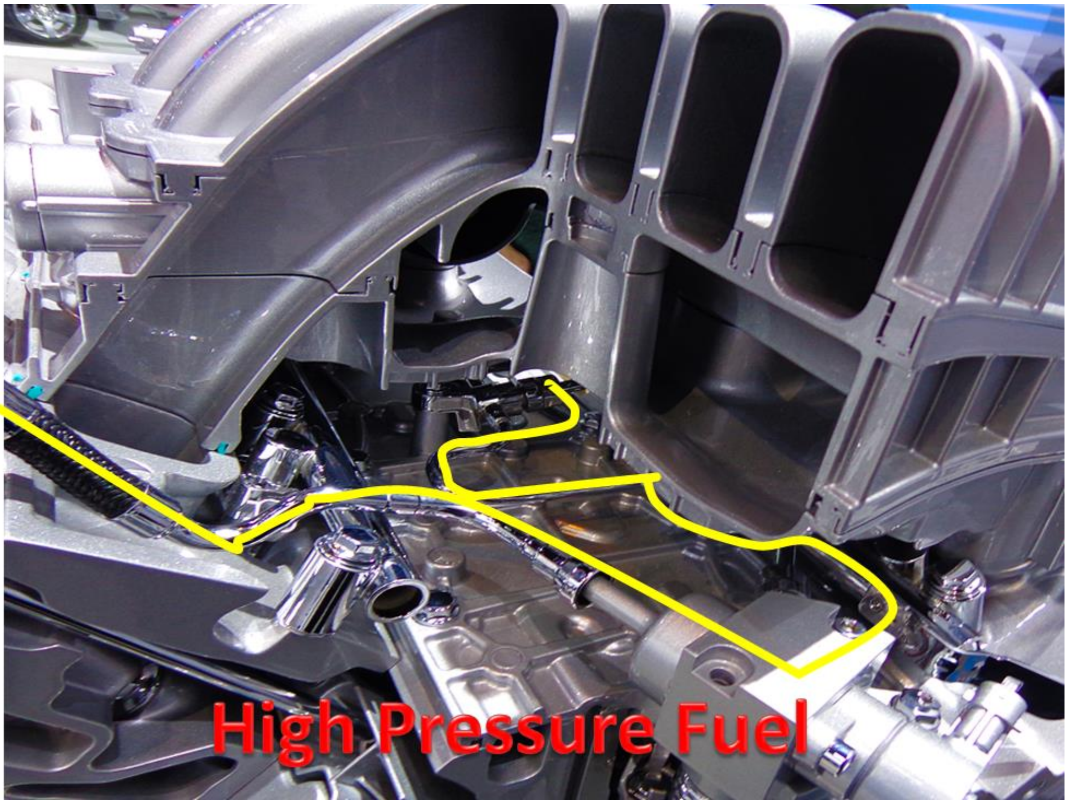
(GDI) Gas Direct Injection



Direct injection injects fuel directly into the combustion chamber. There is a high pressure fuel pump that increases fuel pressure to levels that allow direct combustion chamber injection. The fuel pump is driven be a special lobe on the camshaft.

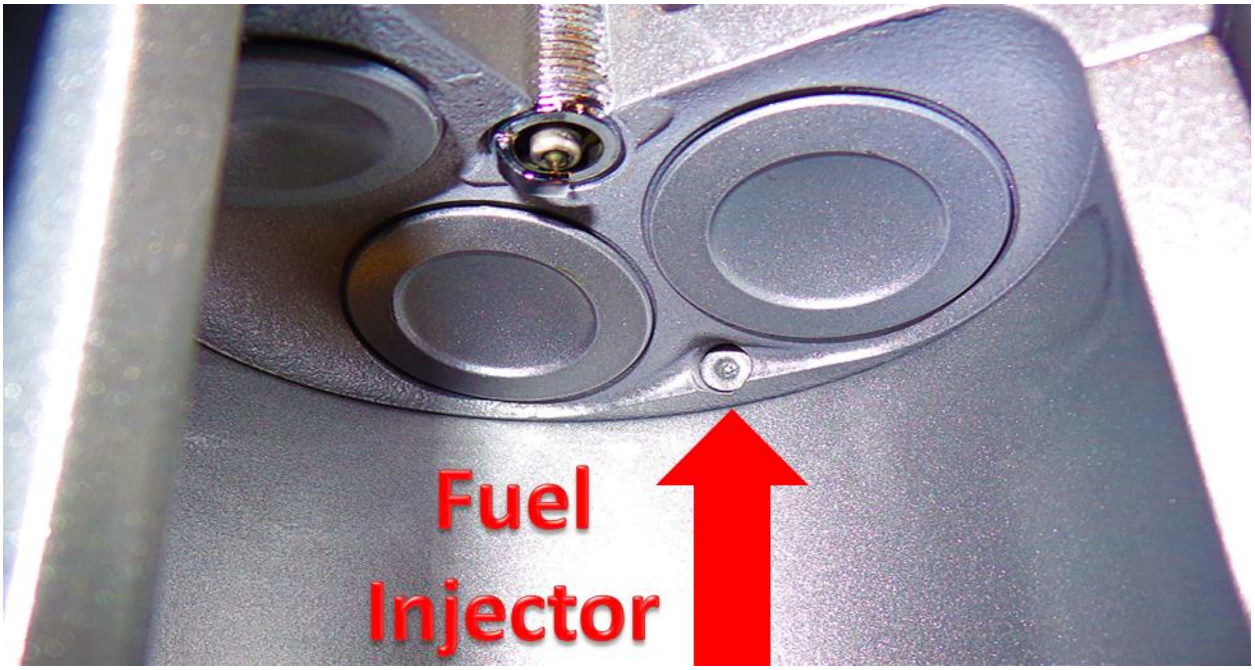


The high pressure fuel goes from the pump into a common rail that is located in the center of the engine under the manifold.
The location makes it difficult to measure the high pressure fuel with a pressure gauge, it fact it is not recommended. We are going to use scan data to do our testing.



This cut way view from the Chicago auto show gives you a good look at the high pressure fuel delivery system.

Two major considerations that have the greatest influence on engine efficiency are compression ratio and air/fuel ratio. The effect of raising compression ratio is to increase the power output and to reduce the fuel consumption. The maximum efficiency (or minimum specific fuel consumption) occurs with a mixture that is leaner than stoichiometric. Because the port fuel injection engines work at stoichiometric air/fuel ratio, it is difficult to improve fuel economy. In these engines, the compression ratio is about 9:1-10:1. To prevent the knock, the compression ratio cannot be increased more. For the same engine volume, increasing volumetric efficiency will raise the engine power output. GDI engines can operate with lean mixture at light loads; this operation provides significantly improvements in fuel economy. At full load, as the GDI engine operates at slightly rich mixture 13.1:1, this produces higher power output during acceleration. In a GDI engine, fuel is injected into cylinder before spark plug ignites at low and medium loads. At this condition, Air/Fuel (A/F) ratio in a cylinder will vary. The fuel, which is injected during the intake stoke, evaporates in the cylinder. The evaporation of the fuel cools the intake charge. The cooling effect permits higher compression ratios and increasing of the volumetric efficiency and thus higher



torque is obtained. The knock does not occur because only air is compressed at low and medium loads. At full load the charge air is cooled as the fuel evaporates and decreases knock.

This is an inside view of the combustion chamber. Notice how the injector is pointing toward the spark plug. This is half of the strategy for stratified charge. A stratified charge concentrates the fuel near the spark plug for better combustion efficiency. The GDI technology results in about 20% better fuel economy.
Direct injection offers an answer by using three fuel strategies;
Stoichiometric mixture at moderate and light loads
Ultra lean stratified charge for steady light loads without acceleration
Richer mixture during higher engine loads 13.1:1

Cool Fuel entering the cylinder

Traditional (indirect) fuel injection systems pre-mix the gasoline and air in a chamber just outside the cylinder called the intake manifold. In a direct-injection system, the air and gasoline are not pre-mixed; air comes in via the intake manifold, while the gasoline is injected directly into the cylinder.
Combined with ultra-precise computer management, direct injection allows more accurate control over fuel metering (the amount of fuel injected) and injection timing (exactly when the fuel is introduced into the cylinder). The location of the injector also allows for a more optimal spray pattern that breaks the gasoline up into smaller droplets. The result is more complete combustion, in other words, more of the gasoline is burned, which translates to more power and less pollution from each drop of gasoline.
The primary disadvantages of direct injection engines are complexity and cost. Direct injection systems are more expensive to build because their components must be more rugged – they handle fuel at significantly higher pressures than indirect injection systems and the injectors themselves must be able to withstand the heat and pressure of combustion inside the cylinder.
The fuel, evaporates as it enters the cylinder. The evaporation of the fuel cools the charge. The cooling effect permits higher compression ratios producing higher torque.
Ultra-precise computer management and direct injection allows more accurate control to achieve maximum power without knock. At full load, the evaporating fuel charge helps decrease knock

Acronyms and Names and for Direct Injection

GDI = Gasoline Direct injection (Mitsubishi GDI)
FSI = Fuel Stratified Injection (VW)
SCi = Smart Charge injection (Ford)
Hpi = High Precision Injection (BMW)
JTS = Jet Thrust Stoichiometric (Alfa Romeo)
GTDI = Gasoline Turbocharged Direct Injection (Ford)
IDE = Injection Direct Essence

Benefits of GDI:

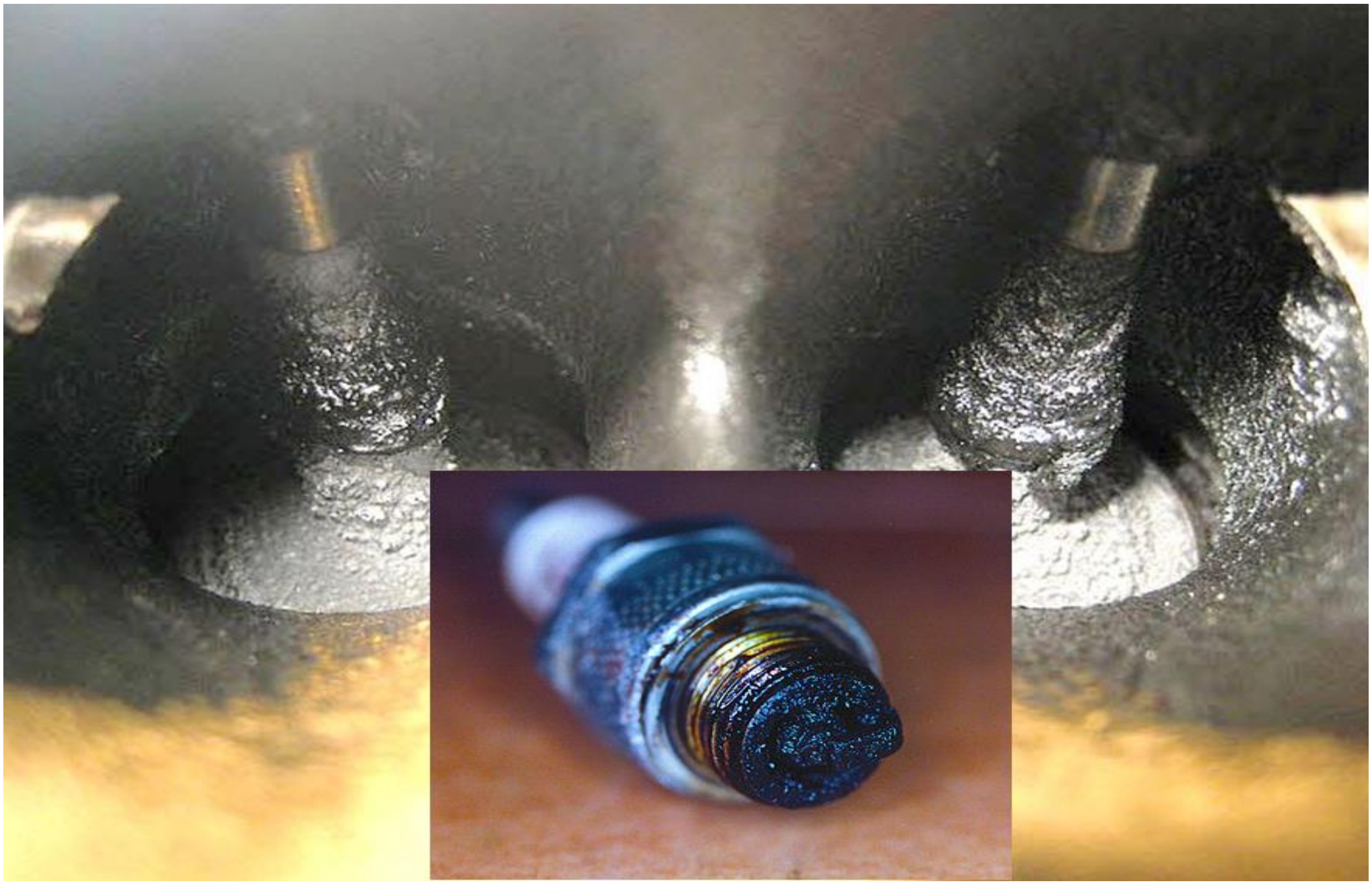
When compared with port injection:

- GDI produces lower emissions, particularly at startup and cold operation.
- GDI can allow higher compression engines (offers additional horsepower).
- GDI offers better fuel economy (especially when paired with a turbocharger).

Carburetors, Throttle body and port fuel injection systems add fuel at a distance from the combustion chamber. The fuel that was atomized liquefies and attaches itself to the walls of the intake manifold. This happens especially during a cold start and engine warm up. This causes increased emissions. GDI systems inject the fuel near the spark plug inside the combustion chamber.

What's not to like

Since the valve doesn't have gasoline flowing across it, (where detergents can do their job) carbon builds up quickly if overspray gets on the back of the intake valve. These deposits are described as a sticky coating of oil and fuel elements that serve as a base for future deposits. This causes problems with air flow which is very important in a lean mixture. Some manufactures have figured it out while others haven't. It seems to come down to how the tip of the injector sprays the fuel and where it sprays it. **Some manufactures have stopped using GDI because of the quick buildup of carbon**. Others manufacturers have developed strategies to reduce carbon build up. Ford di an endurance test on their F-150 EcoBoost when they put 164706 miles during heavy duty hauling and ran the Baja 1000 off road race. The disassembled the engine in public to show there as very little carbon.



This is an example of an engine with less than 100,000 miles on it. We don't want to publish the manufacturer's name. Just search the internet for vehicle manufacturers with GDI problems.

Manufacture's Differences Addressing Carbon

It seems to come down to how the tip of the injector sprays the fuel

And where it sprays it
And when it sprays it

Fuel Injectors

The injectors incorporate piezoelectric actuators required for high-speed activation. The higher switching speed allows the intervals between individual fuel injections to be reduced and controlled more precisely. This feature contributes to a quiet and more efficient engine.

The engine requires a high number of injections during normal operation. At an engine speed of 1000 rpm for example, the ECM may activate the injectors up to 250 times every second. Enough energy needs to be quickly stored to activate the injectors within these time constraints. The piezoelectric actuators also require high-voltage for proper operation.

Boost Voltage

There is a boost stage to build and store the energy required to operate the injectors.

Internal to the ECM is:
A DC-DC Converter is designed to step-up the battery voltage as much as 200 V.
A charge Pump which is a transistor that switches the DC-DC transformer on to induce the high voltage.
A booster Capacitor stores the energy required to activate the piezoelectric actuators.

The charge/discharge driver stage contains the following main components:
A charge Power Transistor that allows power to flow to the piezoelectric high-side transistor.
A discharge Power Transistor that short circuits the piezoelectric actuators to ensure the end of injection.
A stop Power Transistor that short circuits all the piezoelectric actuators in an emergency to end the injection.
A transfer Coil is used to produce a smooth rise and fall of current to avoid damage to the piezoelectric actuators.

- The piezoelectric driver stage contains the following main components:
  High-Side Power Transistor that directs the high-voltage to the specific cylinder for injector activation.
  Low-Side Power Transistors that grounds the specific piezoelectric actuator for injector activation.
- Piezoelectric actuators have a capacitive behavior. When charged at a certain voltage, they will hold the voltage. Fuel is injected when the piezoelectric actuator is charged, and the rail pressure is sufficiently high enough. The piezoelectric actuator is then discharged to end the injection of fuel. The piezoelectric actuator is discharged normally by switching a power transistor ON. If the transistor cannot be switched ON, or if the circuit is interrupted, the piezoelectric actuator remains charged and will continue to inject fuel.
  The charging and discharging phases of a piezoelectric actuator are also similar to that of a capacitor. Injection is performed by charging the piezoelectric actuator to a set voltage and discharging it again when the activation time has elapsed. A current flow is only present during charging and discharging. The travel of the piezoelectric actuator is proportional to the voltage and is transferred to the control valve via the hydraulic coupler. The control valve controls the movement of the nozzle needle.

The fuel injector sprays fuel directly into the combustion chamber towards the valve.

The quantity of fuel injected is based upon the following inputs;

- Fuel rail pressure
- Boost pressure
- Coolant temperature
- Charge air temperature
- Inlet air pressure
- Accelerator pedal position
- Engine speed

This list becomes important when the fuel mixture is a too lean or too rich. As stated; “The ECM calculates the quantity of fuel injected based upon these inputs.” This information is telling us that any one of these inputs can send a bad signal causing the ECM to miscalculate the air fuel ratio. Many technicians overlook the inputs thinking that the too rich or too lean condition is always from a fuel system problem or a vacuum leak. More often than not fuel and vacuum leaks is the culprit, but good diagnostics checks the inputs to be sure. Remember, enhanced diagnostics gathers information to gets a good diagnostic direct so you don’t chase false diagnostic paths that will not locate the problem. Just don't forget to look at the inputs if you check the fuel system and for vacuum leaks and that isn't the problem.

Check the inputs

Most inputs are easily checked with a Scan Tool.
Inputs that have shorted or open circuited can be quickly identified.
The calibration of the sensor can tested by comparing the sensor value to a known good specification, KOEO, idle, city speed, highway speed.
After a good analysis of the input we will start looking at the other information in scan data.

Fuel Injector Operation

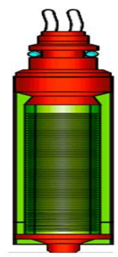
Fuel is injected in precise amounts of highly-pressurized fuel. A new type of injector is used on thes high speed hih pressure injection systems.

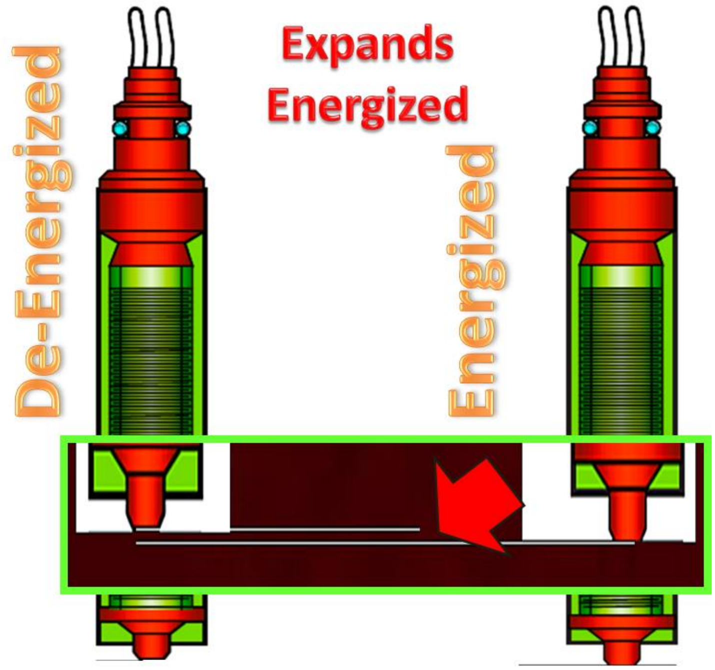
Piezo Injectors

Piezo injectors use piezoelectric technology to open and close the injectors at extremely high speeds and precision to inject fuel into an internal combustion engine. These injectors are used in both gasoline and diesel engines. Piezo electricity results from squeezing or applying pressure from certain crystal like materials or certain ceramics. If this process is reversed and electricity is applied to these same materials they will expand and return to their original size as soon as the electricity is cut off. The expansion of one crystal is too small to see with the naked eye.
How piezo electricity make piezo injectors work is by using the expansion of the crystals to open the injector. The expansion of one crystal is much too small to open the injector so there are several hundred little piezo crystals placed in a stack covering a length of more than half the injector.
When electricity passes through these hundreds of crystals their combined expansion is enough to open the injector. The crystals expand downwards and an upward movement is required to open the injector so two very small levers are used to reverse the process and open the injector and a spring closes it as the crystals retract.
Because of their operation piezo injectors can open and close much faster than mechanical injectors which allow more precision in the injecting of fuel. Piezo injectors are fast enough to allow the computer to make multiple injections during a single combustion cycle.

Piezo Injector Construction

The stack of piezo crystals expand and contract.





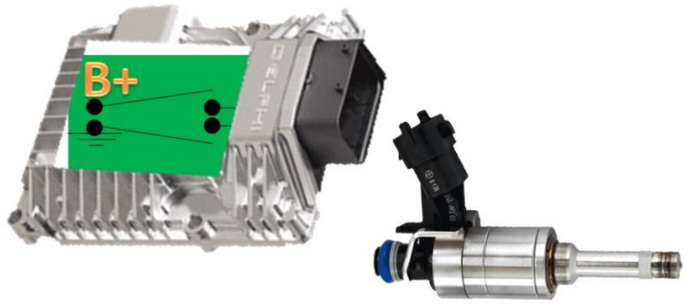
Piezo Injector Operation

Piezo injectors are more expensive to build than solenoid injectors.

Require special control electronics (High current/voltage drivers).
The High voltage needed to fire is high than solenoid type injectors (65 volts typical).
The PCM uses Smart Drivers on both the high and low side on the injector.
The PCM compares high and low side current for diagnosis.
Different manufactures use different sets of drivers

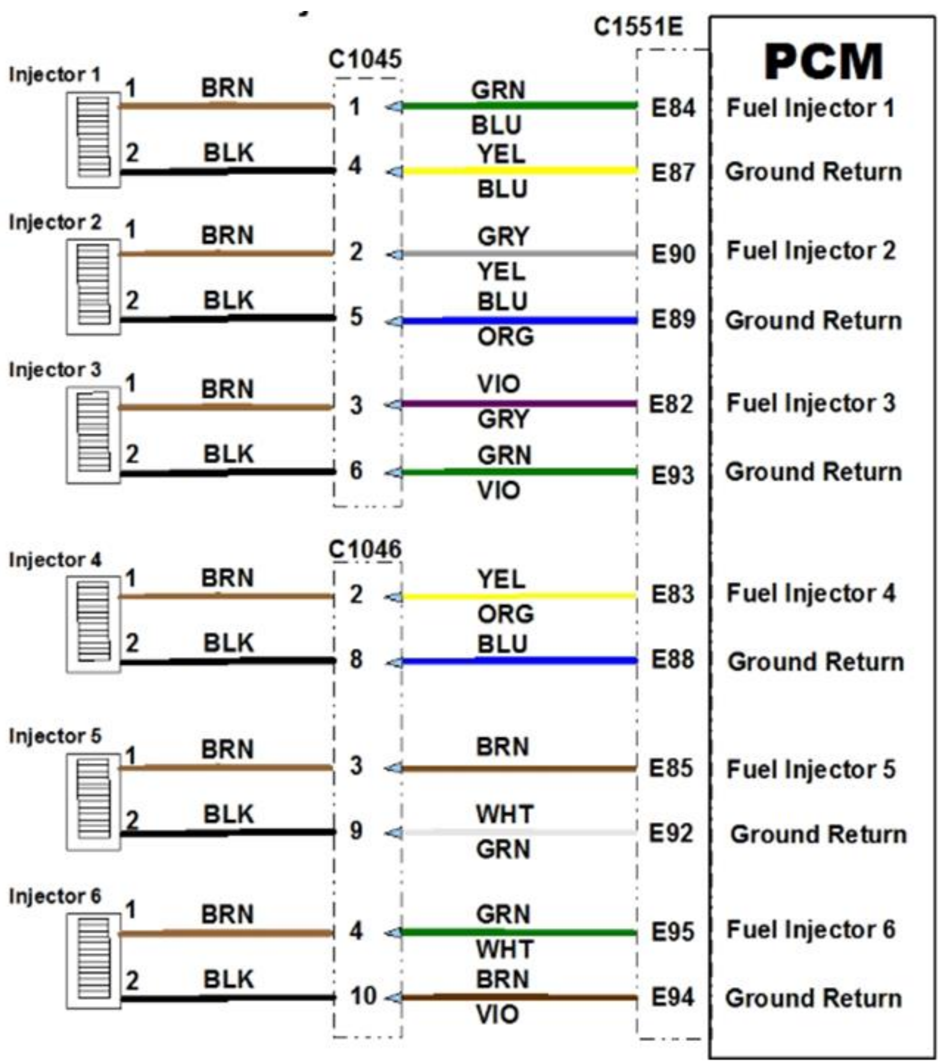
- Low side driver control
- High side driver control

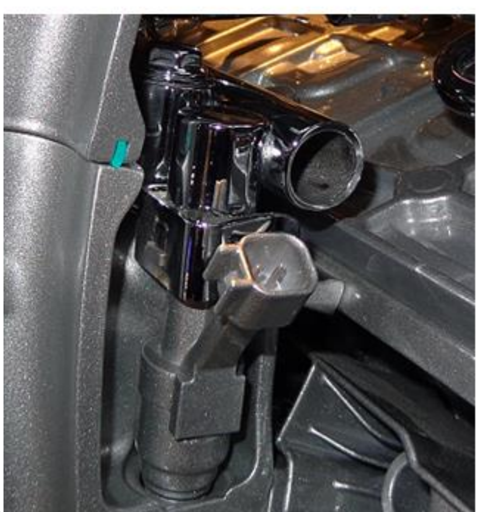
Both high and low side driver controls are used by most manufacturers.



Smart-Spec Diagram for Piezo Injectors

The PCM supplies 65 volts (this example) to each injector and has drivers for both the high side (b+) and low side (ground).





GDI Electrical Operation

GDI injectors use a peak and hold electrical circuit like the older throttle body injectors did. Each injector's resistance ranges between 2.6Ω and 6.37Ω. The ECM uses a higher current to open the injector quickly. The current is reduced to hold the injector open, to protect the injector coil. Some systems have a second lower current stage for holding the injector open.
The ECM steps the voltage from 12 V to 65 V which charges a capacitor.
The capacitor supplies up to 65 V to open the injector.
The ECM then provides a pulse width modulated 12 V to hold the injector open for the programmed on time.

3-Modes of GDI

Based on the engine speed and load, GDI operation can be classified in three basic modes:

- **Ultra lean burn or stratified charge mode** is used for light-load running conditions, at constant or reducing road speeds, where no acceleration is required. The fuel is not injected at the intake stroke but rather at the latter stages of the compression stroke. The combustion takes place in a cavity on the piston's surface which has a shaped dome. The shaped dome creates a swirl effect so that the lean air-fuel mixture is optimally placed near the spark plug. This stratified charge is surrounded mostly by air and residual gases, which keeps the fuel and the flame away from the cylinder walls. This technique enables the use of ultra-lean mixtures that would be impossible with conventional fuel injection.
- **Stoichiometric mode** is used for moderate load conditions. Fuel is injected during the intake stroke, creating a homogeneous fuel-air mixture in the cylinder. From the stoichiometric ratio, an optimum burn results in a clean exhaust emission.
- **Full power mode** is used for rapid acceleration and heavy loads (as when climbing a hill). The air-fuel mixture is homogeneous and the ratio is slightly richer than stoichiometric, which helps prevent detonation (pinging). The fuel is injected during the intake stroke.

Homogeneous Stoichiometric Mode

Fuel is injected early in the intake stroke to allow adequate time before ignition for fuel evaporation, mixing and formation of homogeneous mixture. At high loads, early fuel injection timing is used to operate the engine in stoichiometric homogeneous mode. The point at which the fuel is injected determines the mixture. The earlier the injection the closer the mixture will be to stoichiometric. Later start of injection results in a leaner mixture.

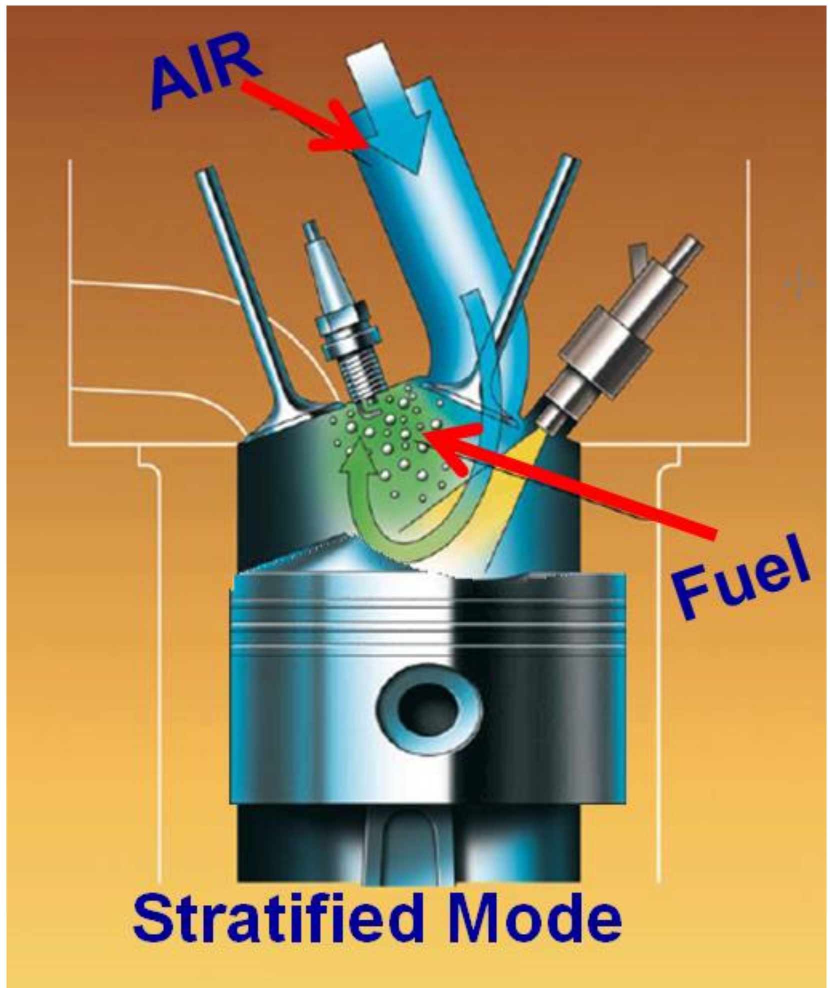
Homogeneous Lean Mode

Homogeneous lean mode is used for light loads (up to 25:1 A/F ratio).
Injection takes place early in the intake cycle but later than in the homogeneous stoichiometric mode.
The Air/Fuel ratio is maintained leaner than stoichiometric
In this mode the CO_2 emissions are reduced and fuel economy is improved.

Stratified Mode

Injection takes place at the end of the compression stroke. Because of the swirl effect that the piston cavity creates, the fuel sprayed by the injector is confined near the spark plug. There is very high pressure in the cylinder at this moment; the injector spray is also concentrated.

The fuel spray is directed by air motion or by the geometry of piston crown or by combination of the both towards spark plug. By the time fuel spray reaches the spark plug electrodes some fuel gets vaporized and forms combustible mixture with air. The vaporized fuel is then ignited by spark, combustion begins and the flame spreads in the combustion chamber. The “directivity” of the spray encourages even greater concentration of the mixture. A very small quantity of fuel is very rich in the zone close to the spark plug, whereas the remainder of the cylinder contains only very lean mixture.



The stratification of air in the cylinder means that even with partial charge it is also possible to obtain a core of mixture surrounded by layers of air and residual gases which limit the transfer of heat to the cylinder walls. This drop in temperature causes the quantity of air in the cylinder to increase by reducing its dilation, delivering the engine additional power. When idling, this process makes it possible to reduce consumption by almost 40% compared to a traditional engine. And this is not the only gain. Functioning with stratified charge also makes it possible to lower the temperature at which the fuel is sprayed. All this leads to a reduction in fuel consumption which is of course reflected by a reduction of engine exhaust emissions. When engine power is required, injection takes place in normal mode. This makes it possible to achieve a homogeneous mixture.

Stratification mode allows the engine to operate part throttle at light load with a very lean air/fuel mixture. This significantly reduces fuel consumption and CO_2 emissions are lower.

Charge stratification allows a more stable combustion with reduction of knock tendency and a faster start of combustion.

Homogeneous Ultra-Lean Mode

Lean Mixture (Ultra Lean Burn combustion cycle) (up to 25:1 A/F Ratio)

Injection takes place early in the intake cycle but later than in the homogeneous stoichiometric mode.

Wide Open Throttle

The fuel system shifts to rich fuel mixture for heavy acceleration with early start of injection and high injection pressure.

Gasoline direct injection Operational Details

A direct injection system precisely delivers a fine mist of fuel directly into each cylinder for optimal performance, economy and emissions.
Unlike port-fuel-injection (PFI) engines that spray fuel in the intake system, the direct injection system puts the

fuel exactly where it needs to be for combustion.
Fuel is sprayed into the cylinders at pressures as high as 2,175 psi, but usually lower.
Fuel Stratified Injection (FSI)

Fuel is injected into the cylinder just before ignition.
This allows for higher compression ratios without "knock."

The piston dome and injection timing can change the concentrations inside the cylinder.

Testing the GDI injector

Traditional testing of direct injection is difficult to test the GDI injector because of its location.
The pressure is changing with operating conditions.
Injection voltage is peak and hold with different voltage levels to open and holding the injector open.
Injection current is changing with the peak and hold action, lab scope and scan data are the best way to check injector function.

Scan Data Testing for GDI

Enhanced diagnostics approach is to gather as much information as possible before going into more difficult testing.

Try to identify the cause of the problem if possible.
Is the problem a fuel flow problem or an electrical problem?

Start by checking diagnostic trouble codes.

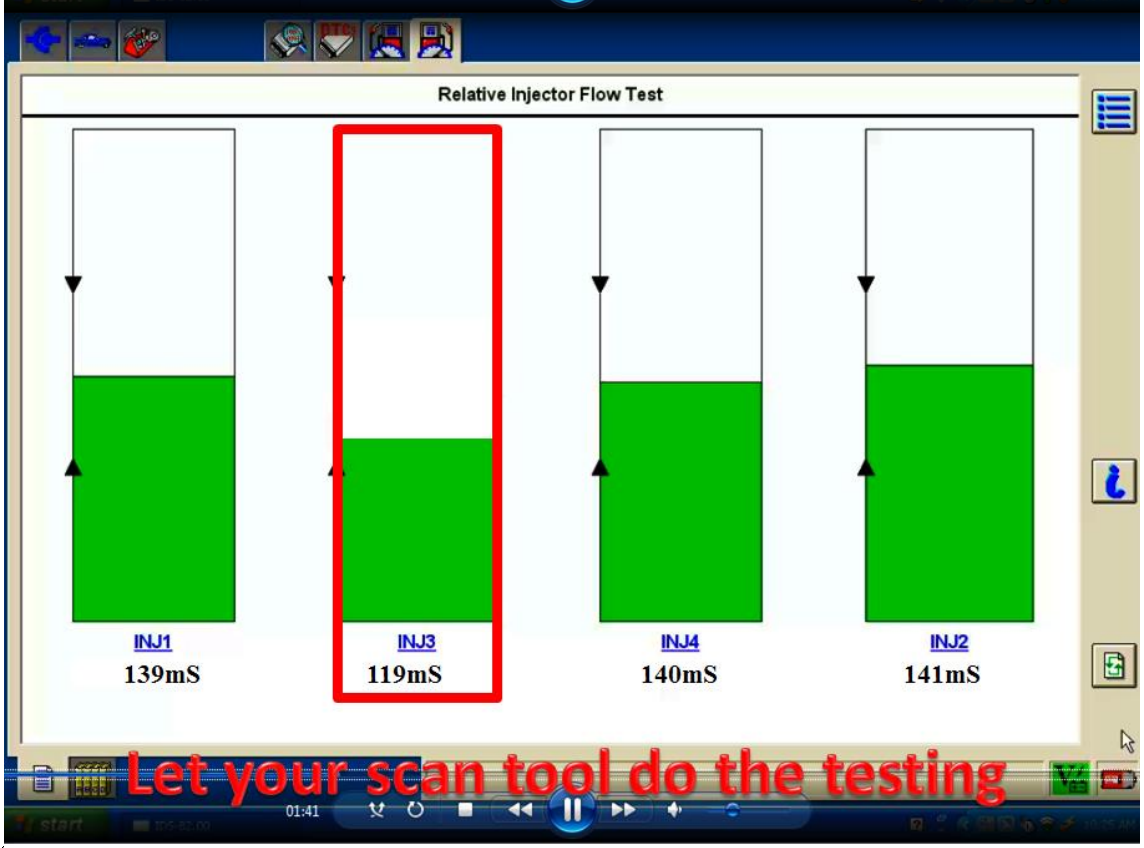
P0261	Cylinder 1 Injector Circuit Low
P0262	Cylinder 1 Injector Circuit High
P0264	Cylinder 2 Injector Circuit Low
P0265	Cylinder 2 Injector Circuit High
P0267	Cylinder 3 Injector Circuit Low
P0268	Cylinder 3 Injector Circuit High
P0270	Cylinder 4 Injector Circuit Low
P0271	Cylinder 4 Injector Circuit High
P0273	Cylinder 5 Injector Circuit Low
P0274	Cylinder 5 Injector Circuit High
P0276	Cylinder 6 Injector Circuit Low
P0276	Cylinder 6 Injector Circuit High
P0279	Cylinder 7 Injector Circuit Low
P0280	Cylinder 7 Injector Circuit High
P0282	Cylinder 8 Injector Circuit Low
P0283	Cylinder 8 Injector Circuit High

Use Bi-directional controls

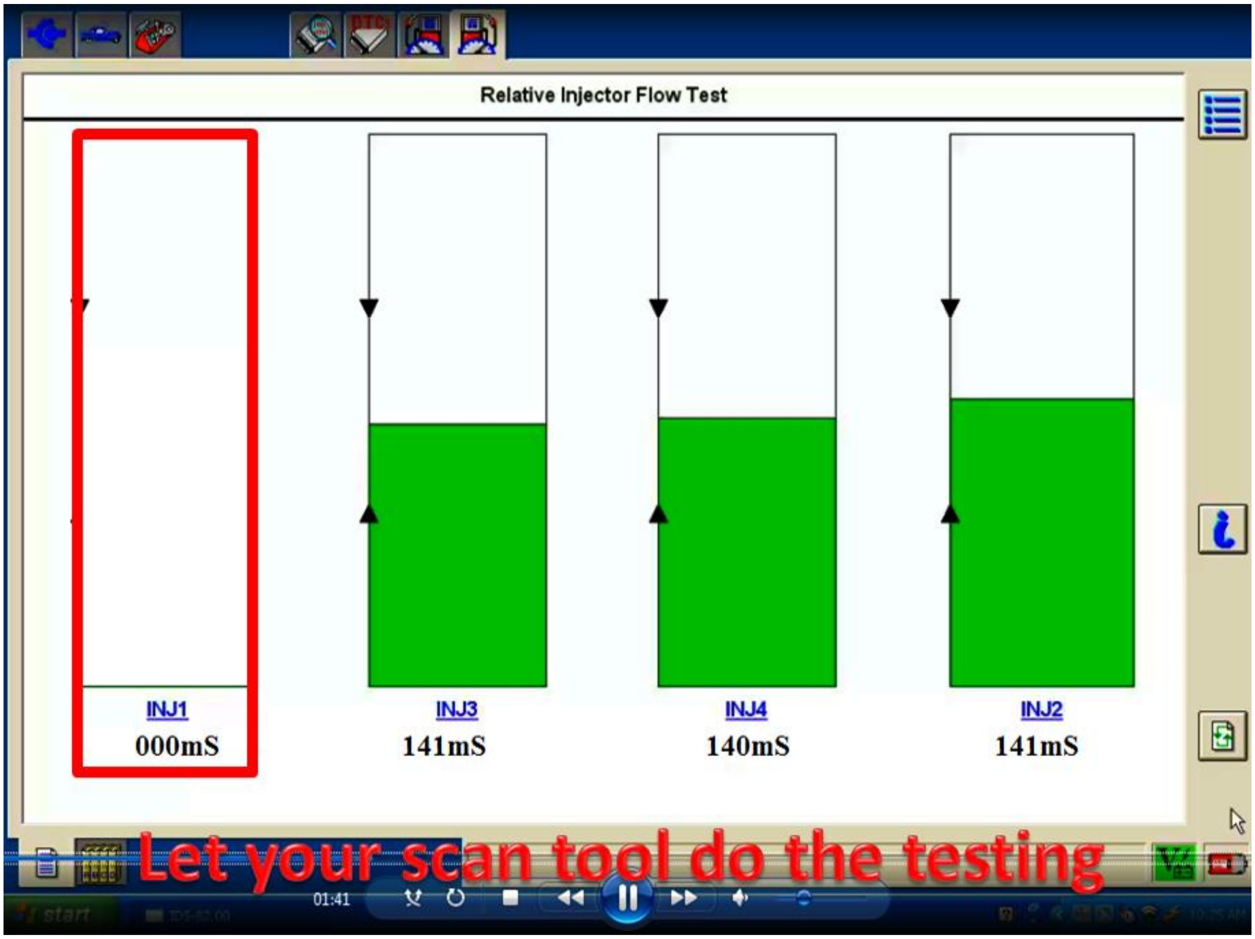
There are specific bi-directional tests that are provided by some manufacturers that can test individual injector operation.

GDI Relative Injector Flow Test

This test compares the relative FLOW FOR EACH INJECTOR UNDER CONTROLLED CONDITIONS.



This example shows good balance.



This example shows a problem with the injector on cylinder #3.

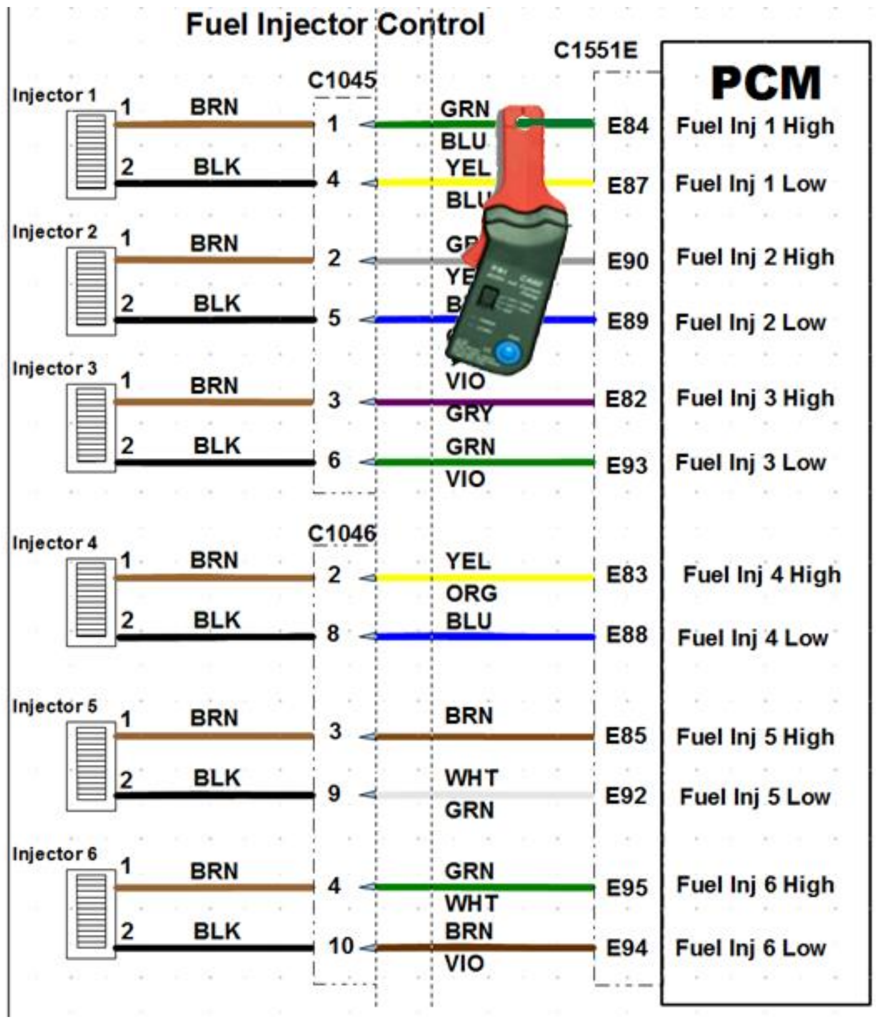
This example shows a major problem in injector for cylinder #1.
The PCM may not attempt this test if it has detected a short or open circuit. Check for trouble codes indicating a circuit problem.

The codes identify high side and low side injector problems. The injector with no results must be tested to see if current and voltage are normal. You need a diagram that shows the circuits and find a reasonable place to connect for the testing. The injectors are difficult to reach so we used the diagram to locate the connector going to each bank on the V-6 engine as a point that is more accessible. The other important aspect of this diagram is the wire color change at the connector.
This is one of our drawings from Smart-Spec our diagnostic program. We do our own drawings to make diagnostics easier when we work on vehicles. The drawing example is for a V-6 engine with GDI.

The wire color on the injector side is Brown while the wire on the PCM side is green-blue tracer. There is more room on the PCM side but more of these connections are easy, that is why we took the time to have a good diagnostic direction before going into detailed testing like this.

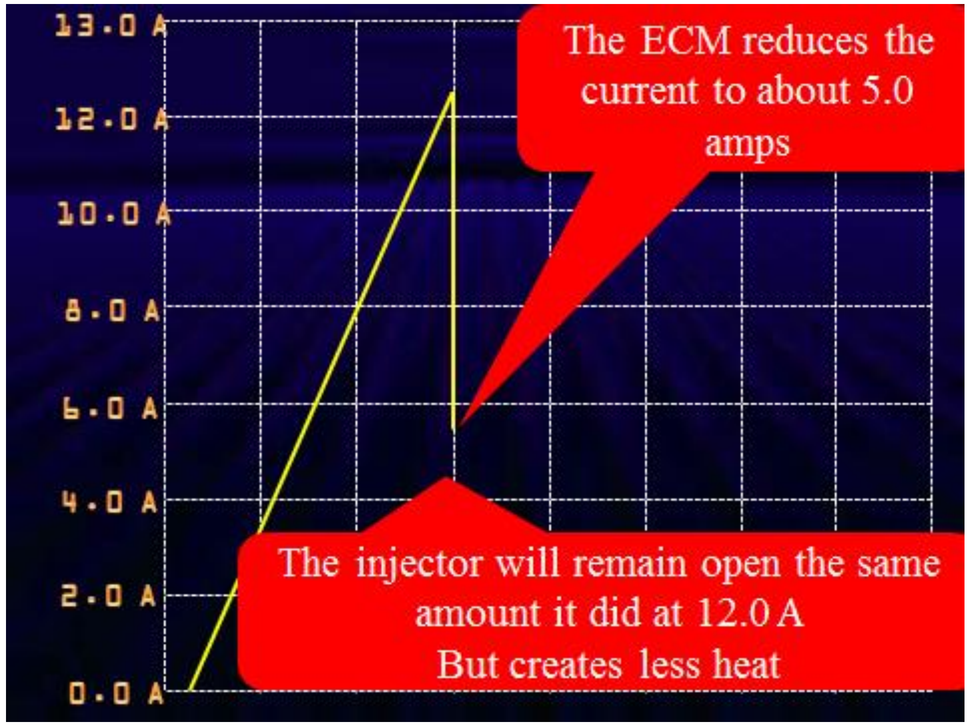
Use advanced testing to pin point the problem

We found a test location on the wiring harness that goes to the PCM

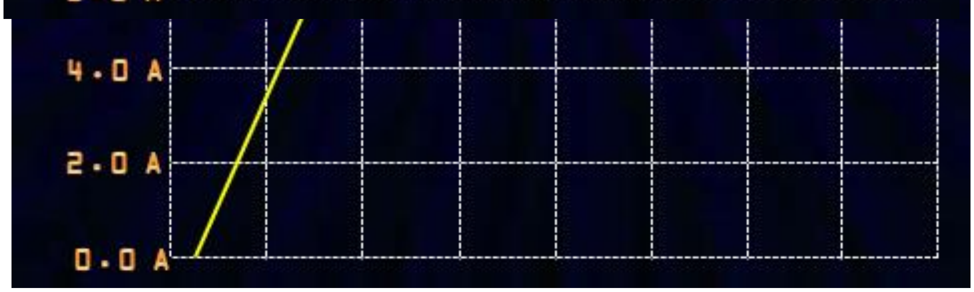


We will walk through the peak and hold current pattern.

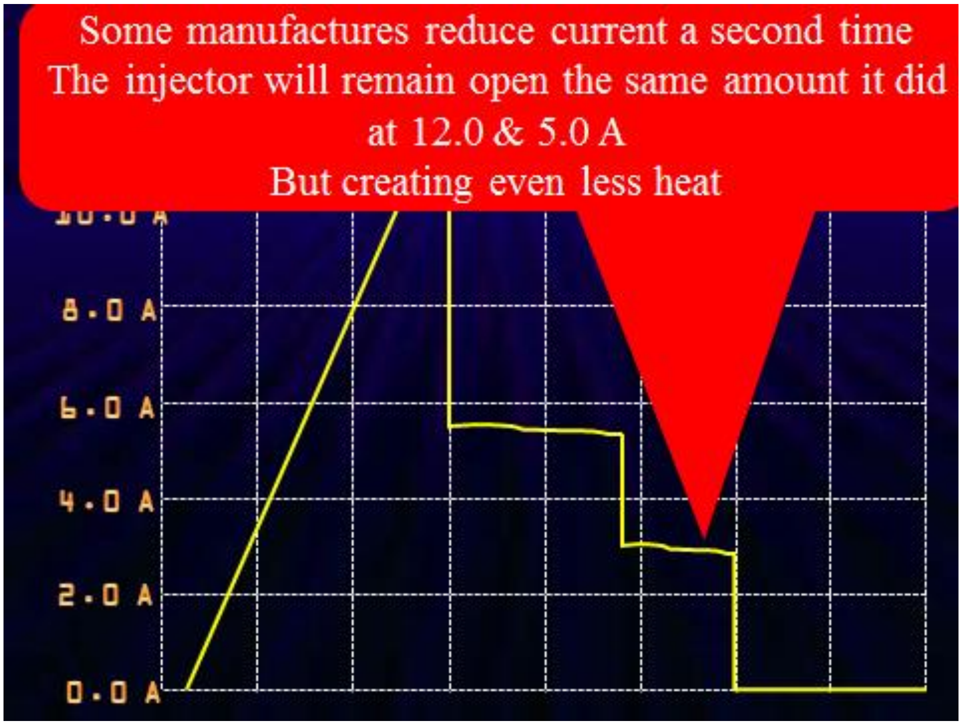
The peak current goes up about 12 amps in this example, used vehicle specific information for diagnostics.



The ECM drops the current down to about 5 amps to hold the injector open. This reduces heating in injector but provides the rapid opening of the injector.



This is the peak and hold action described earlier. The changes in current flow are a result in changes in injector voltage.



Some vehicle applications can have a second reduction in injector current. The reduction will still keep the injector open.

The final step is turn off current to allow the injector to close.

This is GDI voltage and current from a test vehicle.

The Injector Duty Cycle

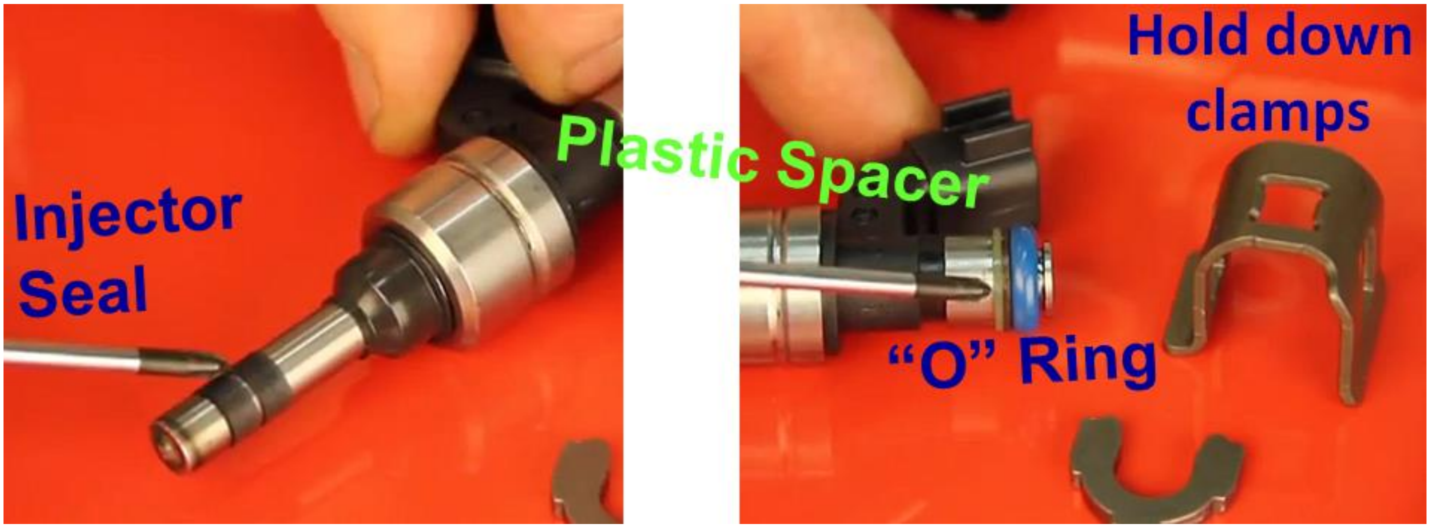
During sequential firing of GDI systems, the injector only opens to a maximum of 7 mS. as the fuel requirement increases, the injector remains at the same injection time while the high pressure pump increases to meet the demand, allowing the injector to open and close quickly and efficiently. No more "Duty Cycle" as we have known it. These engines use a very expensive high specification injector, Hitachi, Bosch, Denso and Siemens being the major suppliers.

- The injector duty cycle ranges for 5 msec to 7 msec.
- As the fuel requirement increases, fuel pressure increases not the duty cycle, the PCM controls fuel pressure and injector opening.
- The injector duty cycle doesn't change as much as a solenoid type injector.

Safety Notice

When working on the high pressure fuel system;

- Depressurize the low pressure system fuel system



and then the high pressure system.

- The low pressure fuel system has pressures close to the values used by PFI fuel injection systems.

Depressurize the fuel system or it will cause serious injury!!!

Use the Bi-directional function on a Scan Tool to command the fuel pump relay off, or remove the relay, then start and run engine until it dies from lack of fuel.

Bi-Directional Capabilities

There are different Bi-directional controls between the manufactures. Access the test mode 8 on the Scan Tool you're using and see what is available. The cylinder power balance test isn't just for testing the fuel system. If any cylinder fails it could be because of ignition, fuel, or a mechanical problem. The cylinder power balance test is a great place to start on any diagnostics when the engine isn't running normally or you feel a miss. The test doesn't point to a certain problem only a specific cylinder that isn't contributing an equal amount of power.

Removing/replacing Injectors

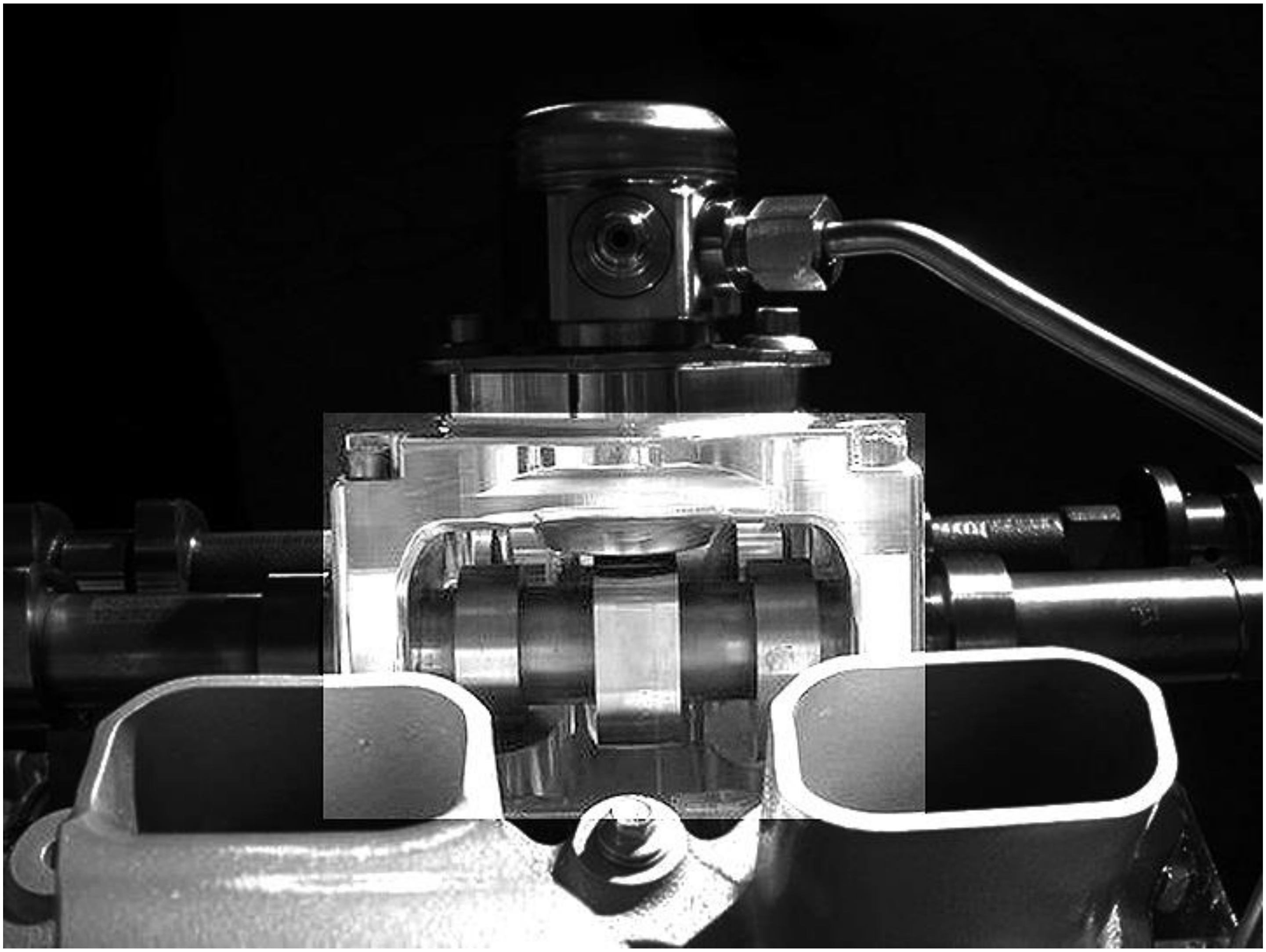
The injector must seal the combustion chamber and the fuel supply.

- Replace the injector hold down clamps
- Replace the "O" ring and plastic spacer
- Replace the injector seal

High pressure pump

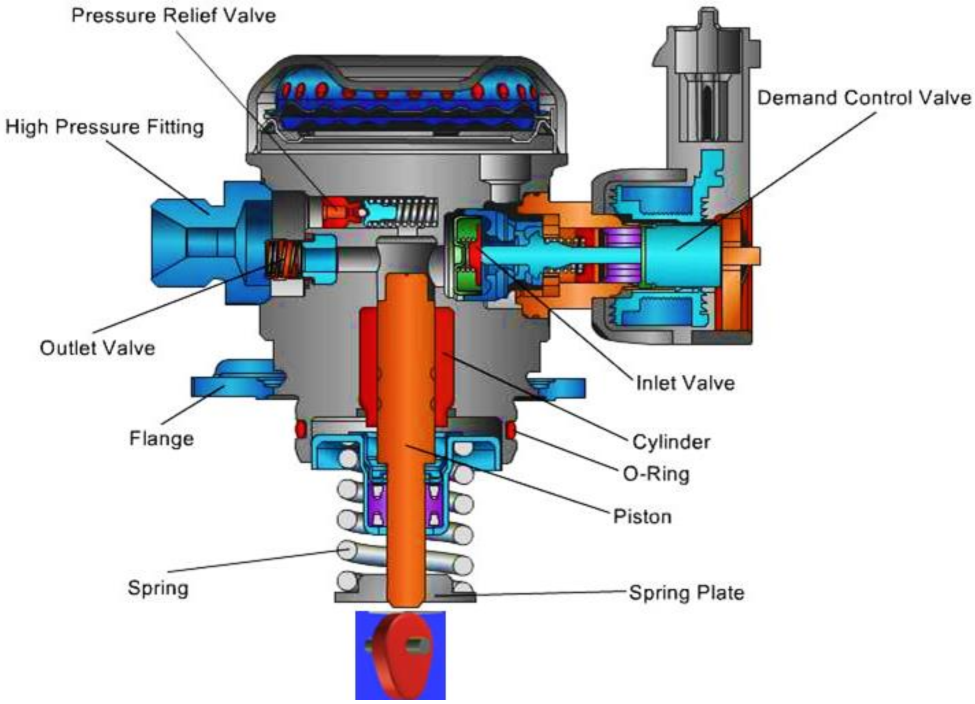
A compact, single piston pump;

- Uses a fuel inlet valve to control fuel pressure
- Has a pressure relief valve to limit the maximum pressure to manufactures specifications
- Driven off of the camshaft by a special lobe



This is a close up of the special cam lobe to drive the high pressure pump.
The pump can supply from 100 psi to 3000 psi;

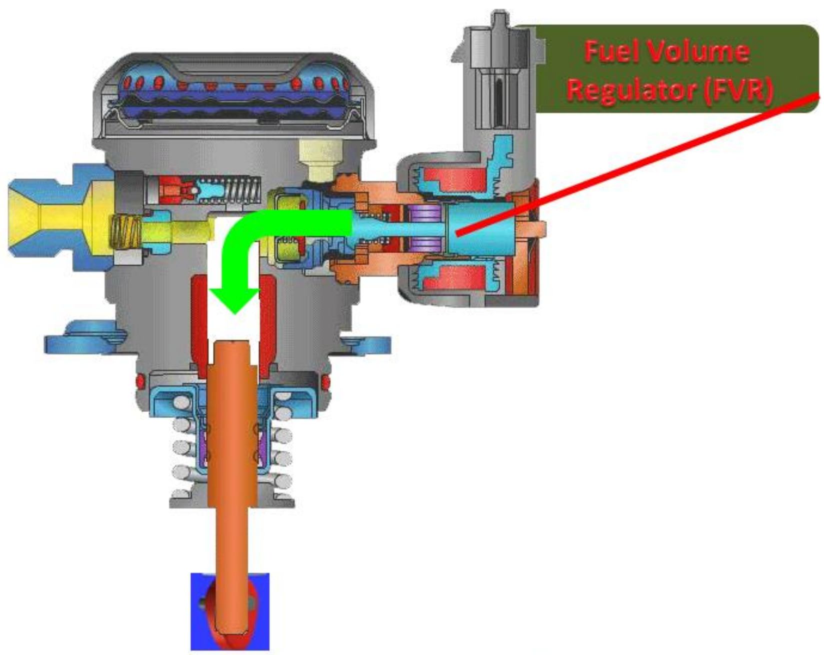
- The pressure is controlled by the ECM through the pressure relief solenoid and a fuel volume valve, also called a fuel demand valve.
- The ECM uses camshaft position and fuel rail pressure inputs to monitor pressure.



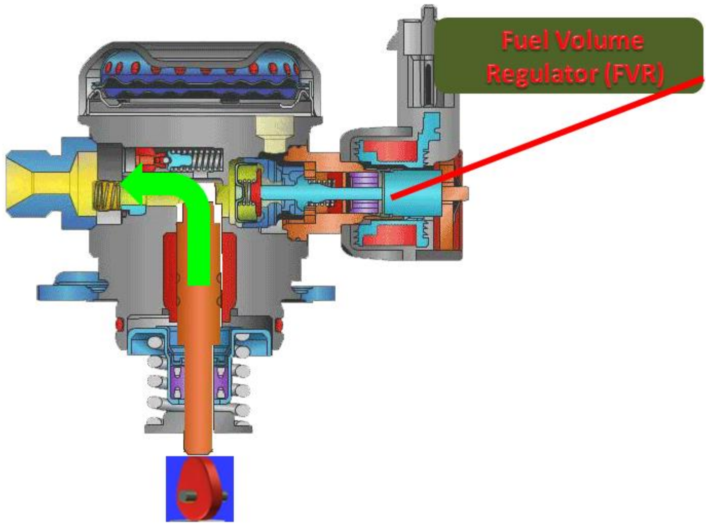
This is the internal parts of the high pressure fuel pump. We will be using scan data to monitor fuel pump control and fuel pressure.

The fuel volume regulator is de-energized to allow fuel to enter the pumping chamber. The ECM will use duty cycle control to regulate fuel rail pressure to match operating conditions. Fuel rail pressure is the primary way to control the amount of fuel delivered to the cylinder. The injector pulse width does not vary as much as the older solenoid type injectors.

If the pumping chamber is allowed to fill compleltly, each pump piston strokecan produce about 800 psi of fuel pressure.

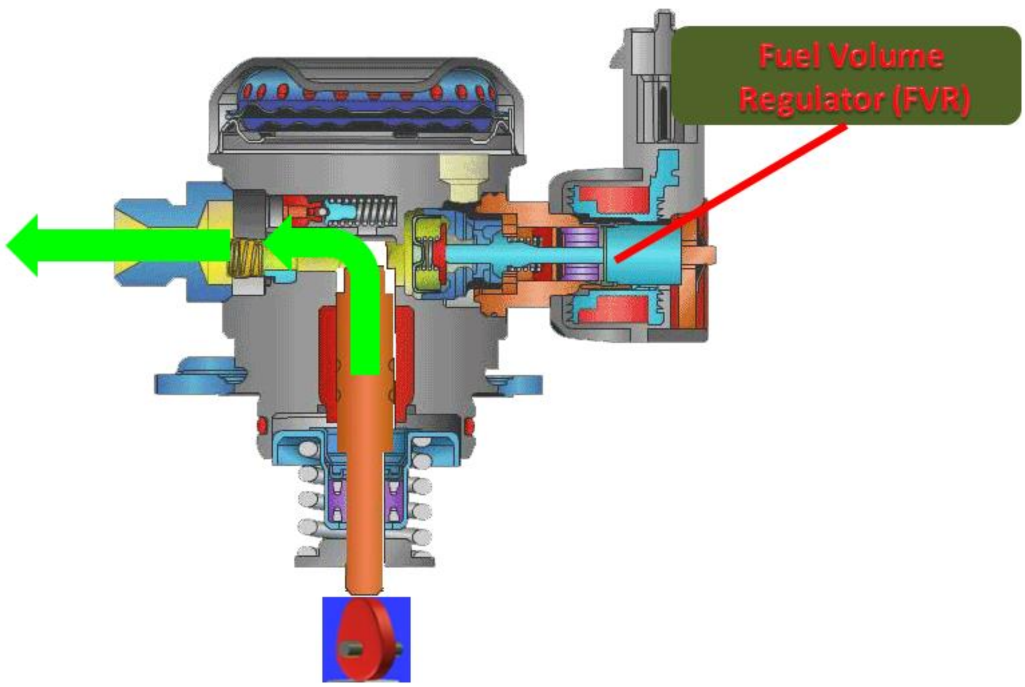


De-energized opens fuel inlet valve, fuel enters the pumping chamber
the piston is at the bottom of the eccentric



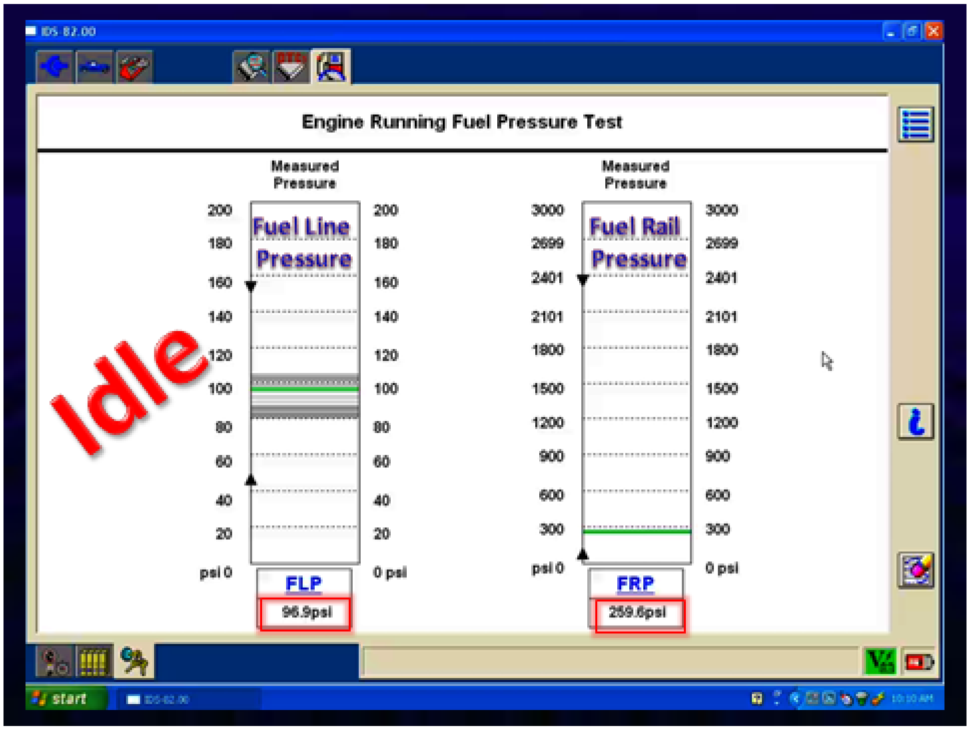
Remember, the ECM uses camshaft position as part of the control of fuel pressure. The ECU controls the opening and closing of the fuel volume regulator to match the cam position.

Energized to close the fuel inlet valve, fuel stops flowing
the piston travels up to the top of the eccentric



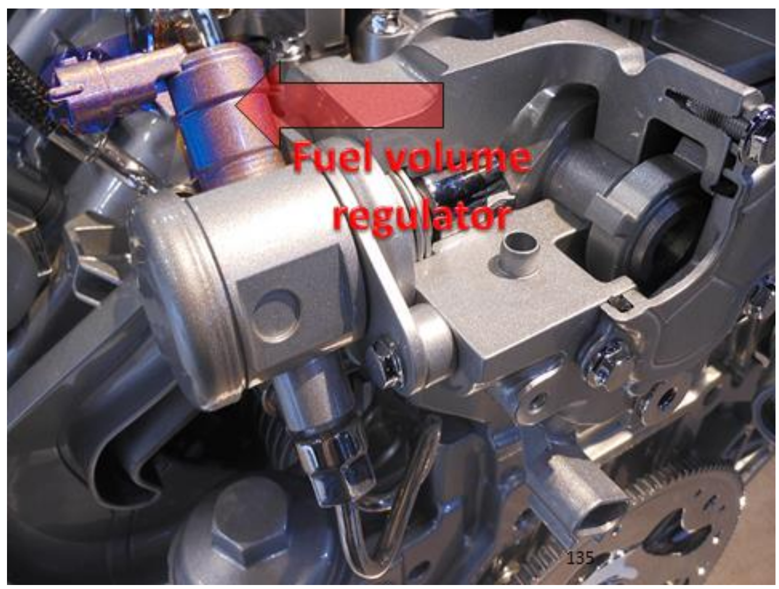
We will monitor FVR, fuel volume regulator, and fuel rail pressure with scan data.

Fuel Pressure is controlled by controlling the volume of fuel allowed to enter the pump by the Fuel Volume Regulator or Demand Control Valve



Some applications refer to the FVR as a Demand Control Valve, the operation is the same.

Fuel line pressure is fthe low pressure fuel delivery to the high pressure pump. The pump can not work without normal fuel line pressure.



This is the fuel volume regulator, shaded in light red, mounted to the high pressure pump.

High pressure pump control/relief solenoid

Electric solenoid operation differ
Different manufactures use different driver control
The PCM supplies both B+ and ground through high and low side drivers

- B+ is controlled by the high side driver
- Ground is controlled by the low side driver

Duty Cycle controlled Fuel Volume Regulator

- A low duty cycle opens the FVR to increase pressure/volume
- A high duty cycle closes the FVR to decrease pressure/volume

Special Note for low pressure pump!

The low pressure pump may run when the engine is off;

- The pump may run four or five times during a 6 hour period

- This is to maintain fuel rail pressure at a minimum level
- A no or low pressure signal from the fuel rail pressure sensor will cause a no spark condition
- Always check residual pressure during engine off if a no/slow start condition is present

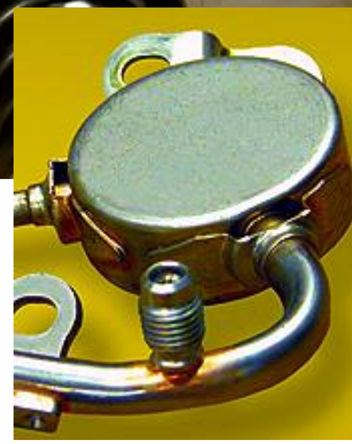
The pump requires good lubrication to prevent premature failure. We have an example of a vehicle with less than 100,000 miles that had a pump failure among other things. Poor maintenance is the enemy of these new systems that require good oil for proper operation.

The fuel pump cam lobe shows wear caused by poor lubrication.

When removing/replacing the high pressure fuel pump

Replace the pumps mounting bolts

- Replace the gasket
- Replace fuel pumps "O" ring
- Replace the fuel line, they should not be reused



When installing the high pressure fuel pump

Ensure the pump is timed correctly;

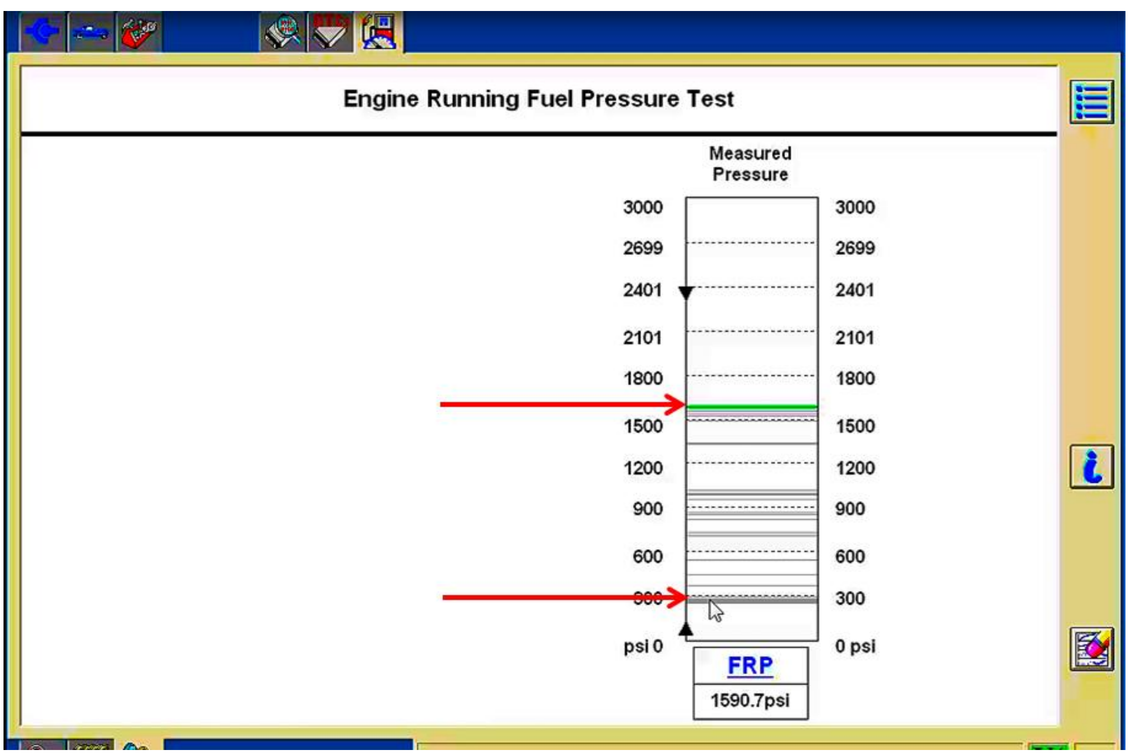
- Check the vehicles service manual, some vehicles have an arrow on the pump body for orientation
- Remember, the ECM uses cam position to control Fuel Volume Regulator operation

All cylinders are affected by fuel pressure problems, we will finish with imbalanced mixture and misfire because that will point out any cylinder specific problems, but first we need to check fuel pressure.

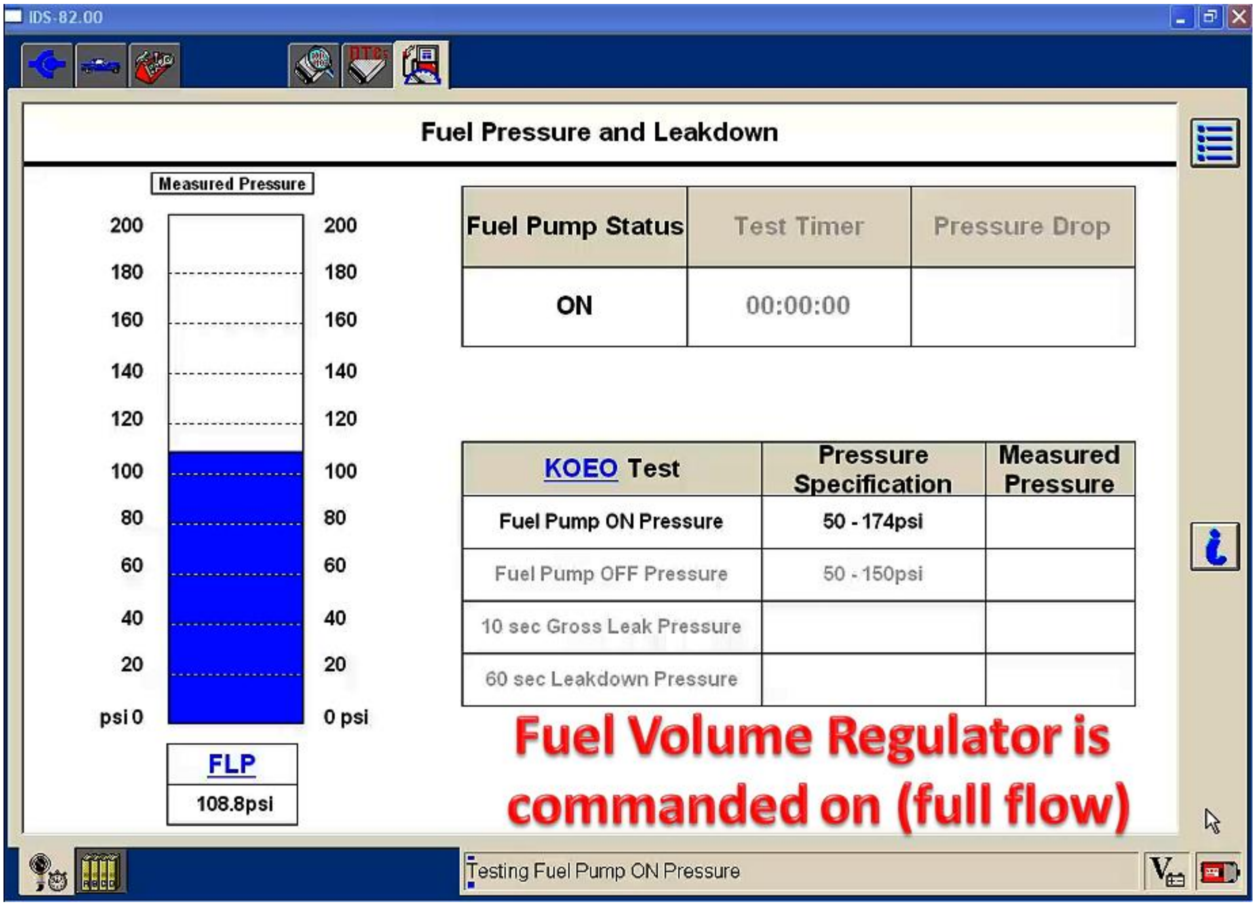
Fuel Pressure Testing

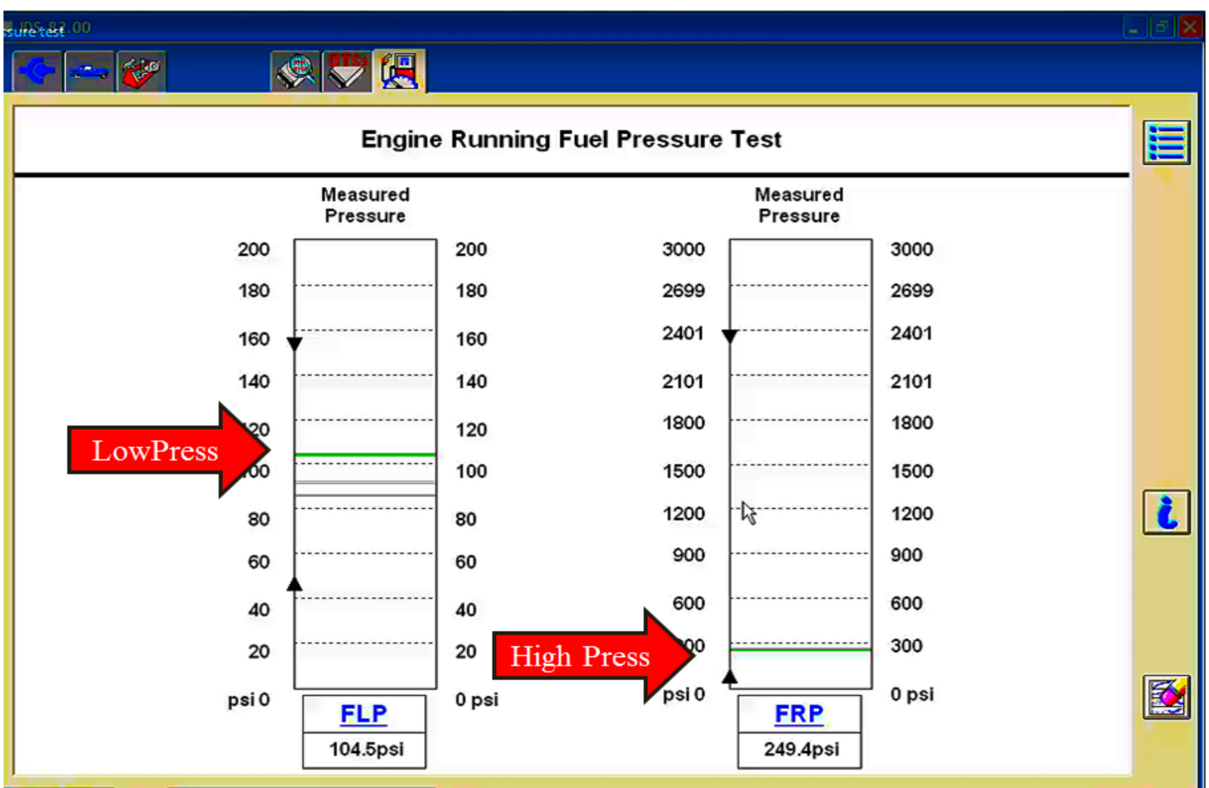
We want to avoid opening the high pressure fuel system.
If you have a 5000 psi gauge, there is a test port for measuring the pressure.
Ensure you disable and bleed off the high pressure fuel before attempting to work with the high pressure system.
Using a Scan-Tool is safer and easier.

Fuel Pressure Test in Scan Data

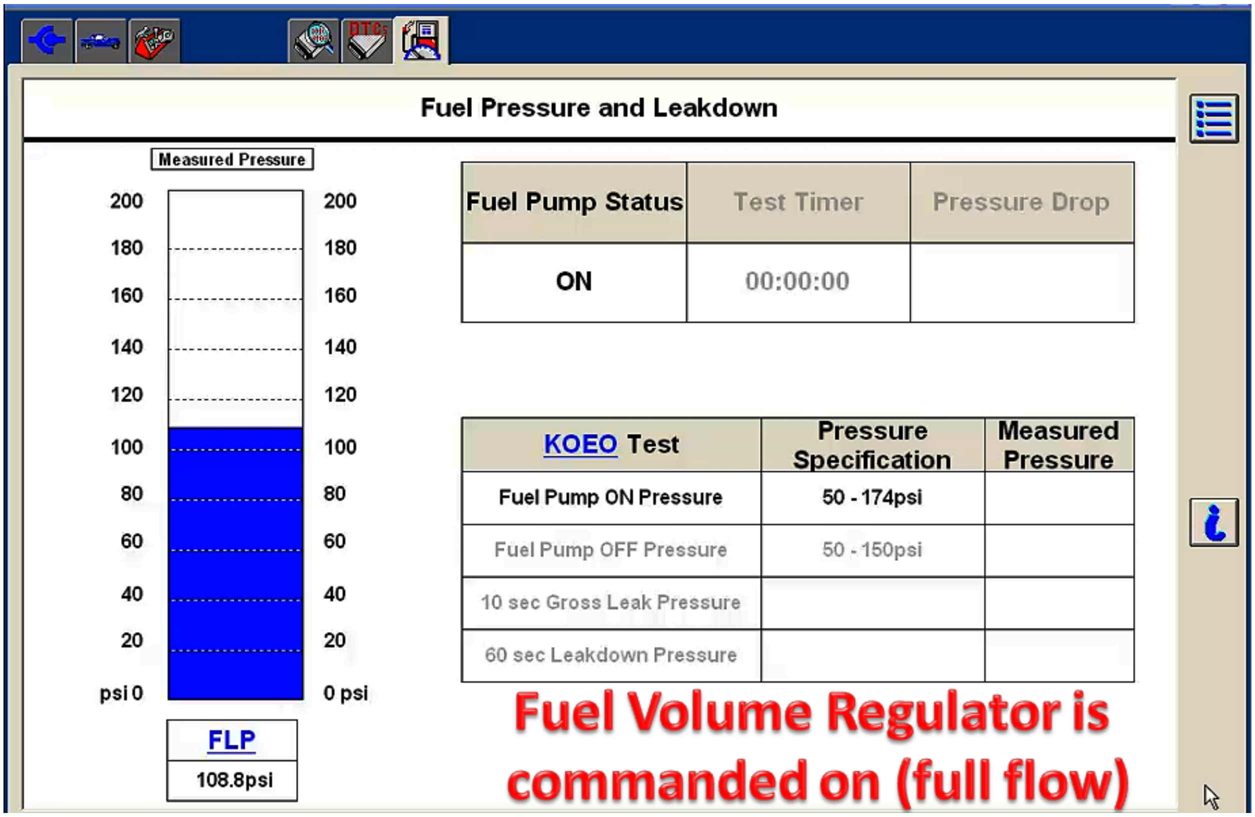


This screen is a dynamic screen the displays the fuel line pressure which is the low pressure supply to the high pressure pump and the fuel rail pressure which is the high pressure to the injections. The light grey bars are the history with the current reading in green. This history can be used to track high pressure pump during a test drive.





We could use this during a wide open throttle test to check to see if the system reached maximum fuel pressure during the WOT high engine speed test.



If we reach full pressure, it indicates the high pressure fuel pump is operating properly and the fuel volume regulator is operating with good fuel line pressure.

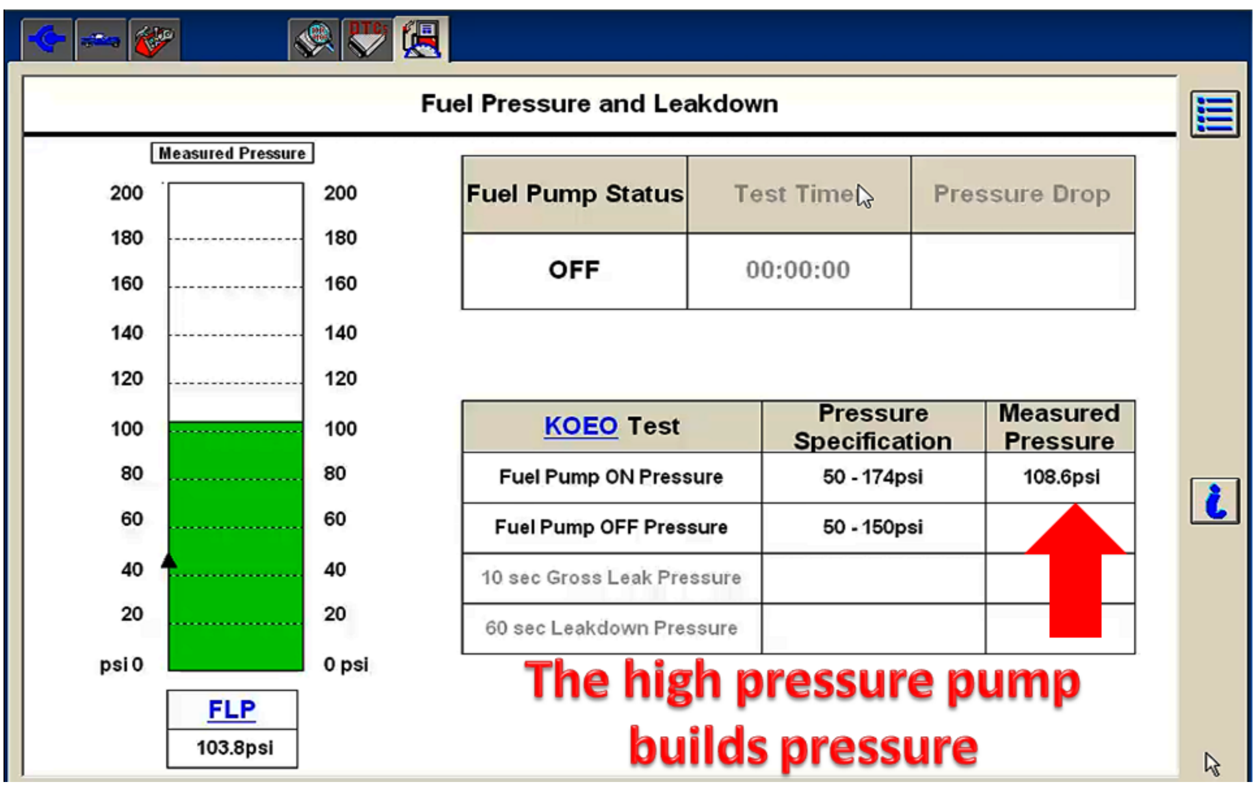
Fuel pressure leak down test

This test reports the leaking down of the high pressure fuel system when the ignition is off. The test automatically cranks the engine over for the test.

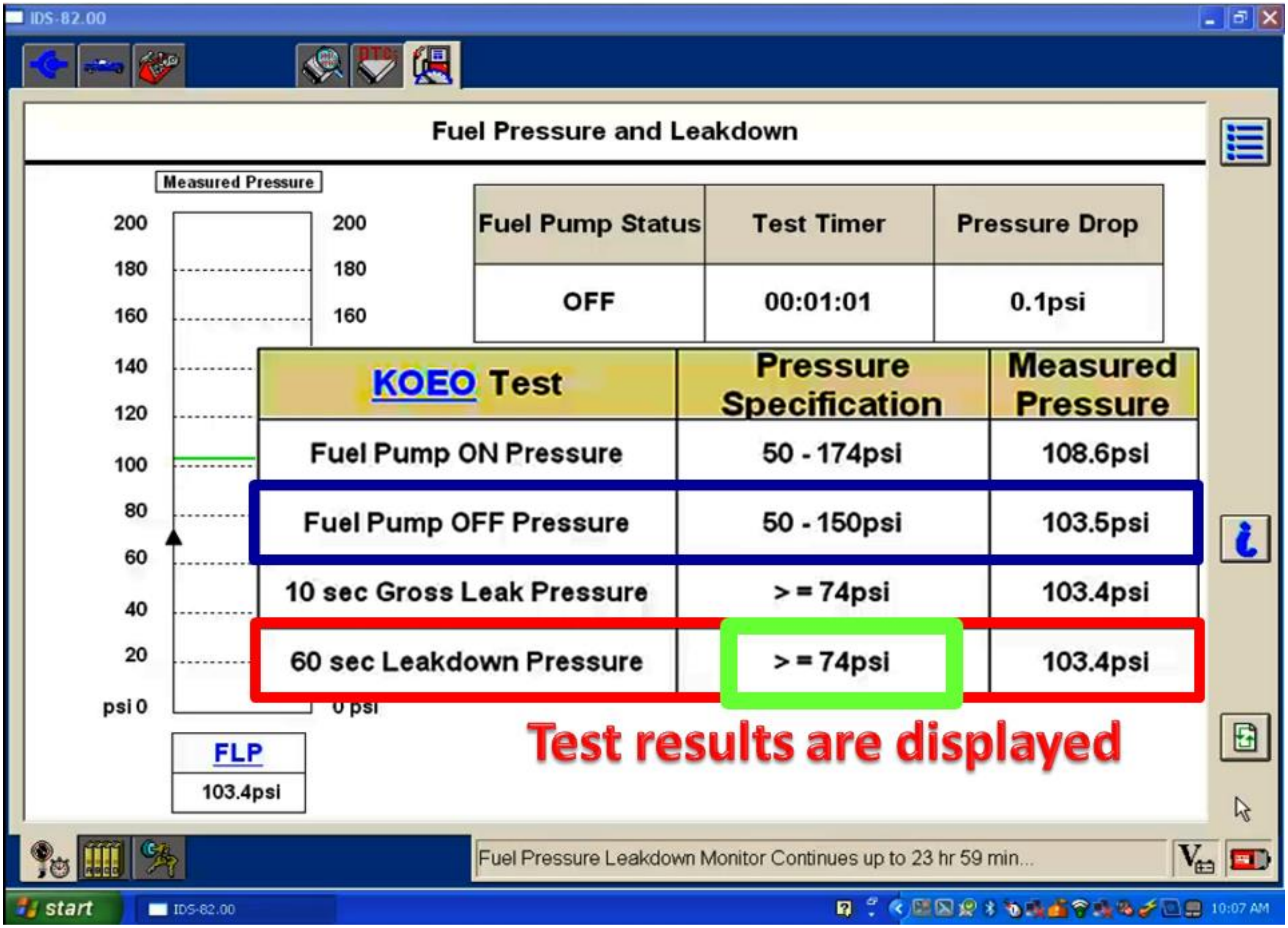
The test replaces, connecting a pressure gauge to the high pressure system and watching for bleed down.

This is a bi-directional test that gives us definitive answers to the leak down test.

The scan tool does the work



for you and gives you the results.



The fuel pump turns off after the test pressure is reached.

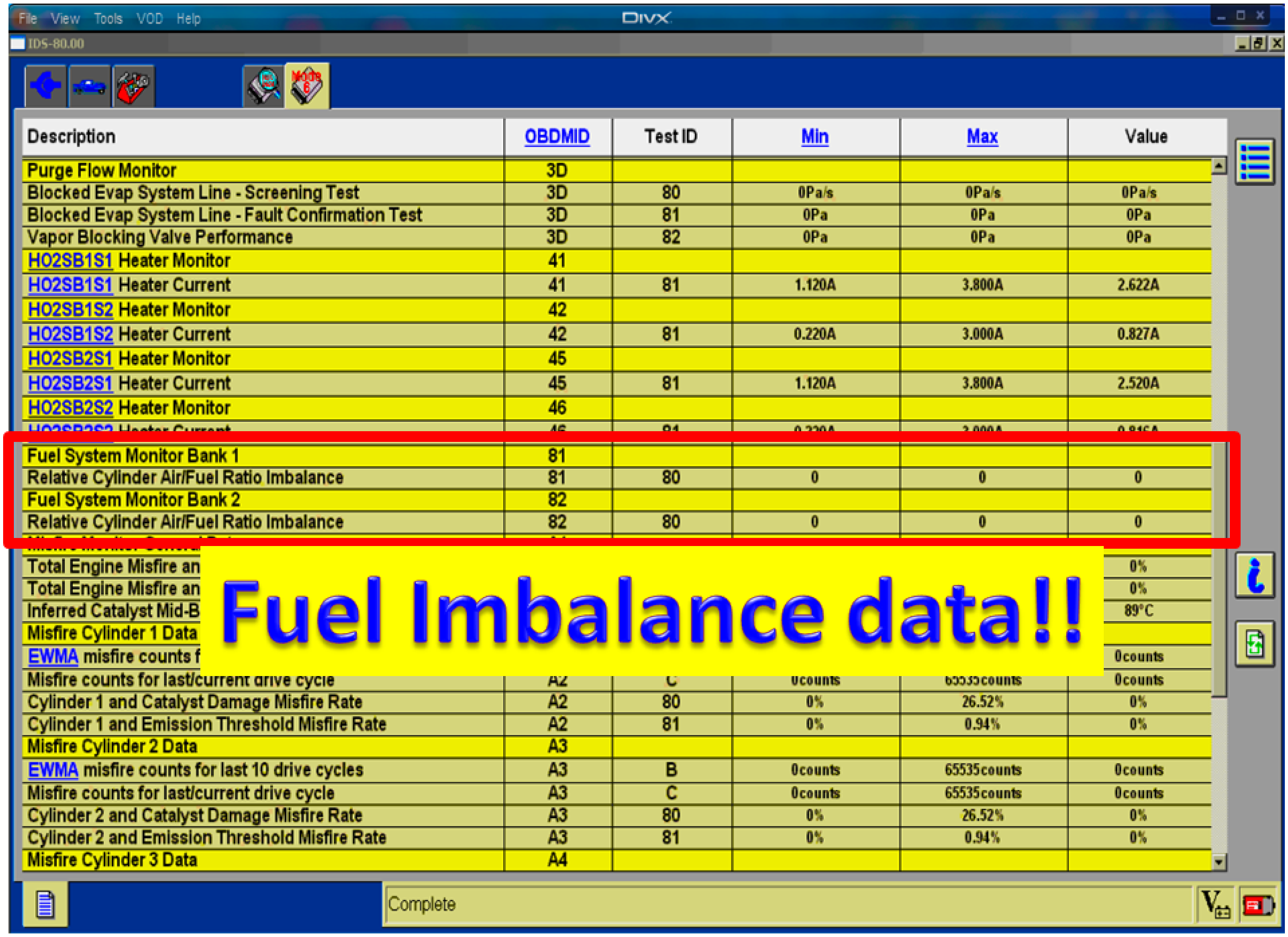
You have the test specification with the test results.

If you fail the low pressure test here, go check the lift or low pressure pump.

The final screen gives you the complete tests result with the minimum pressure shown for you to judge the results.

If Fuel leak Down Test Fails

You need to find the pressure leak.



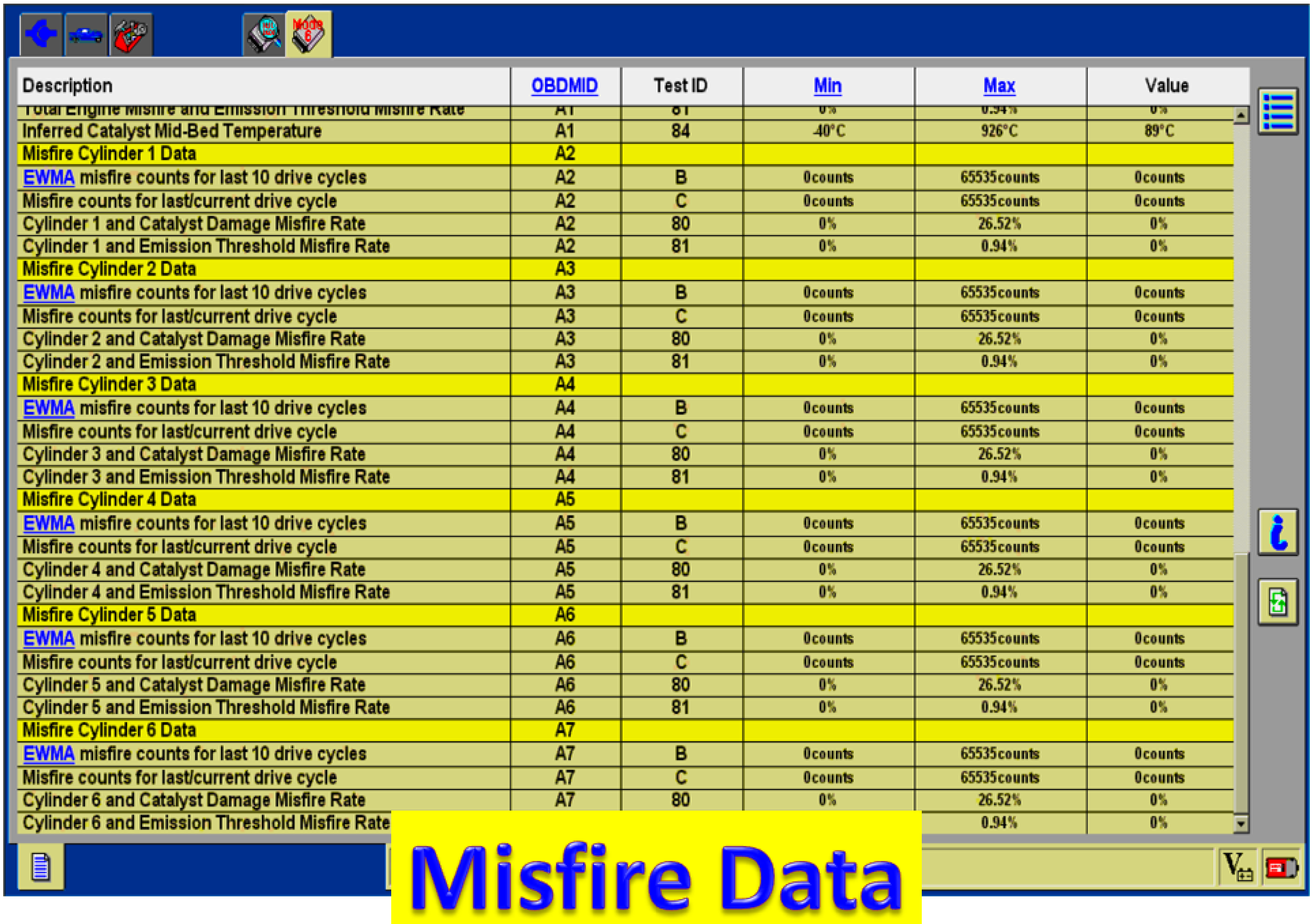
Description	OBDMID	Test ID	Min	Max	Value
Purge Flow Monitor	3D				
Blocked Evap System Line - Screening Test	3D	80	0Pa/s	0Pa/s	0Pa/s
Blocked Evap System Line - Fault Confirmation Test	3D	81	0Pa	0Pa	0Pa
Vapor Blocking Valve Performance	3D	82	0Pa	0Pa	0Pa
H02SB1S1 Heater Monitor	41				
H02SB1S1 Heater Current	41	81	1.120A	3.800A	2.622A
H02SB1S2 Heater Monitor	42				
H02SB1S2 Heater Current	42	81	0.220A	3.000A	0.827A
H02SB2S1 Heater Monitor	45				
H02SB2S1 Heater Current	45	81	1.120A	3.800A	2.520A
H02SB2S2 Heater Monitor	46				
Fuel System Monitor Bank 1	81				
Relative Cylinder Air/Fuel Ratio Imbalance	81	80	0	0	0
Fuel System Monitor Bank 2	82				
Relative Cylinder Air/Fuel Ratio Imbalance	82	80	0	0	0
Total Engine Misfire an					0%
Total Engine Misfire an					0%
Inferred Catalyst Mid-B					89°C
Misfire Cylinder 1 Data					
EWMA misfire counts f					0counts
Misfire counts for last/current drive cycle	A2	C	0counts	65535counts	0counts
Cylinder 1 and Catalyst Damage Misfire Rate	A2	80	0%	26.52%	0%
Cylinder 1 and Emission Threshold Misfire Rate	A2	81	0%	0.94%	0%
Misfire Cylinder 2 Data	A3				
EWMA misfire counts for last 10 drive cycles	A3	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A3	C	0counts	65535counts	0counts
Cylinder 2 and Catalyst Damage Misfire Rate	A3	80	0%	26.52%	0%
Cylinder 2 and Emission Threshold Misfire Rate	A3	81	0%	0.94%	0%
Misfire Cylinder 3 Data	A4				

GDI Summary

Fuel delivery scan data is mode 6 has information about imbalanced fuel delivery. The ECM has run a controlled test and identified fuel imbalance conditions.

The fuel imbalance is not cylinder specific like cylinder specific misfire data in mode 6.

Misfire in Mode 6



Description	OBDMID	Test ID	Min	Max	Value
Total Engine Misfire and Emission Threshold Misfire Rate	A1	81	0%	0.94%	0%
Inferred Catalyst Mid-Bed Temperature	A1	84	-40°C	926°C	89°C
Misfire Cylinder 1 Data	A2				
EWMA misfire counts for last 10 drive cycles	A2	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A2	C	0counts	65535counts	0counts
Cylinder 1 and Catalyst Damage Misfire Rate	A2	80	0%	26.52%	0%
Cylinder 1 and Emission Threshold Misfire Rate	A2	81	0%	0.94%	0%
Misfire Cylinder 2 Data	A3				
EWMA misfire counts for last 10 drive cycles	A3	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A3	C	0counts	65535counts	0counts
Cylinder 2 and Catalyst Damage Misfire Rate	A3	80	0%	26.52%	0%
Cylinder 2 and Emission Threshold Misfire Rate	A3	81	0%	0.94%	0%
Misfire Cylinder 3 Data	A4				
EWMA misfire counts for last 10 drive cycles	A4	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A4	C	0counts	65535counts	0counts
Cylinder 3 and Catalyst Damage Misfire Rate	A4	80	0%	26.52%	0%
Cylinder 3 and Emission Threshold Misfire Rate	A4	81	0%	0.94%	0%
Misfire Cylinder 4 Data	A5				
EWMA misfire counts for last 10 drive cycles	A5	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A5	C	0counts	65535counts	0counts
Cylinder 4 and Catalyst Damage Misfire Rate	A5	80	0%	26.52%	0%
Cylinder 4 and Emission Threshold Misfire Rate	A5	81	0%	0.94%	0%
Misfire Cylinder 5 Data	A6				
EWMA misfire counts for last 10 drive cycles	A6	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A6	C	0counts	65535counts	0counts
Cylinder 5 and Catalyst Damage Misfire Rate	A6	80	0%	26.52%	0%
Cylinder 5 and Emission Threshold Misfire Rate	A6	81	0%	0.94%	0%
Misfire Cylinder 6 Data	A7				
EWMA misfire counts for last 10 drive cycles	A7	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A7	C	0counts	65535counts	0counts
Cylinder 6 and Catalyst Damage Misfire Rate	A7	80	0%	26.52%	0%
Cylinder 6 and Emission Threshold Misfire Rate				0.94%	0%

Use the scan data like this to determine if a performance problem is caused by fuel delivery with imbalanced fuel data, the injector flow test covered earlier. We are showing these together for a reason. If the ECM detects a fuel delivery failure, it will not run the misfire test. A misfire test done with a fuel delivery problem would not be valid. If the ECM detects a misfire, it will not run the fuel delivery test.

Now we need to look at oxygen sensors that will used to monitor fuel delivery for fuel trim corrections. The latest generations of oxygen sensors are the universal or wide band oxygen sensors.

Universal Oxygen Sensors

Universal Oxygen Sensors have various names

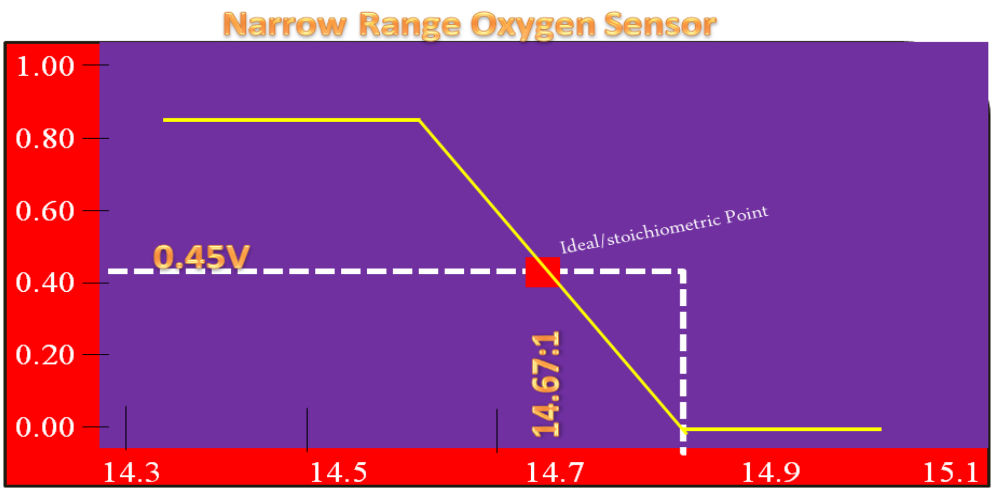
1. Wide-band oxygen sensors
2. Air fuel sensors
3. Wide-range oxygen sensors
4. Lean-air fuel sensors (LAF)
5. Broadband oxygen sensors
6. Wide-range oxygen sensors
7. Wide-range air-fuel sensors (WRAF)

Notice the use of the words like wide and broad in the different names. That is because these sensors can measure a wider range of air/fuel ratios then the narrow band sensor can. Oxygen sensors were not referred to narrow band sensors. They were called simply oxygen sensors. It wasn't until the Universal Oxygen Sensors came out in 1992 on a Honda that the use of the name narrow band came into use. Honda needed to measure air fuel ratios that were higher than 14.9:1, which is the limit for narrow band oxygen sensors. The word wide is also used because universal sensors can measure a wider air/fuel mixture than the narrow band sensors.

Major Advantages of Universal O_2 Sensors

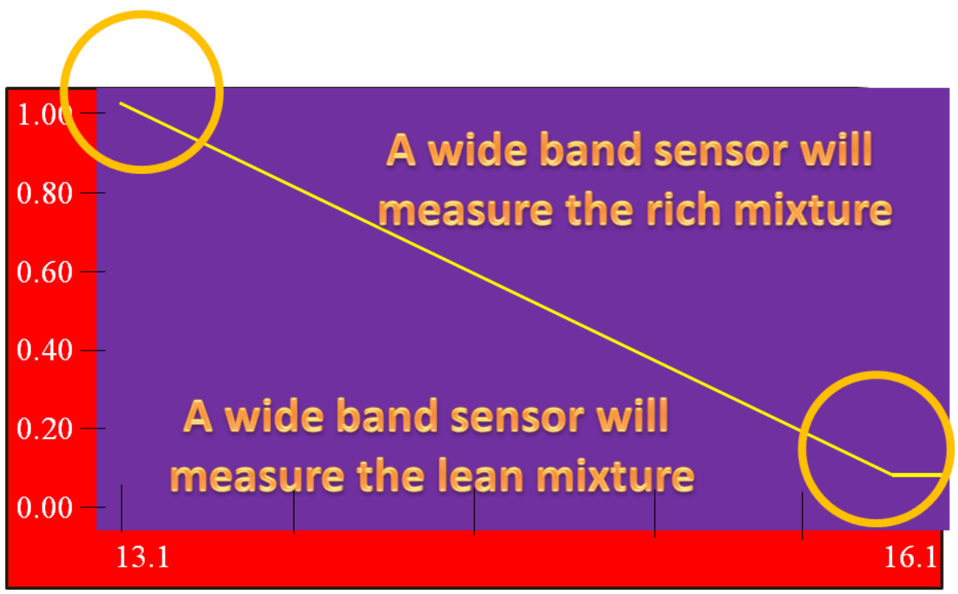
The major advantages of the Universal oxygen sensor are;

- They measure a wider range of Air Fuel mixtures than standard O_2 sensors
- The PCM has faster control of fuel delivery with fast warm up to get to closed loop operation.



Normal range for a narrow band oxygen sensor is 14.4 to 14.8 AFR.

Full power for wide open throttle acceleration needs an AFR of about 13.2 to 1. Fuel shut off on deceleration leans out to about 16:1 AFR.

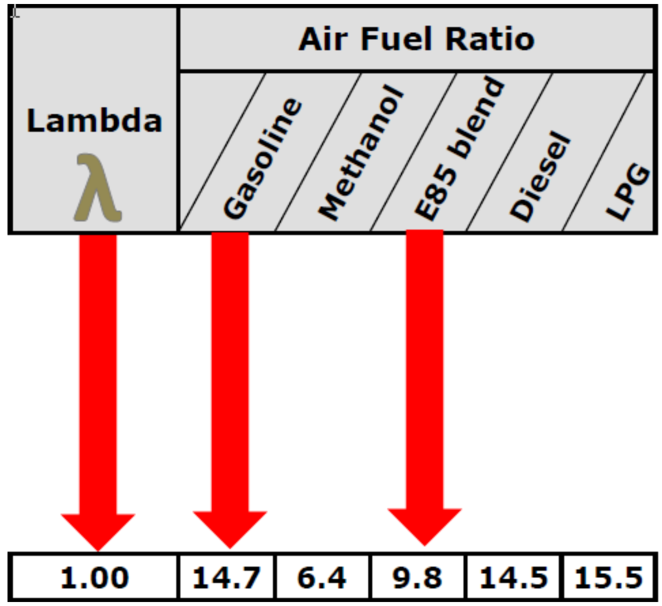


λ Lambda λ

Lambda is an engineering term used to describe an ideal Air Fuel Ratio with a perfect balance of fuel and air. A lambda air-to-fuel ratio is another way of expressing the value of the air and fuel mixture inside an engine's exhaust. Instead of a comparison of numbers, such as 12:0 to-1, the lambda value is more accurate, as stated in a decimal value, like 1.051.

Lambda represents a ratio of the amount of oxygen actually present in a combustion chamber compared to the amount that should have been present in order to obtain "perfect" combustion. Thus, when a mixture contains exactly the amount of oxygen required to burn the amount of fuel present, the ratio will be one to one and lambda will equal 1.00. If the mixture contains too much oxygen for the amount of fuel (a lean mixture), lambda will be greater than 1.00. If a mixture contains too little oxygen for the amount of fuel (a rich mixture), lambda will be less than 1.00. Stoichiometric ratio: λ 1.00 (no excess fuel and no excess air) for gasoline

- Lambda > (greater) 1.00 Lean: more air than fuel
- Lambda < (less than) 1.00 Rich: more fuel than air



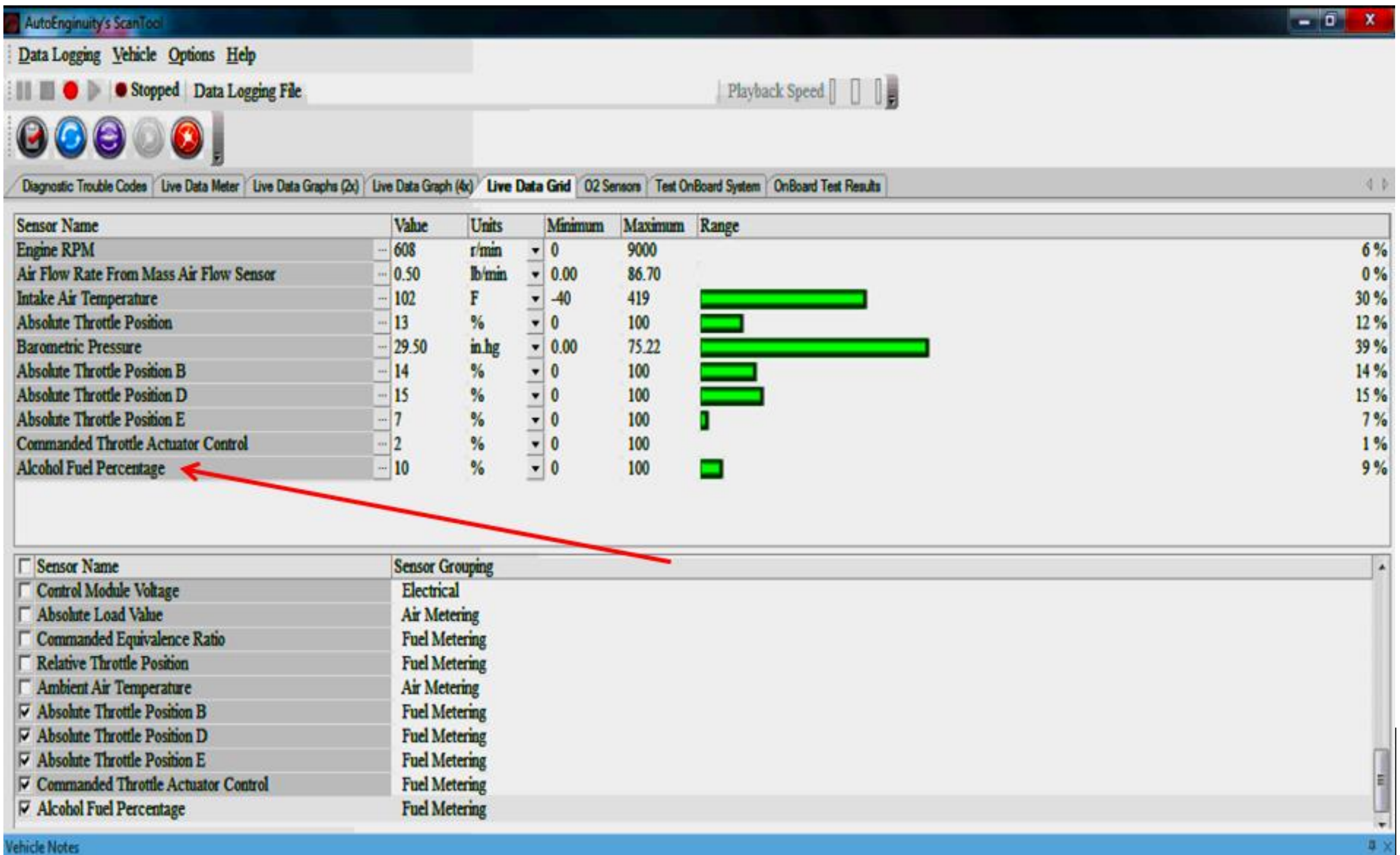
Stoichiometric Point

Each Fuel Has an Ideal AFR the variation is because each fuel requires more or less oxygen to reach the "ideal" or Stoichiometric point. Oxygenated fuels like Ethanol have oxygen present in the fuel and need less air in the fuel mixture to reach the Stoichiometric point.

Lambda λ	Air Fuel Ratio				
	Gasoline	Methanol	E85 blend	Diesel	LPG
0.70	10.3	4.5	6.8	10.2	10.9
0.75	11.0	4.8	7.3	10.9	11.6
0.80	11.8	5.1	7.8	11.6	12.4
0.85	12.5	5.4	8.3	12.3	13.2
0.90	13.2	5.8	8.8	13.1	14.0
0.95	14.0	6.1	9.3	13.8	14.7
1.00	**14.7**	**6.4**	**9.8**	**14.5**	**15.5**

Air Fuel Ratio VS Lambda

This chart shows the relationship of lambda to AFR from rich to ideal by fuel type.



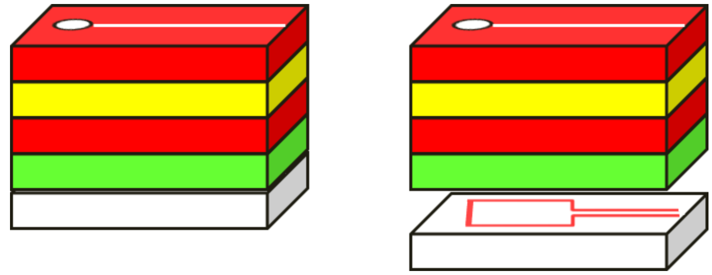
This chart shows the relationship of lambda to AFR from rich to ideal by fuel type.

λ	Gasol	Metha	E85 b	Diese	LPG
1.00	**14.7**	**6.4**	**9.8**	**14.5**	**15.5**
1.05	15.4	6.7	10.3	15.2	16.3
1.10	16.2	7.0	10.8	16.0	17.1
1.15	16.9	7.4	11.2	16.7	17.8
1.20	17.6	7.7	11.7	17.4	18.6
1.25	18.4	8.0	12.2	18.1	19.4
1.30	19.1	8.3	12.7	18.9	20.2
1.35	19.8	8.6	13.2	19.6	20.9
1.40	20.6	9.0	13.7	20.3	21.7
1.45	21.3	9.3	14.2	21.0	22.5
1.50	22.1	9.6	14.7	21.8	23.3
1.55	22.8	9.9	15.1	22.5	24.0
1.60	23.5	10.2	15.6	23.2	24.8

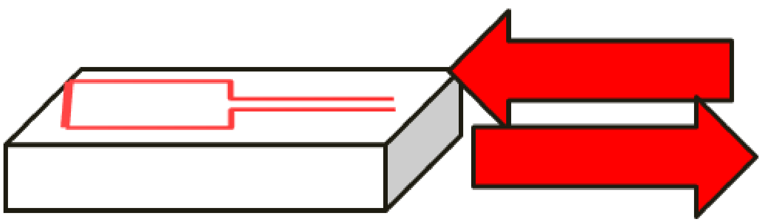
There is a new Scan Data PID that represents the amount of alcohol in the fuel. In this example the percentage is 10%. This is what is found at many fuel pumps. Gasoline has an ideal mixture of 14.7:1 while E-85 has an ideal mixture of 9.8:1. Looking at the Air/Fuel ratio PID it indicates those values when the mixture is correct. The Lambda PID would show a value 1.0.

- Air/Fuel ratio sensors utilize a more sophisticated sensing element that enables them to produce a precise output signal in proportion to the air/fuel ratio
- Wideband A/F sensors measures exhaust gas AFR accurately from as rich as 9.0:1 and as lean as 100% air.

Modern vehicles employ oxygen sensors to tell the vehicle's computer calculate the air/fuel mixture and determine the fuel type being used. The computer uses the information from the 0_2 sensor to determine if more or less fuel should be added to the mixture in order to maintain the correct proportion. Up until recently, all oxygen sensors were of a type known as narrow band sensors. These sensors are only able to tell us if the air/fuel ratio is above or below a single known amount or a single narrow range. It can tell us that the mix is either rich or lean, but it doesn't tell us how rich or how lean the mix is.



Wide band oxygen sensors are also called wide range oxygen sensors, air fuel ratio (AFR) sensors, or just A/F sensors. They are called "wide band" sensors due to the fact that unlike narrow band sensors, they are not only able to tell the computer if the air/fuel mix is rich or lean, but how rich or how lean it is. It is able to signal to the computer a wide range of air/fuel mix readings. This makes it much easier for the computer to make adjustments to the fuel trim to achieve its targeted air fuel ratio.



Wide band sensors use a voltage source to an oxygen pump that is controlled the current flow into and out of the pump. An air/fuel ratio of 14.7 to 1 (by weight), is considered to be the optimum air/fuel ratio. When the ratio is above this value, the current flows in one direction, and when it is below this value it flows in the other. When the air/fuel ratio is exactly 14.7 to 1, the current doesn't flow at all. In order to signal increasing rich or lean conditions, the current flow increases in ratio to how rich or lean the air/fuel ratio is.

Universal Oxygen Sensor Operation

Universal Oxygen Sensors are made up from with two oxygen sensors sandwiched together with a shared electrode between the cells.

The voltages on these current pump wires vary from manufacturer to manufacturer. One of the 2 current pump wires will have a voltage supplied to the sensor by the ECU. The other wire will be a return wire from the sensor to the ECU. Some have 3.0 volts on their reference wire and the 3.3 volts on the current return wire. Note that the 3.3 volts will vary slightly as the current flows, but these changes are very tiny. Others use 2.7 volts on their reference wire, and the current wire is approximately 3.0 volts. So far, in all of the 4-wire wide band sensors we've seen, the difference between the 2 current pump wires has been a nominal .300 (300 millivolts), that fluctuates slightly based on current flow.

The computer controls an electric current to an oxygen pump to release or absorb oxygen as determined by the fuel mixture measured by a reference cell.

> The optimum air/fuel ratio a **λ**=1, remember, this will be different ARF values as determined by the fuel used.
>
> When the ratio is rich, current flows in one direction (Positive).
>
> And when it is lean, it flows in the opposite direction.

When the air/fuel ratio is exactly 14.7 to 1 (gasoline), the current is zero.

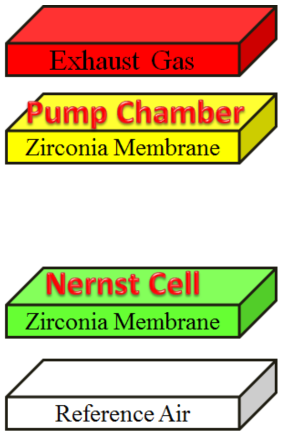
The amount of current flow indicated the correction needed to return the sensor back to **λ=1.**

The two wires are called the current pumping wires.

The voltage on these current pumping wires varies between manufacturers.

One of the 2 current pumping wires will have a voltage supplied to the sensor by the ECU.

The other wire will be a return wire from the sensor to the ECU.



Some 4 wire sensors have 3.0 volts on their reference wire and 3.3 volts on the current return wire
Understand that the 3.3 volts will vary slightly as the current flows, but these changes are very tiny
Others use 2.7 volts on their reference wire, and the current wire is approximately 3.0 volts
It is common to see a difference between the 2 current pumping wires of a nominal 300 millivolts that fluctuates slightly based on current flow
There are sensors that use another wire that gives a voltage representation of the current flow on the current pumping wires.
This is called the "signal wire".
There are even sensors that have another wire and it would be the ground reference for the signal wire.
On the signal circuit, there is circuitry to convert the current flow on the current pumping wires into a voltage.

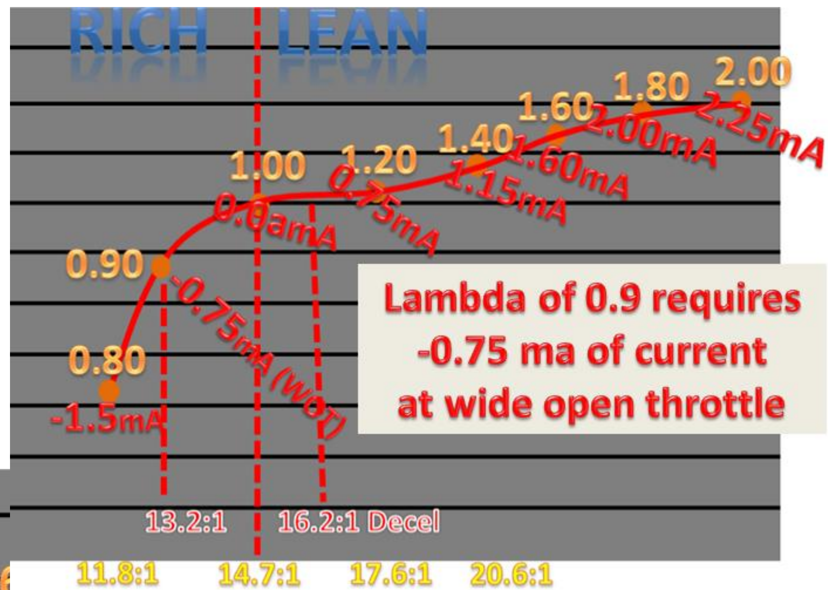
This is where good vehicle specific specifications and diagrams are necessary.

There are Two Oxygen sensors inside the Universal Oxygen Sensor

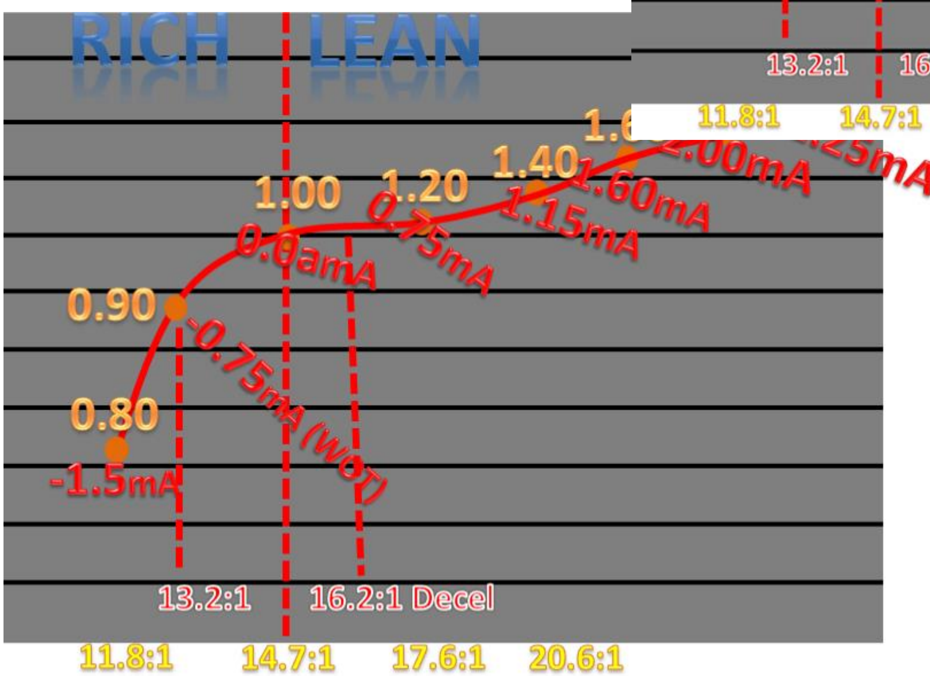
One sensor is a reference to ambient O_2, and the mixture captured in a sample cell that is fed by exhaust gas. The reference sensor signal indicates the oxygen concentration in the sample cell. The ECM uses the reference signal to calculate the current needed to bring the oxygen content of the gas in the sample cell back to "ideal".
The actual "ideal" is determined by the type fuel being used. The universal AFR sensor will find the Stoichiometric point for the any of the fuel type being used, these vehicles are Flex Fuel vehicles because the system adapts to the fuel type.

Lambda and pump current

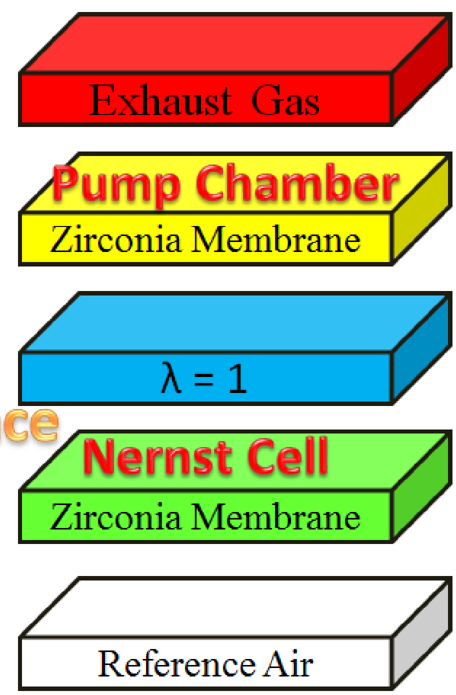
The ECM pumps current in or out to bring the sample chamber back to Stoichiometric by using the signal from the "Nernst cell.
This happens very quickly because the sample cell has is small in size and uses a small opening to the exhaust stream. So changes can be very fast.
Don't get confused here, the oxygen pump does not change the exhaust gas; it changes a small sample of the exhaust gas isolated in a small chamber.



The reference sensor voltage is about 0.45 volts with λ=1.



The ECM pumps oxygen in and out of the pump chamber to return the reference back to λ=1.



The reference Sensor

Current Equates to Air Fuel Ratio

The ECM calculates the current required to pump oxygen in and out of the pump chamber. The ECM calculates AFR by monitoring the current needed to bring the chamber back to lambda of 1.0.

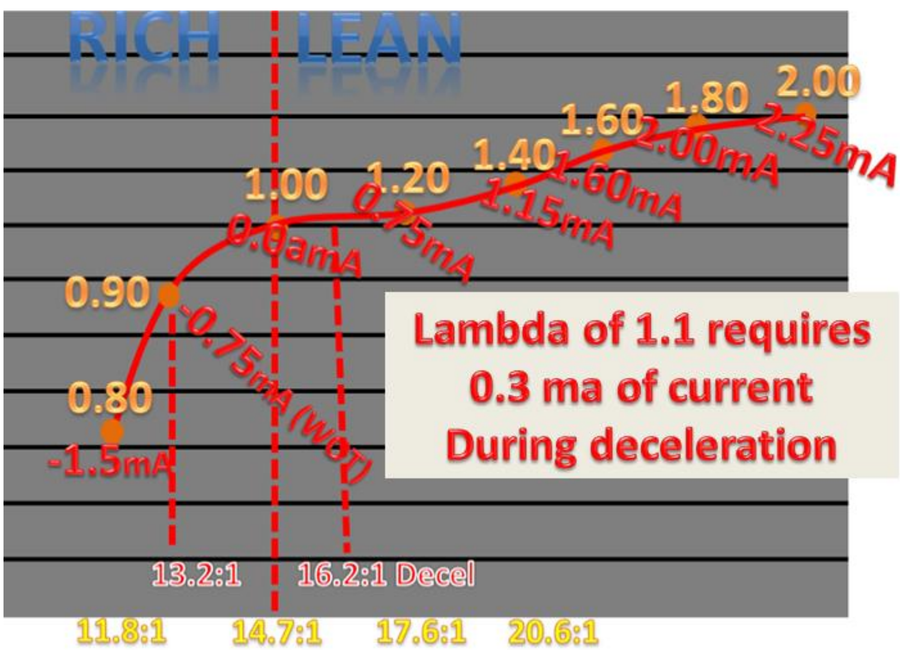
Notice the extra notions for **wide open throttle at 0.9λ and deceleration at 1.10λ. During acceleration and deceleration we know special AFR is required and now we can measure to see if the fuel delivery matches what is expected.**

A <u>rich</u> mixture requires <u>negative current</u> flow, to return the diffusion chamber to

Stoichiometric; this would be expected during wide open throttle acceleration.

Use this data to evaluate fuel delivery during heavy loads where a rich fuel mixture is expected. Cold startup will also require a rich mixture until coolant temperature gets above 160° F.

A lean mixture requires positive current flow, to return the diffusion chamber to Stoichiometric; this would be expected during deceleration.

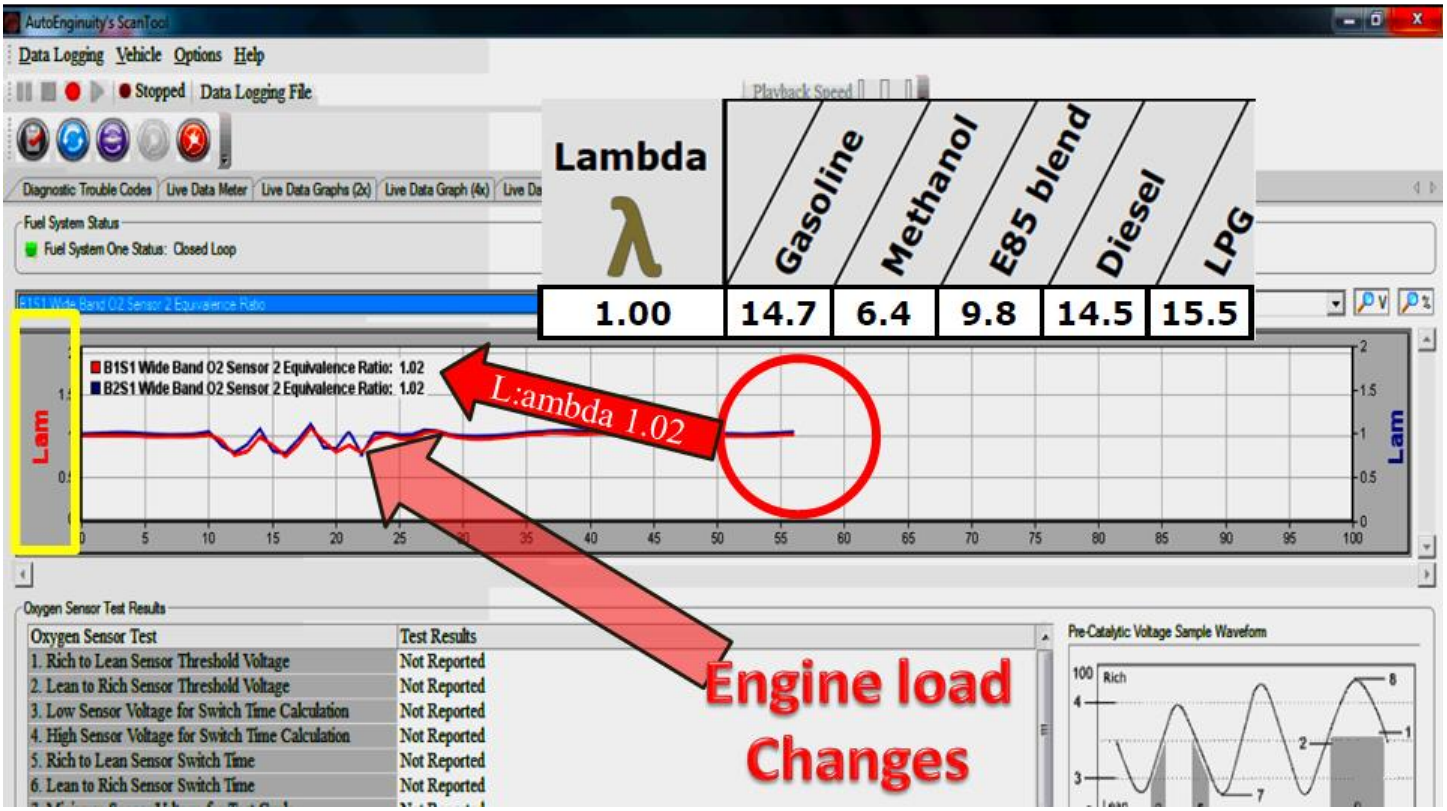


Use this data to evaluate fuel delivery during deceleration where fuel shutoff is expected.

Long term fuel trim will adjust fuel delivery, if the lambda value does not match the target value during operation.

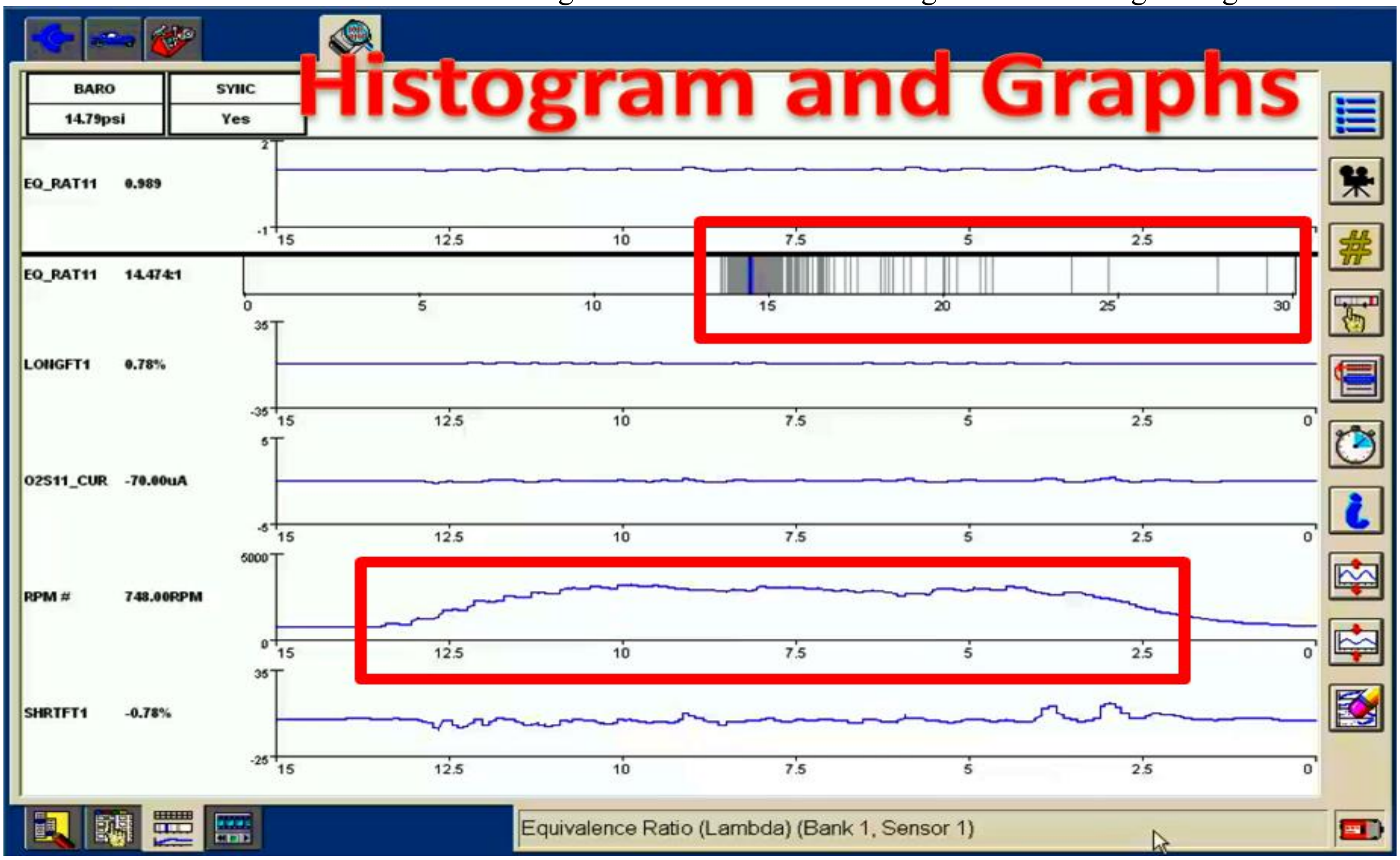
Scan Data for Lambda

This simple is a service bay test that shows both sensors are working normally during a series of snap acceleration and idle operation. On the first throttle snap the bank 1 sensor 1 didn't go as rich as the bank 2 sensor 1. You can't perform the test one time and attempt to intrepid the results. What happen here was the computer didn't up-date the bank 1 sensor 1 at the same rate as the bank 2 sensor 1. It doesn't indicate anything wrong. It doesn't mean there is anything wrong with the Scan Tool. It "Just" happens. That is why you need to snap the throttle more than once (in this example). If the one sensor never moves as it should, you would do additional test on that sensor.



The two sensors on this V-6 engine tracked well. There was one point that showed a difference, we see this sometimes during rapid changes because the scan data can't keep up with the speed of changes in the data.

When we use some scan tools we have histograms that show the total range covered during testing.



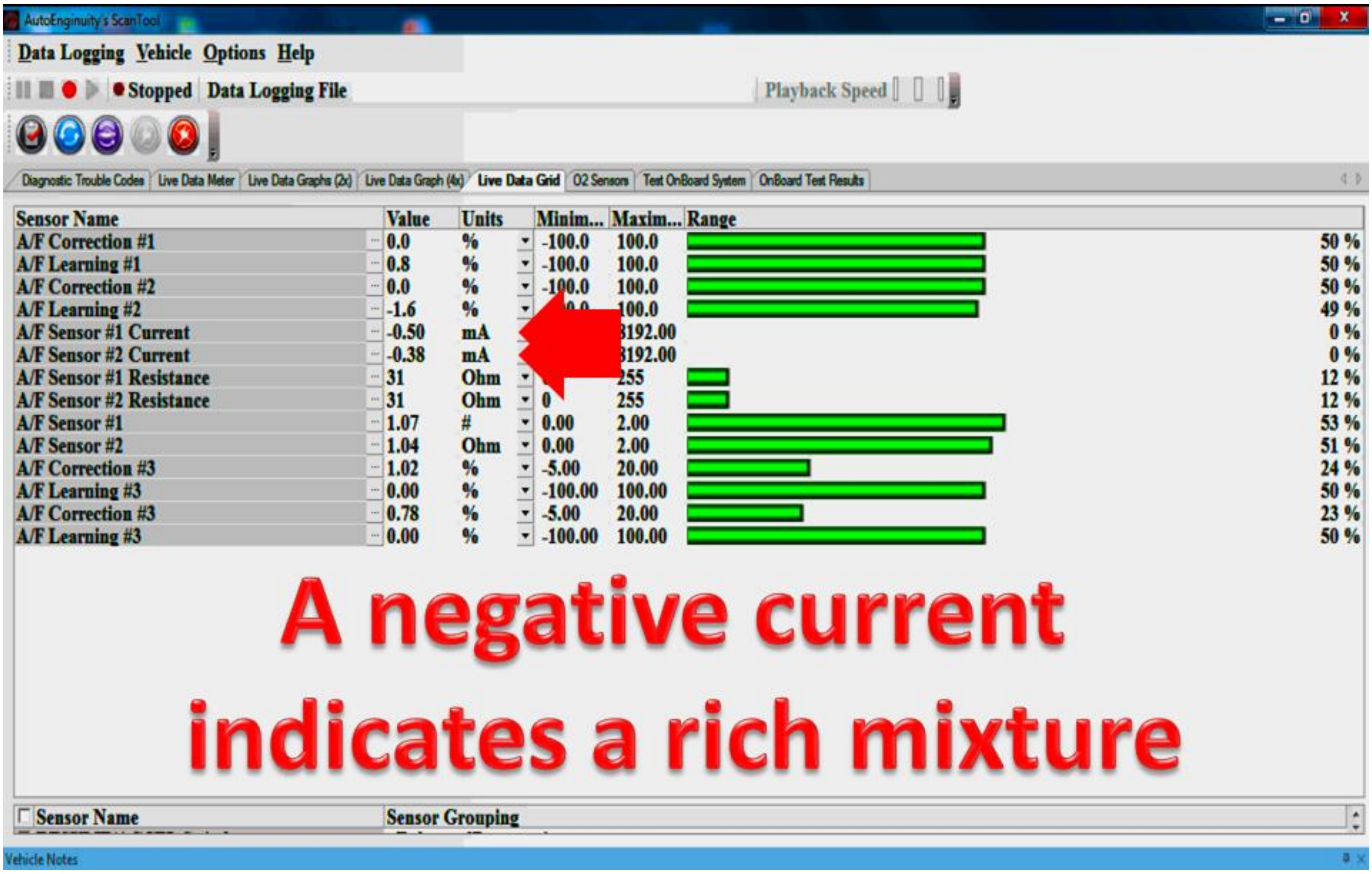
The histogram shows most of the air fuel ration stayed close to 14.7:1, but during some decelerations we went as high as 28:1 AFR. During heavy load operation we were down to around 13:1 AFR. The graphs show the last 15 seconds of operation. **Understand that the graphs do not represent the entire test drive but the histogram is for the entire test drive.**

We expect the two banks to be balanced. Look at the Scan Data where the circle is and both banks are in balance.

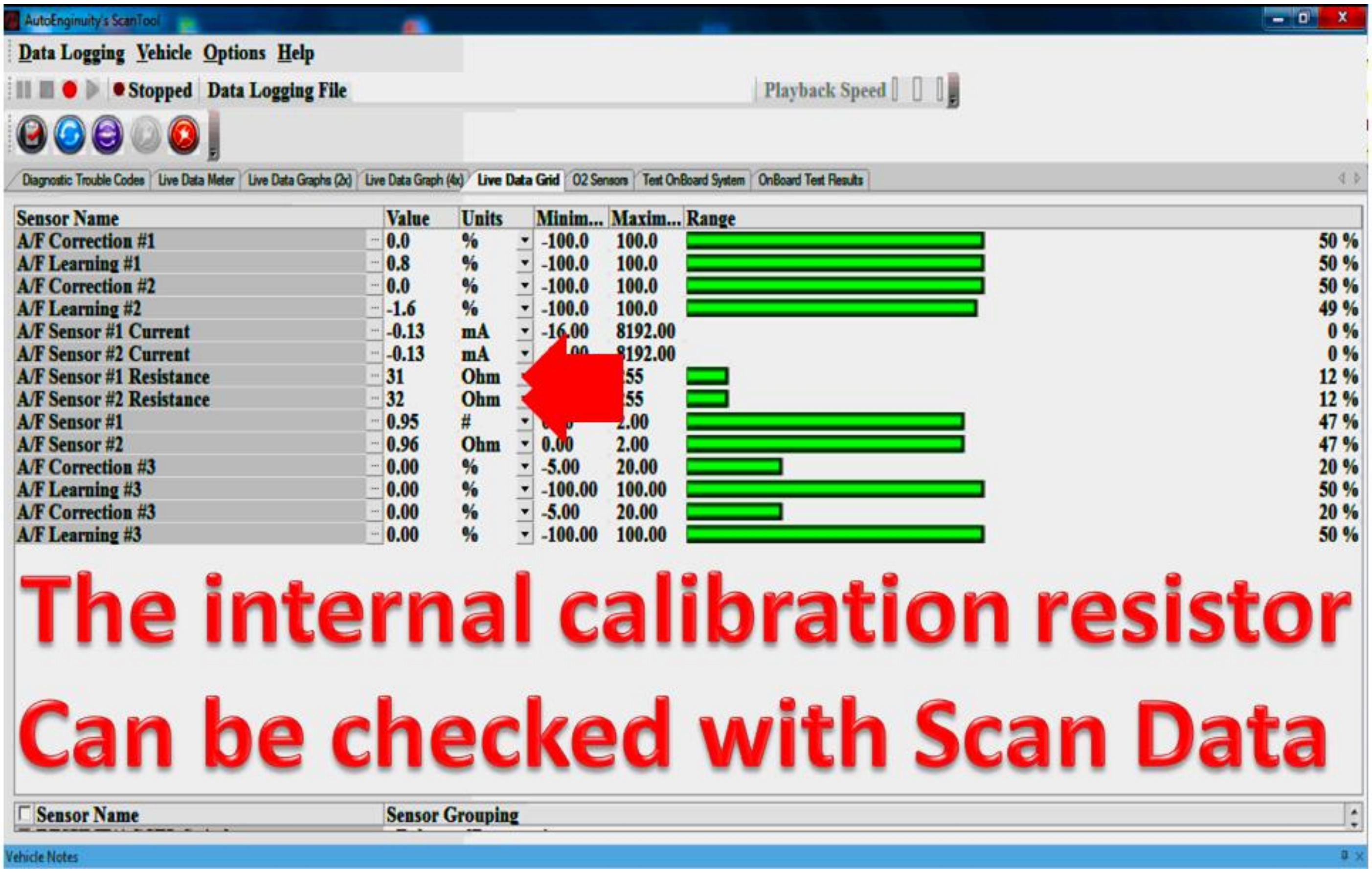
In the second screen grab we can see that the current in fact did change. This indicates that the sensor is working normally. Look at the next image of Scan Data ad we can see a difference in each bank. The second images of the Scan Data are data during a throttle snap. The unbalance Data values are normal because of the Scan Data update rate we have talked about before and will again in this class. This is an advance class and any

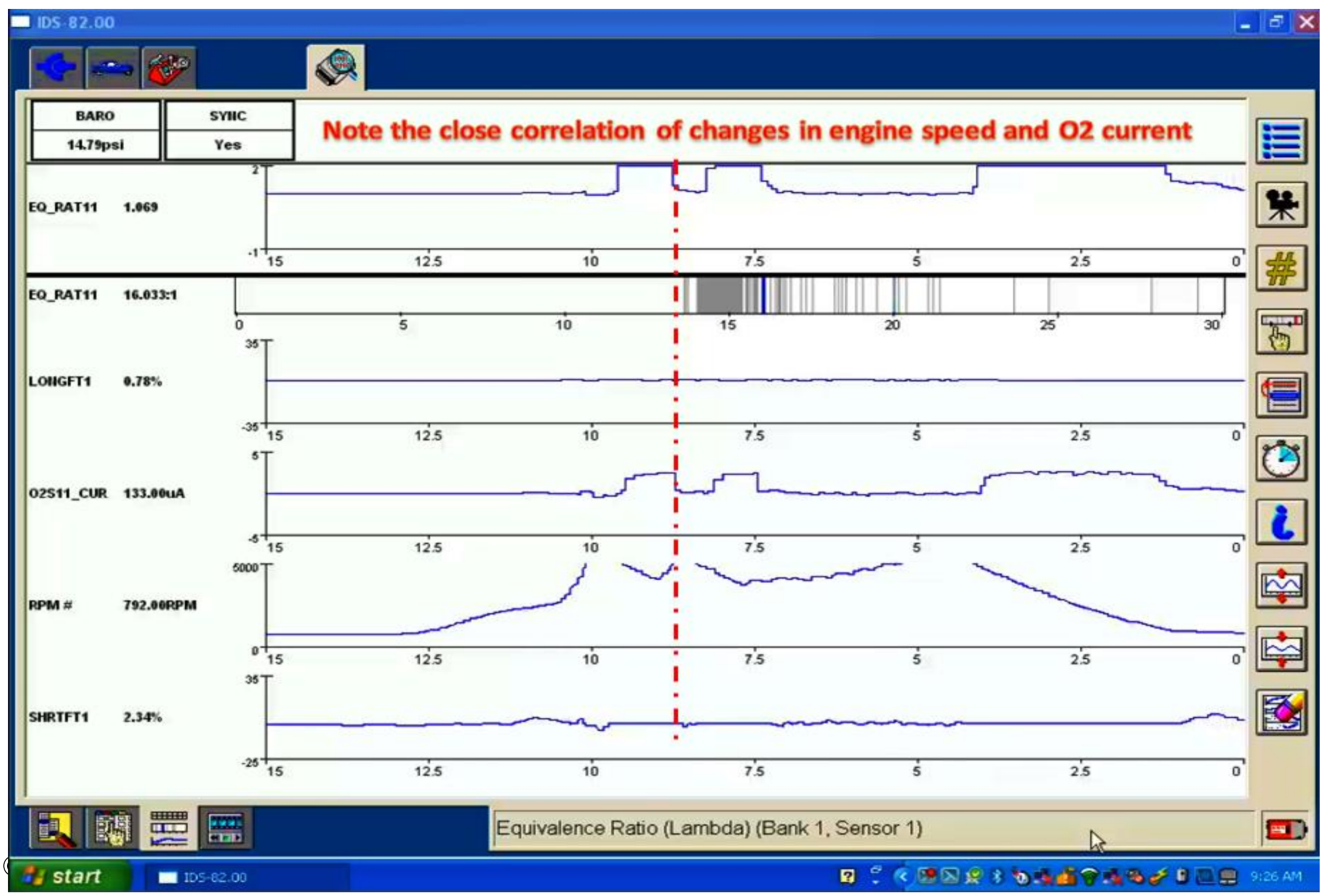
technician wanting to advance their skills must have knowledge about the equipment. In the service bay we would be looking at live Data and not a screen grab as in this book. If this is what we saw when we snapped open the throttle multiple time to ensure that the banks responded quickly.

Another PID that will help with oxygen sensor testing is the sensor's current value. As stated the current changes with the air fuel mixture. During the drive we should see the current report positive and negative. In most Scan Tools when the current is negative there will be a symbol for negative in front of the value. When the



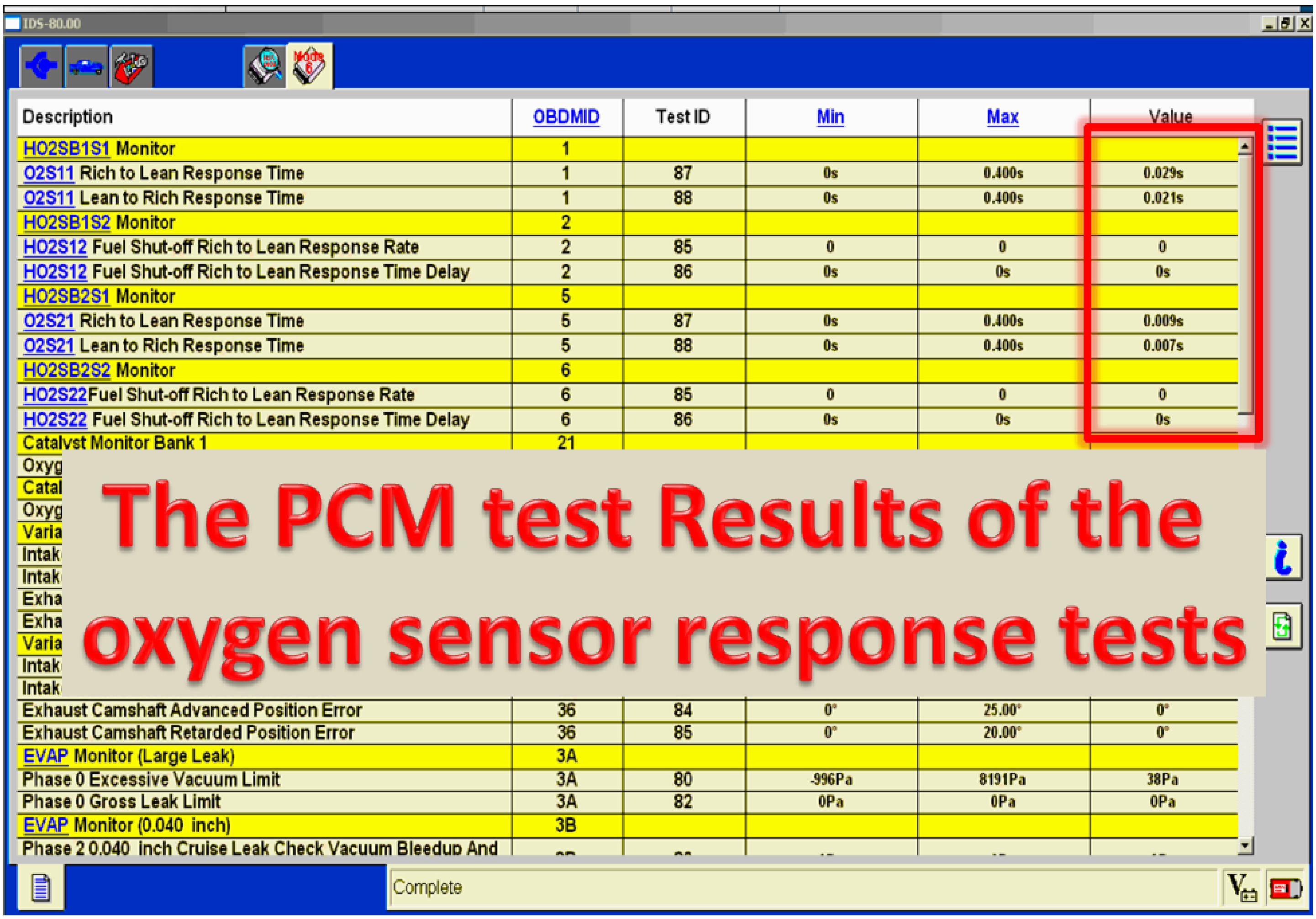
value is positive there won't be any symbol in front of it.
There isn't a specification for what the current value should be at any giving moment. You use this PID this way. The current should show a vale when the throttle is opened or closed, quickly or slowly. The value shouldn't remain at 0 all the time that would indicate that the sensor has an open circuit. The value shouldn't go above 3 mA or that would indicate that the sensor is shorted. For any indication of an open or a shorted sensor, check the circuit between the sensor and the PCM that has the problem before replacing the sensors it. If the voltage signals changes, the current value should change if the sensor is working normally.
Compare operation condition to the expected fuel status, WOT should be rich, decel should be lean. Idle should be Stoichiometric. Add fuel with a snap acceleration to check rich mixture operation, the mixture will go lean during deceleration. Action/reaction testing is one our favorite test methods.


AutoEnginuity's ScanTool
Data Logging Vehicle Options Help
Stopped Data Logging File
Playback Speed
Diagnostic Trouble Codes | Live Data Meter | Live Data Graphs (2x) | Live Data Graph (4x) | Live Data Grid | O2 Sensors | Test OnBoard System | OnBoard Test Results
Sensor Name | Value | Units | Minim... | Maxim... | Range
A/F Correction #1 | 0.0 | % | -100.0 | 100.0 | 50 %
A/F Learning #1 | 0.8 | % | -100.0 | 100.0 | 50 %
A/F Correction #2 | 0.0 | % | -100.0 | 100.0 | 50 %
A/F Learning #2 | -1.6 | % | -100.0 | 100.0 | 49 %
A/F Sensor #1 Current | -0.13 | mA | -16.00 | 8192.00 | 0 %
A/F Sensor #2 Current | -0.13 | mA | 8192.00 | 0 %
A/F Sensor #1 Resistance | 31 | Ohm | 12 %
A/F Sensor #2 Resistance | 32 | Ohm | 12 %
A/F Sensor #1 | 0.95 | # | 47 %
A/F Sensor #2 | 0.96 | Ohm | 0.00 | 2.00 | 47 %
A/F Correction #3 | 0.00 | % | -5.00 | 20.00 | 20 %
A/F Learning #3 | 0.00 | % | -100.00 | 100.00 | 50 %
A/F Correction #3 | 0.00 | % | -5.00 | 20.00 | 20 %
A/F Learning #3 | 0.00 | % | -100.00 | 100.00 | 50 %
The internal calibration resistor
Can be checked with Scan Data
Sensor Name
Sensor Grouping
Vehicle Notes


IDS-82.00
BARO
14.79psi
SYNC
Yes
Note the close correlation of changes in engine speed and O2 current
EQ_RAT11 1.069
EQ_RAT11 16.033:1
LONGFT1 0.78%
O2S11_CUR 133.00uA
RPM # 792.00RPM
SHRTFT1 2.34%
Equivalence Ratio (Lambda) (Bank 1, Sensor 1)
start
9:26 AM

Notice how the oxygen sensor current flowws the action of engine speed changes which are the result of changes in throttle opening.
One of our favorite tools is Mode 6 where the PCM has done a controlled test and stored the result for diagnostic trouble code activation. Remember, thes are the test results that are going to set the DTCs. Slow oxygen sensor response codes are set when the PCM records two consective failures on the oxygen sensor response test.

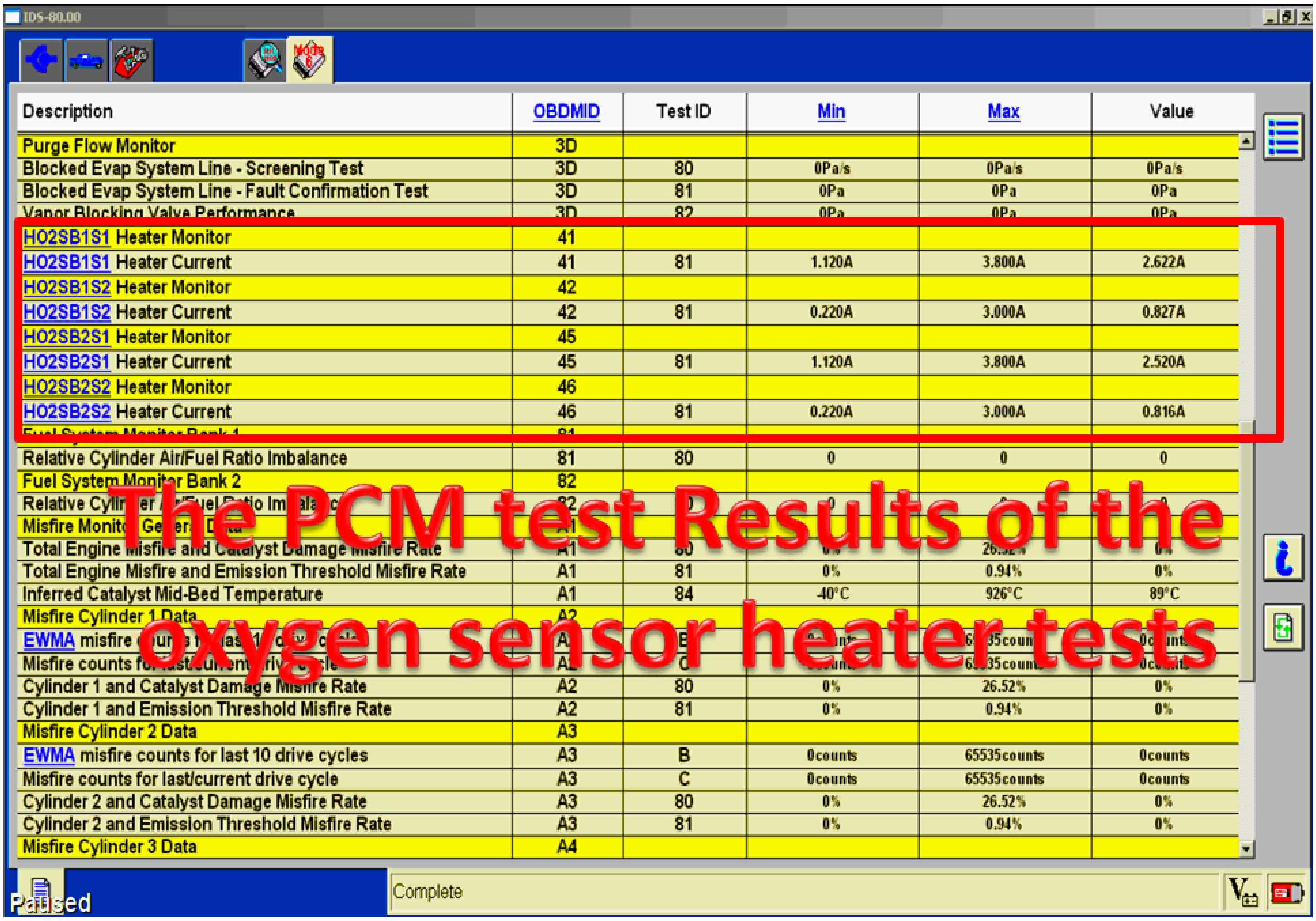
The test covers rich to to lean and lean to rich response times. These values indicate the sensors respond quickly, because the failure limit is 0.400 seconds and our test value is 0.029 seconds rich to leah and 0.021 seconds lean to rich. We can wait for the test to fail two times to set a code and then repair the problem or we can check for values that are close to failing to prevent a comeback for check engine light after srevice is complete.



Description	OBDMID	Test ID	Min	Max	Value
H02SB1S1 Monitor	1				
02S11 Rich to Lean Response Time	1	87	0s	0.400s	0.029s
02S11 Lean to Rich Response Time	1	88	0s	0.400s	0.021s
H02SB1S2 Monitor	2				
H02S12 Fuel Shut-off Rich to Lean Response Rate	2	85	0	0	0
H02S12 Fuel Shut-off Rich to Lean Response Time Delay	2	86	0s	0s	0s
H02SB2S1 Monitor	5				
02S21 Rich to Lean Response Time	5	87	0s	0.400s	0.009s
02S21 Lean to Rich Response Time	5	88	0s	0.400s	0.007s
H02SB2S2 Monitor	6				
H02S22Fuel Shut-off Rich to Lean Response Rate	6	85	0	0	0
H02S22 Fuel Shut-off Rich to Lean Response Time Delay	6	86	0s	0s	0s
Catalyst Monitor Bank 1	21				
Oxyg					
Catal					
Oxyg					
Varia					
Intak					
Intak					
Exha					
Exha					
Varia					
Intak					
Intak					
Exhaust Camshaft Advanced Position Error	36	84	0°	25.00°	0°
Exhaust Camshaft Retarded Position Error	36	85	0°	20.00°	0°
EVAP Monitor (Large Leak)	3A				
Phase 0 Excessive Vacuum Limit	3A	80	-996Pa	8191Pa	38Pa
Phase 0 Gross Leak Limit	3A	82	0Pa	0Pa	0Pa
EVAP Monitor (0.040 inch)	3B				
Phase 2 0.040 inch Cruise Leak Check Vacuum Bleedup And					

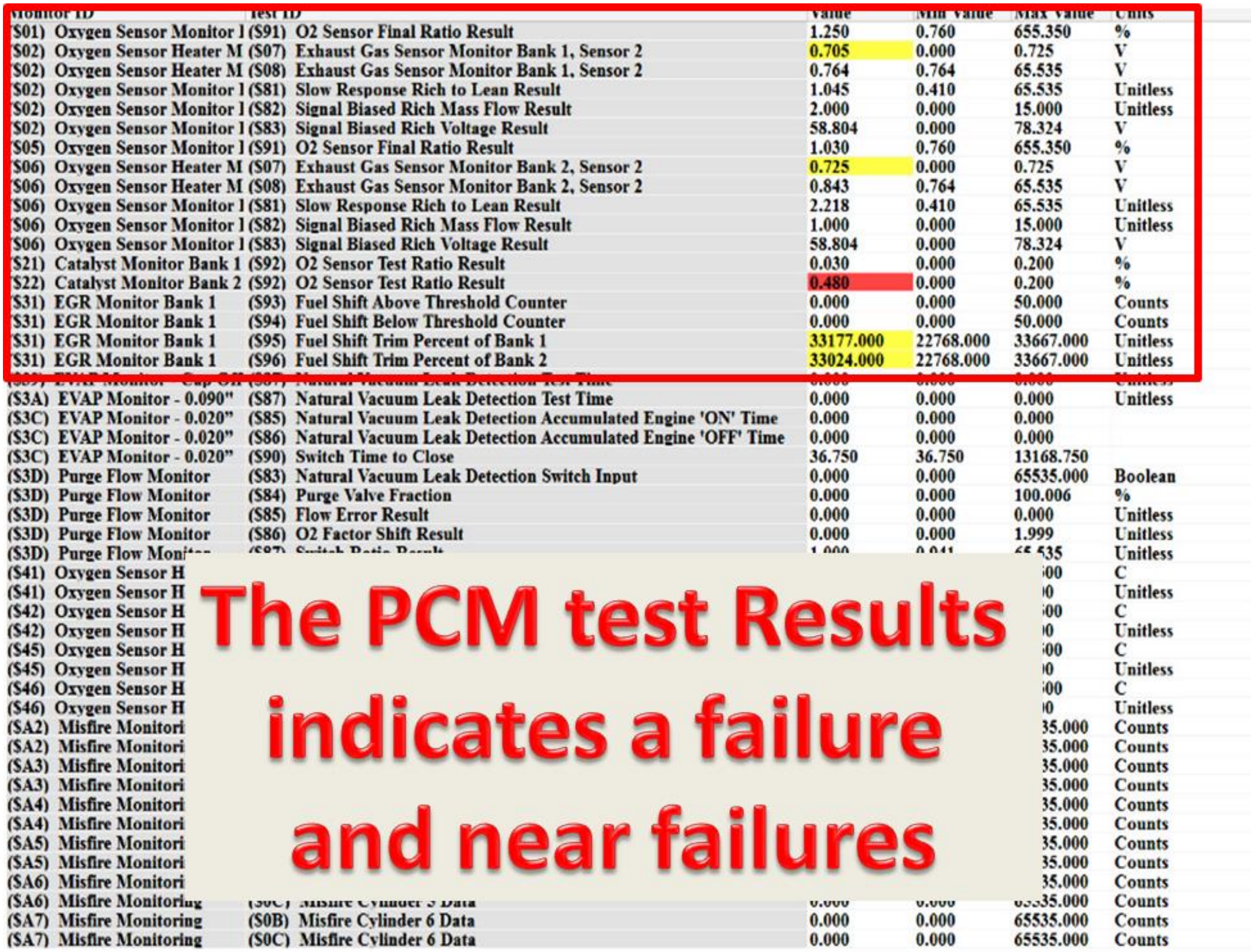
We have the opinion that this is a highly accurate test, because OBDII codes that are generated by this data ideentifies more emission failures than an IM-240 driving cycle on a dyno according to an EPA study.
This mode-6 screen is showing that the oxygen sensors past all of the tests. The next screen is showing that the heaters past the test also. This combined with the PID screens tells us that the sensors are find and require no further testing. The third screen is using a different Scan Tool and is showing that the sensors and their circuits are in need of additional testing.

On the last screen grab the O_2 sensors look good and pass the test. Also we can see that the readiness monitor shows that required monitors have run.



Description	OBDMID	Test ID	Min	Max	Value
Purge Flow Monitor	3D				
Blocked Evap System Line - Screening Test	3D	80	0Pa/s	0Pa/s	0Pa/s
Blocked Evap System Line - Fault Confirmation Test	3D	81	0Pa	0Pa	0Pa
Vapor Blocking Valve Performance	3D	82	0Pa	0Pa	0Pa
HO2SB1S1 Heater Monitor	41				
HO2SB1S1 Heater Current	41	81	1.120A	3.800A	2.622A
HO2SB1S2 Heater Monitor	42				
HO2SB1S2 Heater Current	42	81	0.220A	3.000A	0.827A
HO2SB2S1 Heater Monitor	45				
HO2SB2S1 Heater Current	45	81	1.120A	3.800A	2.520A
HO2SB2S2 Heater Monitor	46				
HO2SB2S2 Heater Current	46	81	0.220A	3.000A	0.816A
Fuel System Monitor Bank 1	81				
Relative Cylinder Air/Fuel Ratio Imbalance	81	80	0	0	0
Fuel System Monitor Bank 2	82				
Relative Cylinder Air/Fuel Ratio Imbalance	82	[illegible]	0	[illegible]	0
Misfire Monitor General Data	A1				
Total Engine Misfire and Catalyst Damage Misfire Rate	A1	80	0%	26.52%	0%
Total Engine Misfire and Emission Threshold Misfire Rate	A1	81	0%	0.94%	0%
Inferred Catalyst Mid-Bed Temperature	A1	84	-40°C	926°C	89°C
Misfire Cylinder 1 Data	A2				
EWMA misfire counts for last 10 drive cycles	A2	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A2	C	0counts	65535counts	0counts
Cylinder 1 and Catalyst Damage Misfire Rate	A2	80	0%	26.52%	0%
Cylinder 1 and Emission Threshold Misfire Rate	A2	81	0%	0.94%	0%
Misfire Cylinder 2 Data	A3				
EWMA misfire counts for last 10 drive cycles	A3	B	0counts	65535counts	0counts
Misfire counts for last/current drive cycle	A3	C	0counts	65535counts	0counts
Cylinder 2 and Catalyst Damage Misfire Rate	A3	80	0%	26.52%	0%
Cylinder 2 and Emission Threshold Misfire Rate	A3	81	0%	0.94%	0%
Misfire Cylinder 3 Data	A4				

We have test data for some example that show failures and near failures.



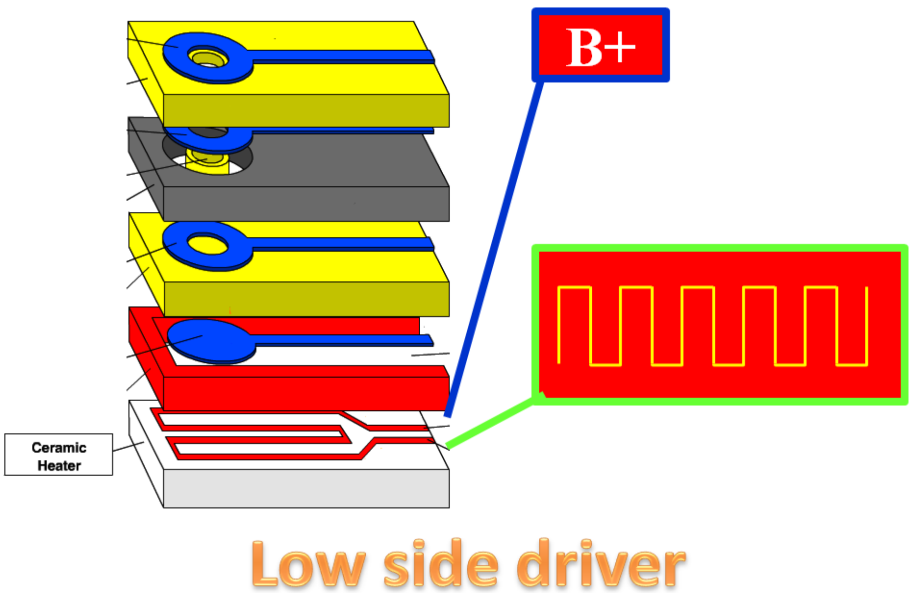
Monitor ID	Test ID	Value	Min Value	Max Value	Units
(S01) Oxygen Sensor Monitor 1	(S91) O2 Sensor Final Ratio Result	1.250	0.760	655.350	%
(S02) Oxygen Sensor Heater M	(S07) Exhaust Gas Sensor Monitor Bank 1, Sensor 2	0.705	0.000	0.725	V
(S02) Oxygen Sensor Heater M	(S08) Exhaust Gas Sensor Monitor Bank 1, Sensor 2	0.764	0.764	65.535	V
(S02) Oxygen Sensor Monitor 1	(S81) Slow Response Rich to Lean Result	1.045	0.410	65.535	Unitless
(S02) Oxygen Sensor Monitor 1	(S82) Signal Biased Rich Mass Flow Result	2.000	0.000	15.000	Unitless
(S02) Oxygen Sensor Monitor 1	(S83) Signal Biased Rich Voltage Result	58.804	0.000	78.324	V
(S05) Oxygen Sensor Monitor 1	(S91) O2 Sensor Final Ratio Result	1.030	0.760	655.350	%
(S06) Oxygen Sensor Heater M	(S07) Exhaust Gas Sensor Monitor Bank 2, Sensor 2	0.725	0.000	0.725	V
(S06) Oxygen Sensor Heater M	(S08) Exhaust Gas Sensor Monitor Bank 2, Sensor 2	0.843	0.764	65.535	V
(S06) Oxygen Sensor Monitor 1	(S81) Slow Response Rich to Lean Result	2.218	0.410	65.535	Unitless
(S06) Oxygen Sensor Monitor 1	(S82) Signal Biased Rich Mass Flow Result	1.000	0.000	15.000	Unitless
(S06) Oxygen Sensor Monitor 1	(S83) Signal Biased Rich Voltage Result	58.804	0.000	78.324	V
(S21) Catalyst Monitor Bank 1	(S92) O2 Sensor Test Ratio Result	0.030	0.000	0.200	%
(S22) Catalyst Monitor Bank 2	(S92) O2 Sensor Test Ratio Result	0.480	0.000	0.200	%
(S31) EGR Monitor Bank 1	(S93) Fuel Shift Above Threshold Counter	0.000	0.000	50.000	Counts
(S31) EGR Monitor Bank 1	(S94) Fuel Shift Below Threshold Counter	0.000	0.000	50.000	Counts
(S31) EGR Monitor Bank 1	(S95) Fuel Shift Trim Percent of Bank 1	33177.000	22768.000	33667.000	Unitless
(S31) EGR Monitor Bank 1	(S96) Fuel Shift Trim Percent of Bank 2	33024.000	22768.000	33667.000	Unitless
[illegible] EVAP Monitor - Cap Off	(S87) Natural Vacuum Leak Detection Test Time	[illegible]	[illegible]	[illegible]	Unitless
(S3A) EVAP Monitor - 0.090"	(S87) Natural Vacuum Leak Detection Test Time	0.000	0.000	0.000	Unitless
(S3C) EVAP Monitor - 0.020"	(S85) Natural Vacuum Leak Detection Accumulated Engine 'ON' Time	0.000	0.000	0.000	
(S3C) EVAP Monitor - 0.020"	(S86) Natural Vacuum Leak Detection Accumulated Engine 'OFF' Time	0.000	0.000	0.000	
(S3C) EVAP Monitor - 0.020"	(S90) Switch Time to Close	36.750	36.750	13168.750	
(S3D) Purge Flow Monitor	(S83) Natural Vacuum Leak Detection Switch Input	0.000	0.000	65535.000	Boolean
(S3D) Purge Flow Monitor	(S84) Purge Valve Fraction	0.000	0.000	100.006	%
(S3D) Purge Flow Monitor	(S85) Flow Error Result	0.000	0.000	0.000	Unitless
(S3D) Purge Flow Monitor	(S86) O2 Factor Shift Result	0.000	0.000	1.999	Unitless
(S3D) Purge Flow Moni[illegible]	(S87) Switch Ratio Result	1.000	0.041	65.535	Unitless
(S41) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	C
(S41) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Unitless
(S42) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	C
(S42) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Unitless
(S45) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	C
(S45) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Unitless
(S46) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	C
(S46) Oxygen Sensor H[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Unitless
(SA2) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA2) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA3) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA3) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA4) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA4) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA5) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA5) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA6) Misfire Monitori[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35.000	Counts
(SA6) Misfire Monitoring	(S0C) Misfire Cylinder 5 Data	0.000	0.000	65535.000	Counts
(SA7) Misfire Monitoring	(S0B) Misfire Cylinder 6 Data	0.000	0.000	65535.000	Counts
(SA7) Misfire Monitoring	(S0C) Misfire Cylinder 6 Data	0.000	0.000	65535.000	Counts

Oxygen sensor bank 1 sensor #2 and sensor bank 2 sensors #2 are close to setting a heater codes. Heater B+ is common to these two heaters with the ground circuit duty cycled by the PCM for heater control. This could because both sensors are near failure or they have a common problem. Catalyst monitor bank 2 is failing, note that his uses the Bank 2 Sensor #2 for diagnostics.

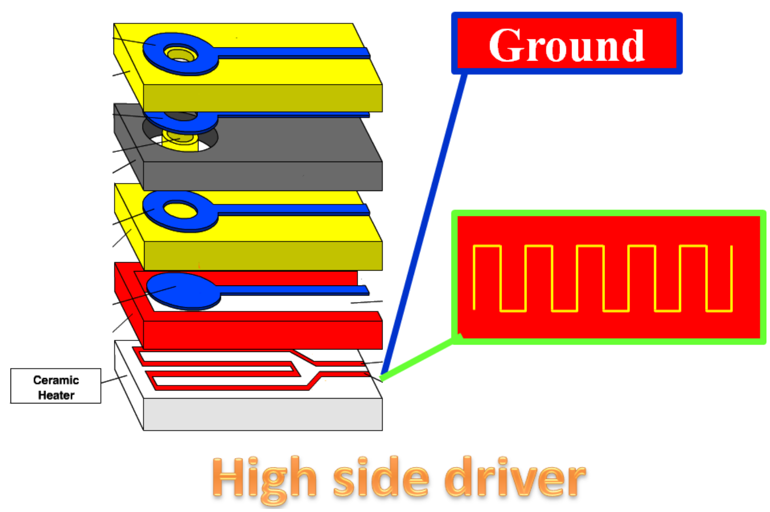
The EGR data indicates we should take a look at EGR flow because it is offsetting fuel trim an excessive amount. This should give you an idea of why we like this data. We need to look at oxygen sensor heaters, they are very critical for normal operation of the universal oxygen sensors.

O_2 Heater Circuitry

Wide range sensors require a tip temperature over twice as hot as narrow band sensors.
12 volts is pulsed to the sensors heater, and the “ON" time of the pulse varies as needed to keep the temperature in the proper range.



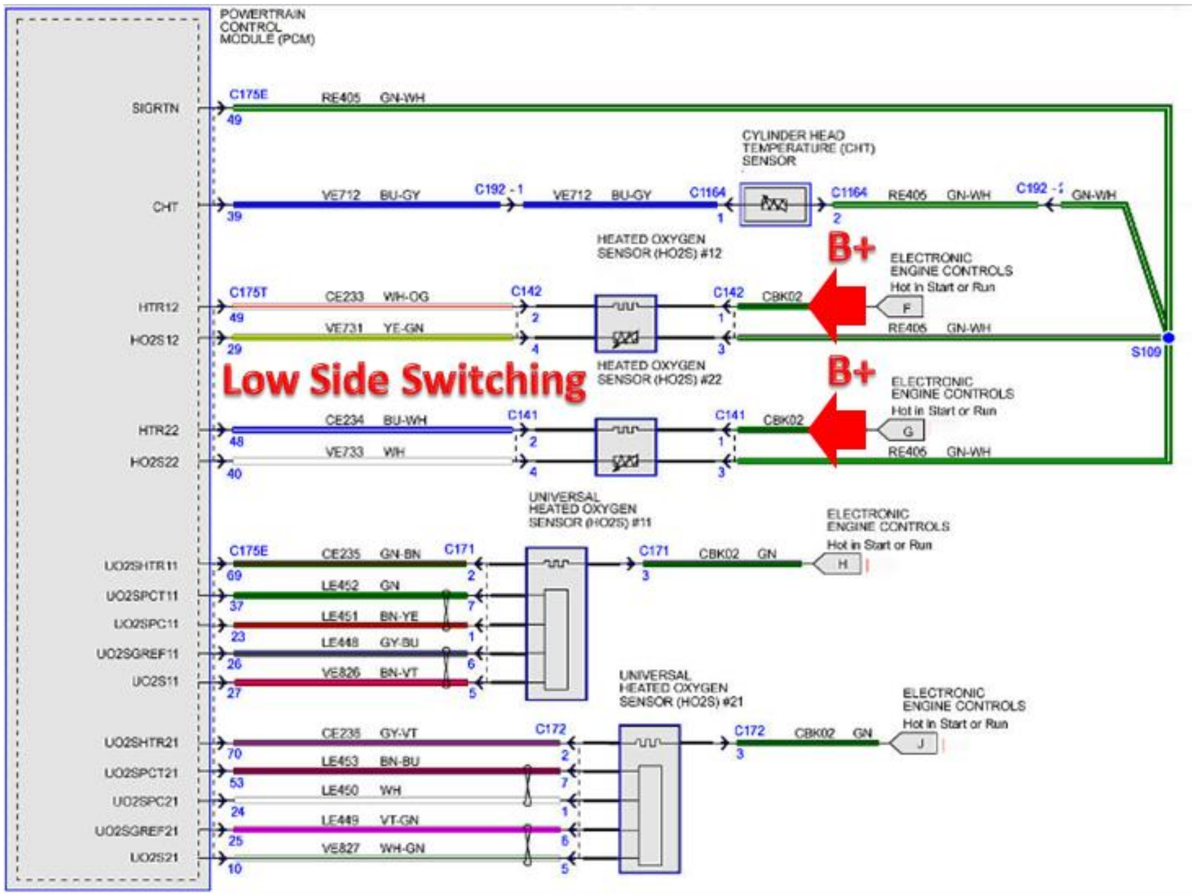
When testing the heater there should be B+ on one of the heaters circuits and a Pulsed Width Modulated (PWM) signal on the ground.



The ground circuit uses duty cycle control with low side switching. B+ is switched on and on with high side control.

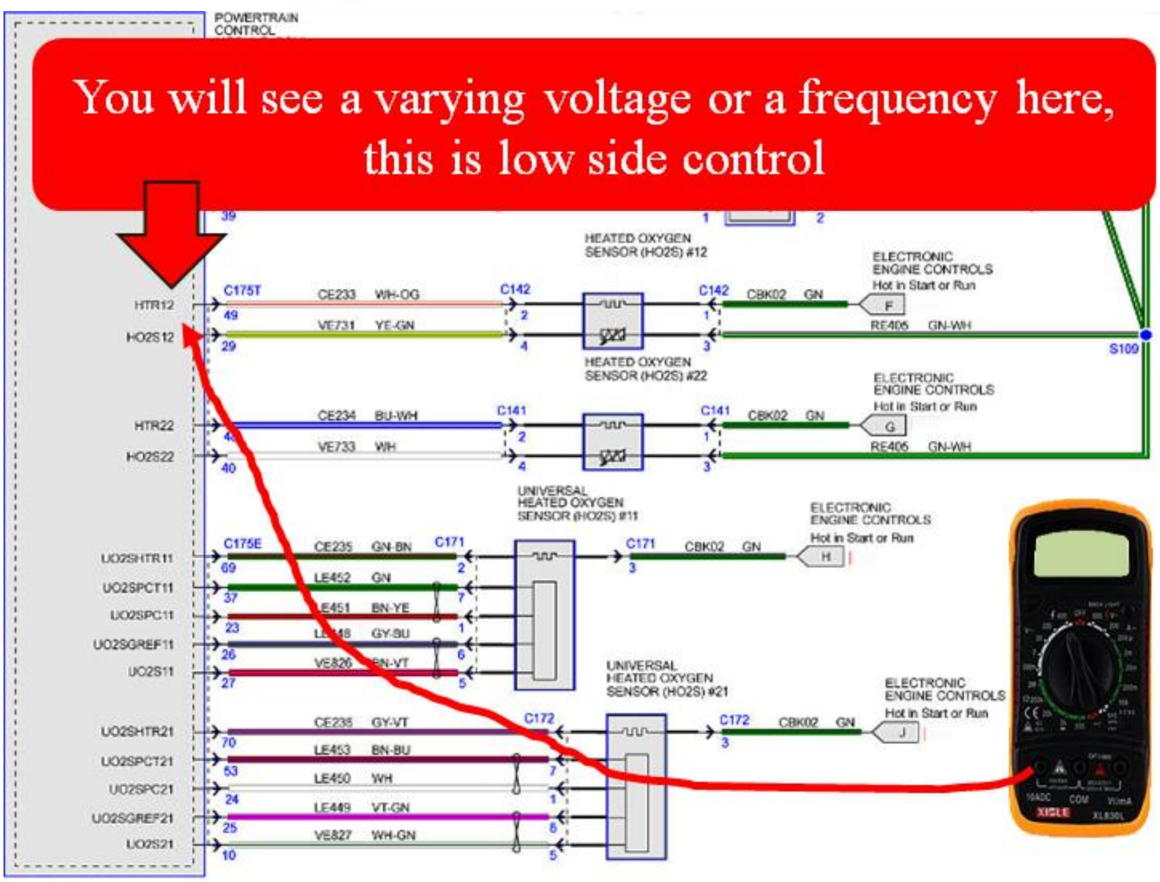
A Voltmeter can be used to check the heater circuit.
Remember that the DVOM will average the measured value.
As an example a 12 volt value will appear as something different depending on the duty cycle, 50% duty cycle will indicate 6 volts when full voltage is 12 volts.
Voltage testing can be a bit tricky;

- When the 12 volts is being pulsed you will not see 12 volts (B+)
- You will see an average (lower) voltage
- 6 or 8 volts as an example (dependent on the duty cycle)
- This is because the meter is trying to give you the average voltage over a period of time



This diagram indicates low side switching because the B+ side is hot in start and run position.

High side switching would have a ground connection where the B+ connection is presently.

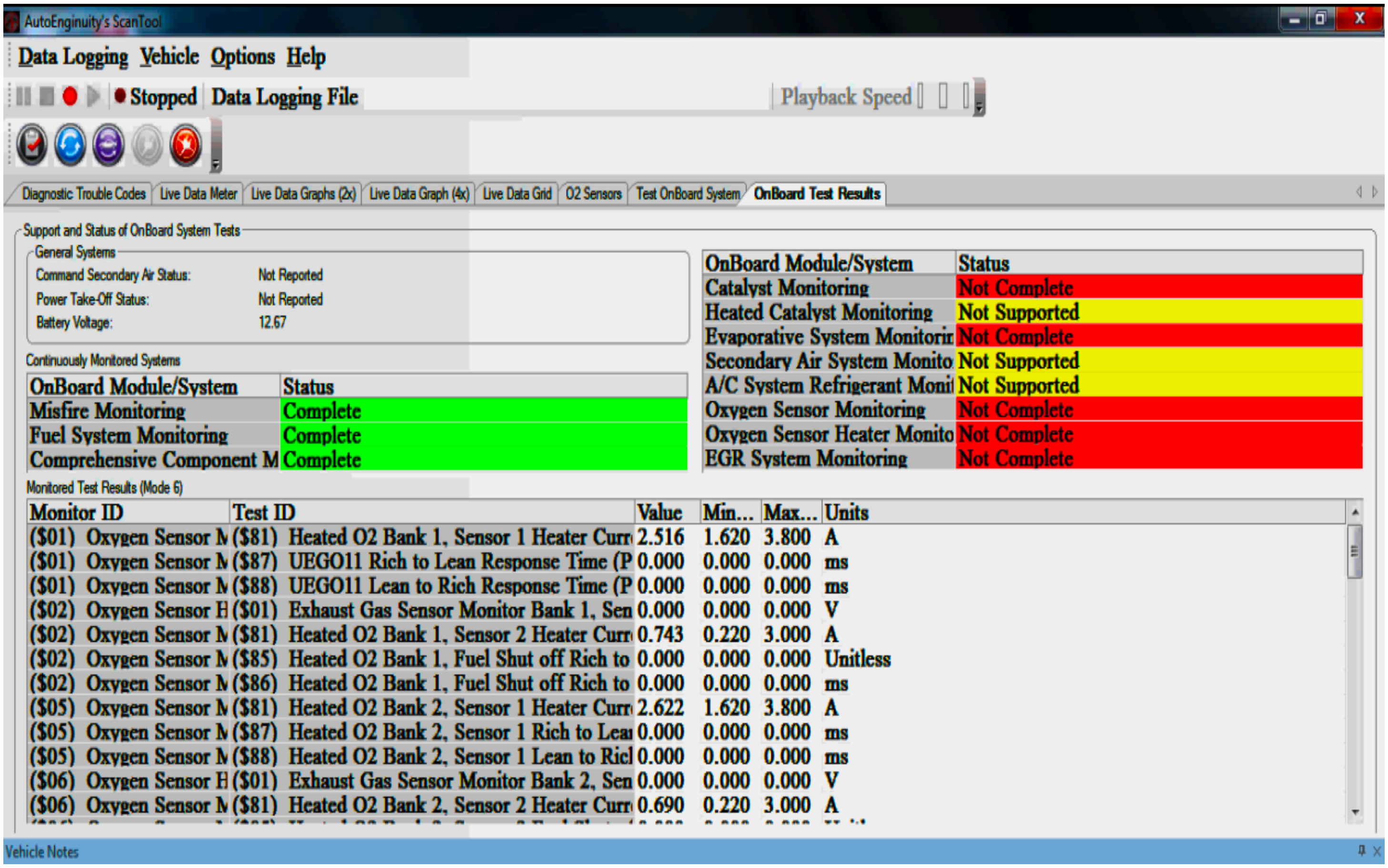


Pin 49 and 29 will have the ground switched off/on to duty cycle the heater current.

Use Mode-6 test results

The PCM performs test with controlled conditions and knows the expected results;

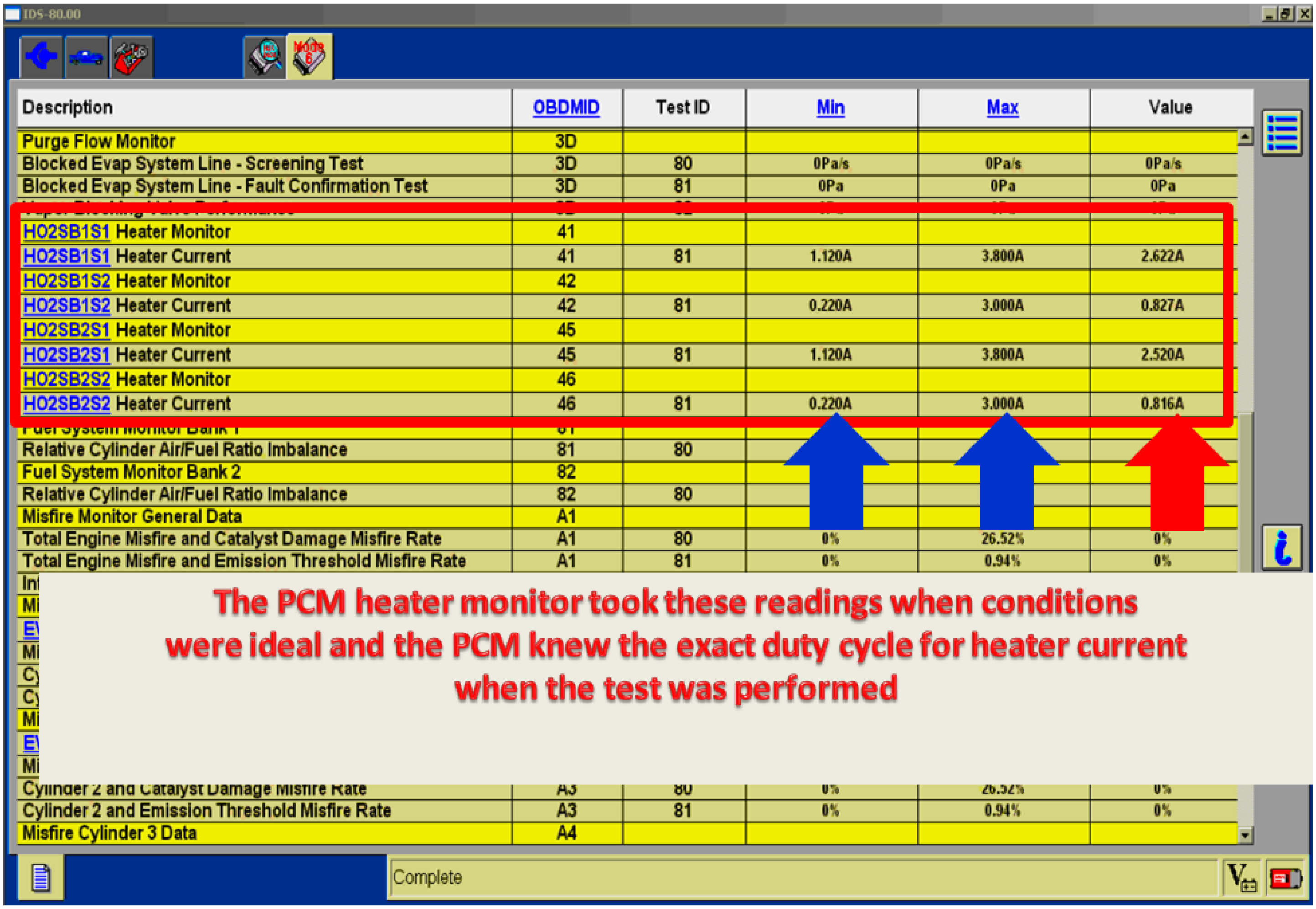
- Many of these tests cannot be done by a technician using scan data.
- Mode-6 data is the test results of special monitors that the PCM has done remember, these are NOT live data.



The readiness monitor shows that required monitors have not run, Oxygen Sensor Heater Monitor-NOT COMPLETE. **These test results are from an earlier test.** The PCM doesn't erase the mode-6 test results only update them. They will always have a value unless the codes have been cleared or the battery has been disconnected. It is important to check the readiness results to ensure that the monitor has run recently. When we see that the monitor hasn't run, we have to question the test results.

Universal O_2 Sensor Testing

Even if the manufacture supplies specifications for some sensors, there are some versions that cannot be measured with a DVOM or a DSO (These specifications simply say voltage or current will vary).
The data readings must be taken under controlled conditions, which is the way the PCM captures the data. The PCM sets special operating conditions and measures the data values when the conditions are perfect. These tests are more accurate and it's easier to use mode-6 to look at the test results than trying to predict normal operation to take your data readings.



Description	OBDMID	Test ID	Min	Max	Value
Purge Flow Monitor	3D				
Blocked Evap System Line - Screening Test	3D	80	0Pa/s	0Pa/s	0Pa/s
Blocked Evap System Line - Fault Confirmation Test	3D	81	0Pa	0Pa	0Pa
HO2SB1S1 Heater Monitor	41				
HO2SB1S1 Heater Current	41	81	1.120A	3.800A	2.622A
HO2SB1S2 Heater Monitor	42				
HO2SB1S2 Heater Current	42	81	0.220A	3.000A	0.827A
HO2SB2S1 Heater Monitor	45				
HO2SB2S1 Heater Current	45	81	1.120A	3.800A	2.520A
HO2SB2S2 Heater Monitor	46				
HO2SB2S2 Heater Current	46	81	0.220A	3.000A	0.816A
Relative Cylinder Air/Fuel Ratio Imbalance	81	80			
Fuel System Monitor Bank 2	82				
Relative Cylinder Air/Fuel Ratio Imbalance	82	80			
Misfire Monitor General Data	A1				
Total Engine Misfire and Catalyst Damage Misfire Rate	A1	80	0%	26.52%	0%
Total Engine Misfire and Emission Threshold Misfire Rate	A1	81	0%	0.94%	0%
Cylinder 2 and Catalyst Damage Misfire Rate	A3	80	0%	26.52%	0%
Cylinder 2 and Emission Threshold Misfire Rate	A3	81	0%	0.94%	0%
Misfire Cylinder 3 Data	A4				

This page displays the test value above the red arrow and the minimum and maximum values for this specific vehicle above the blue arrows.

Universal O_2 Summary

This section covered the construction, operation of the universal oxygen sensor. The value of Mode 6 data for sensor performance and heater operation was detailed. Now it is time to move on to Coil on Plug.

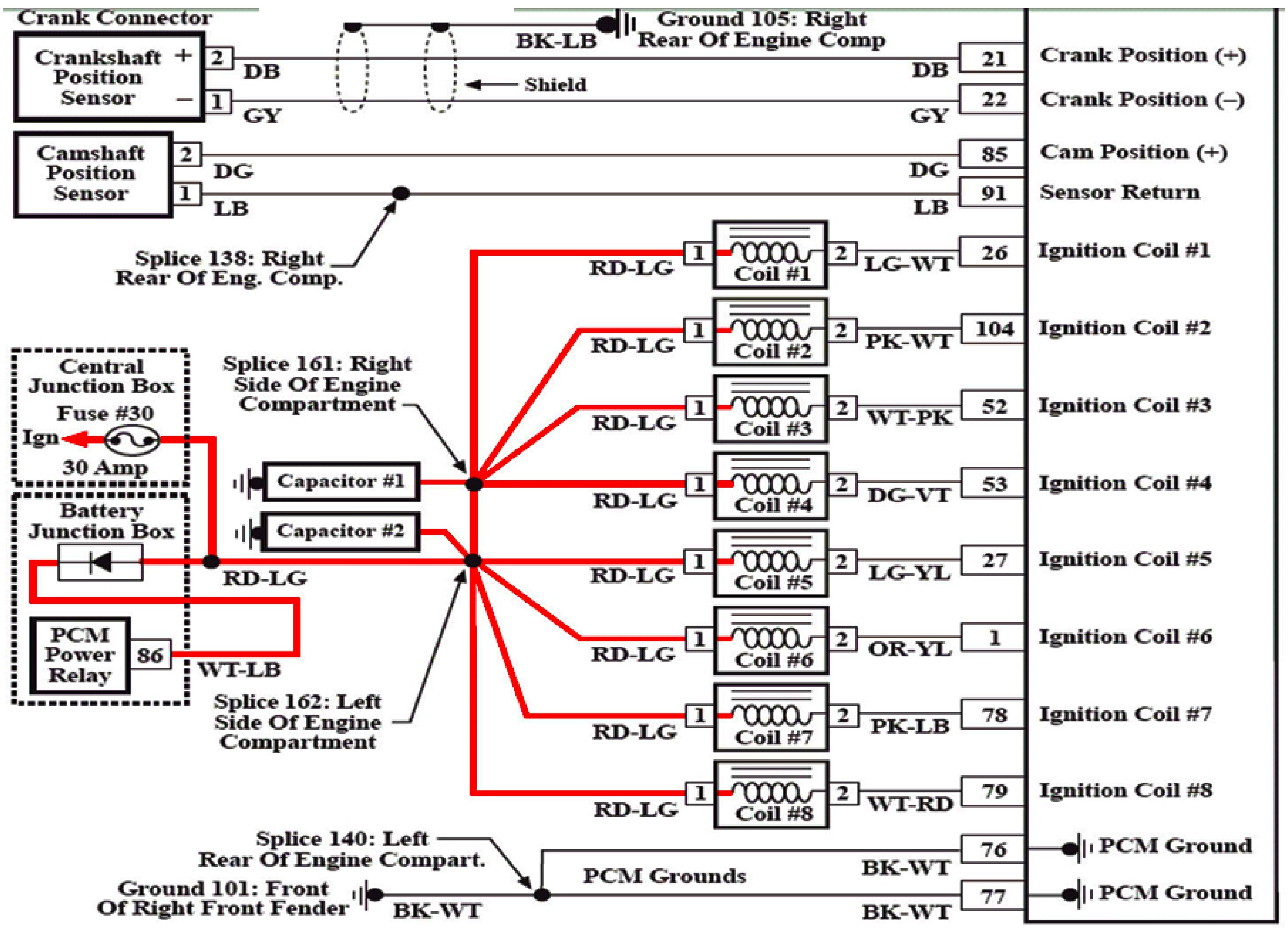
Coil on Plug

Each cylinder has its own ignition coil.

COP has 3 Circuit Arrangements

2 wire COP units are the most basic with one circuit being B+ and the other the control
3 wire units have an additional circuit from the PCM to the COP unit for control
4 wire units have a fourth circuit that is a ground reference
The difference between the 3 and 4 wire units is the ground reference circuit

Typical 2 wire COP

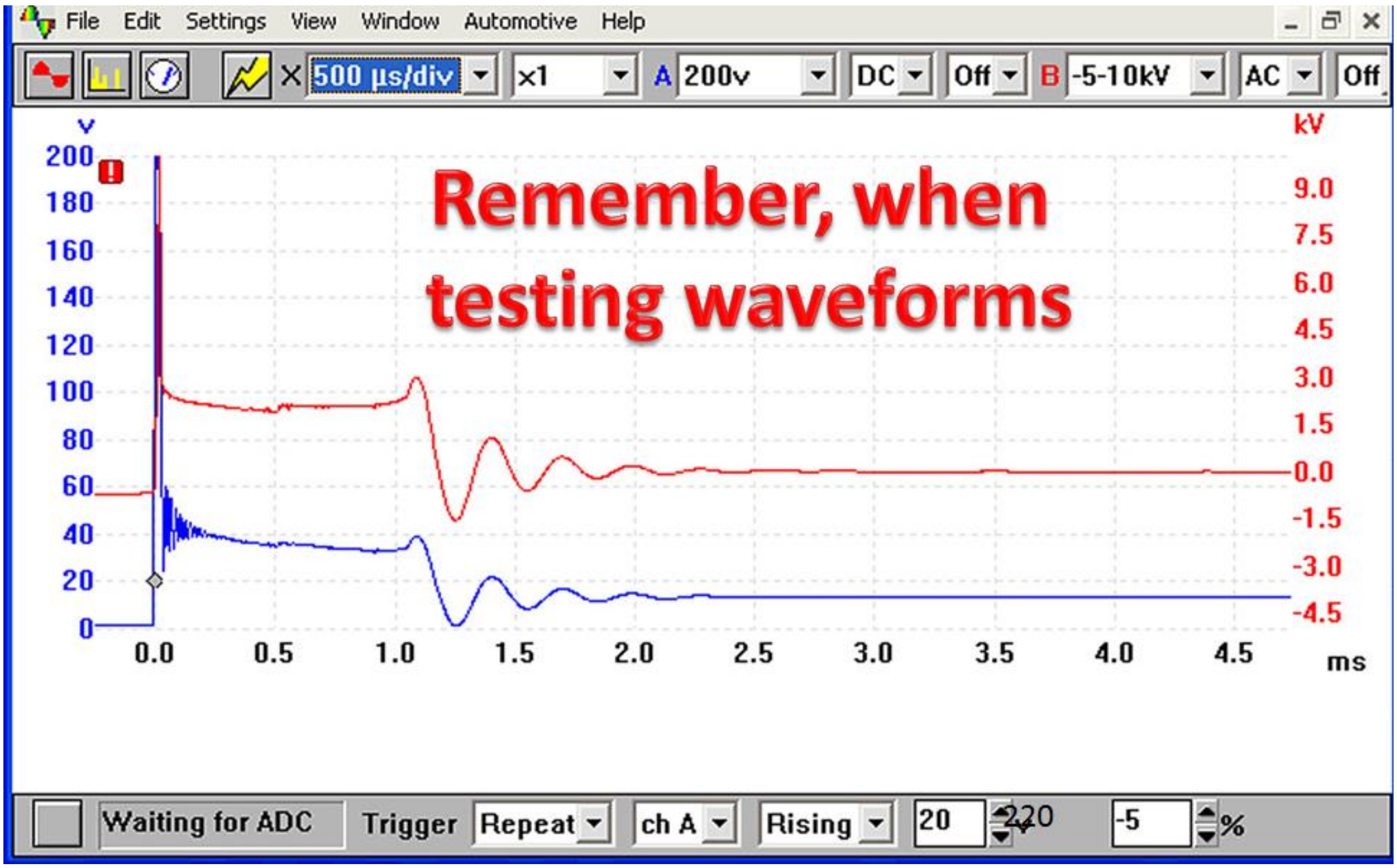


Typical 2 wire COP unit:
This is the most basic system. There is a power (B+) and a control circuit. The B+ comes through a fuse and supplies power to each COP unit. The control circuit supplies a ground to complete the circuit. The control is connected to a driver in the PCM. The PCM grounds the driver supplying a ground for the COP unit turning it on. Current flows through the primary winds. When the PCM needs to fire the spark plug it opens the driver, primary current stops flowing and collapses into the secondary and current flows through the secondary to ground having to jump the spark plug gap. When the spark jumps the gap, the electrical arc ignites the air fuel

mixture. The 3 and 4 wire COP units have these basic two circuits to create the spark. With the 2 wire units the PCM is the ignition module. It supplies the ground to control the COP's circuit.

Ignition coils:

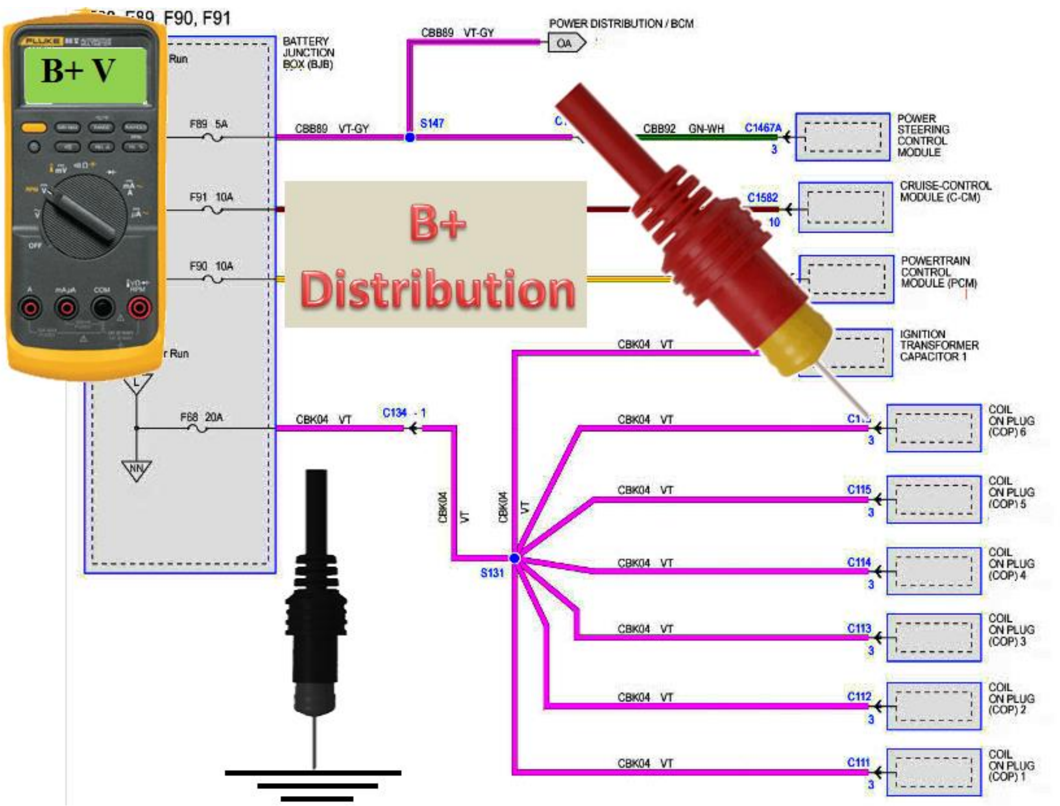
Ignition coils are basically step up transformers. A transformer takes low voltage to create the high voltage to send an arc across the spark plug. The transformer has two coils a primary and a secondary coil. The primary windings have larger diameter wire and less winding. The primary has a low resistance value, between 0.5 and 2 ohms. The secondary has smaller diameter wire and a lot more windings. The primary has a low resistance value, between 7,000 and 16,000 ohms. The primary windings are shorter or have less turns than does the



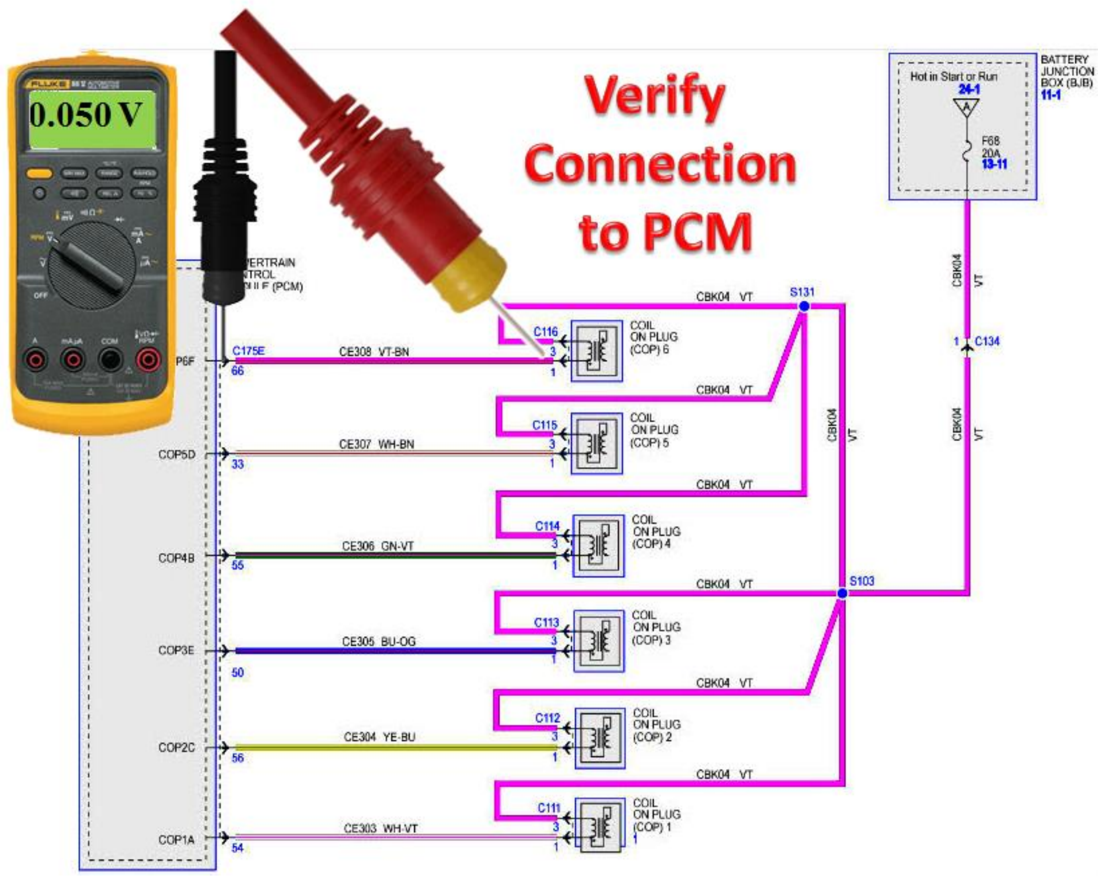
secondary. For every 1 turn in primary there are 100 turns in secondary. The primary and the secondary are a mirror image of each other. What can be seen in the primary voltage wave form can also be seen in the secondary voltage waveform.

COP Testing

Each COP unit must have B+ and have a good ground.
If B+ and ground are <u>normal</u>, the current flow in the circuit will be <u>determined by the COP unit's</u> primary and secondary windings.

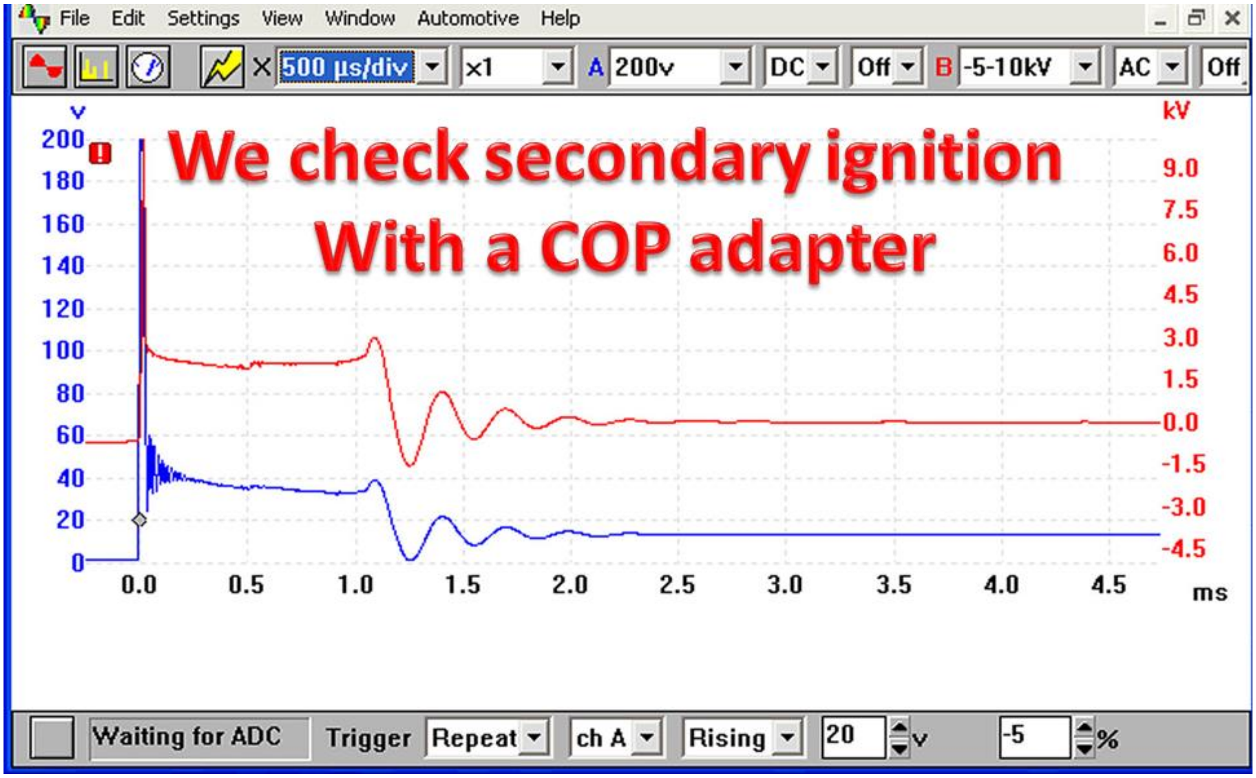


Basic circuit testing is used to insure there are no wiring problems that would keep the COP for operating.



We sometimes see this type problem after a collision or when someone has damaged a connector.

Current flow will not be normal with a wiring problem.

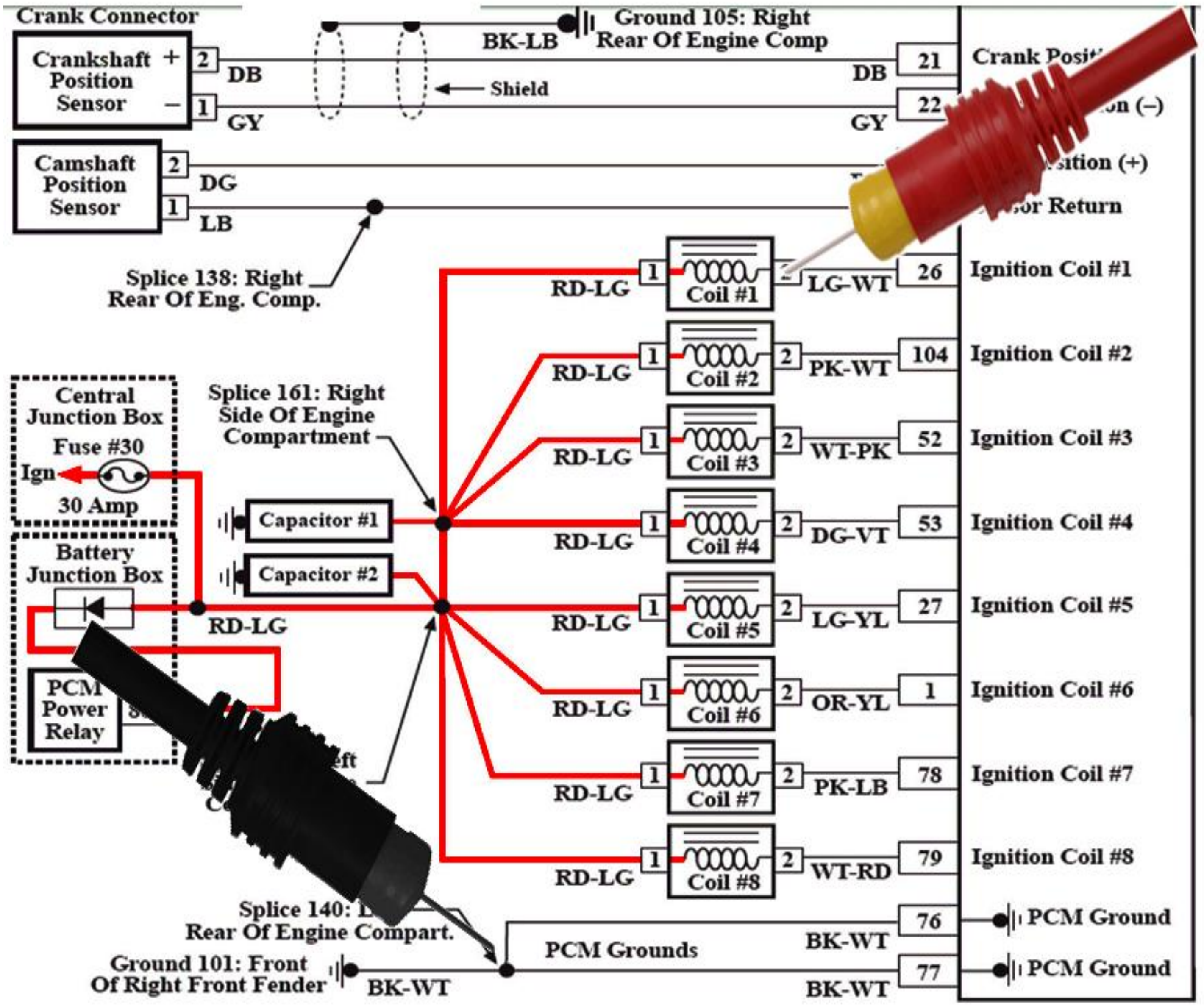

File Edit Settings View Window Automotive Help
500 µs/div
x1
A 200v
DC
Off
B -5-10kV
AC
Off
V
kV
We check secondary ignition
With a COP adapter
200
180
160
140
120
100
80
60
40
20
0
9.0
7.5
6.0
4.5
3.0
1.5
0.0
-1.5
-3.0
-4.5
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
ms
Waiting for ADC
Trigger
Repeat
ch A
Rising
20
v
-5
%


Automotive Test Solutions
ECOP Quick Start Guide
Patent Pending. Copyright © 2009 ATS
ECOP

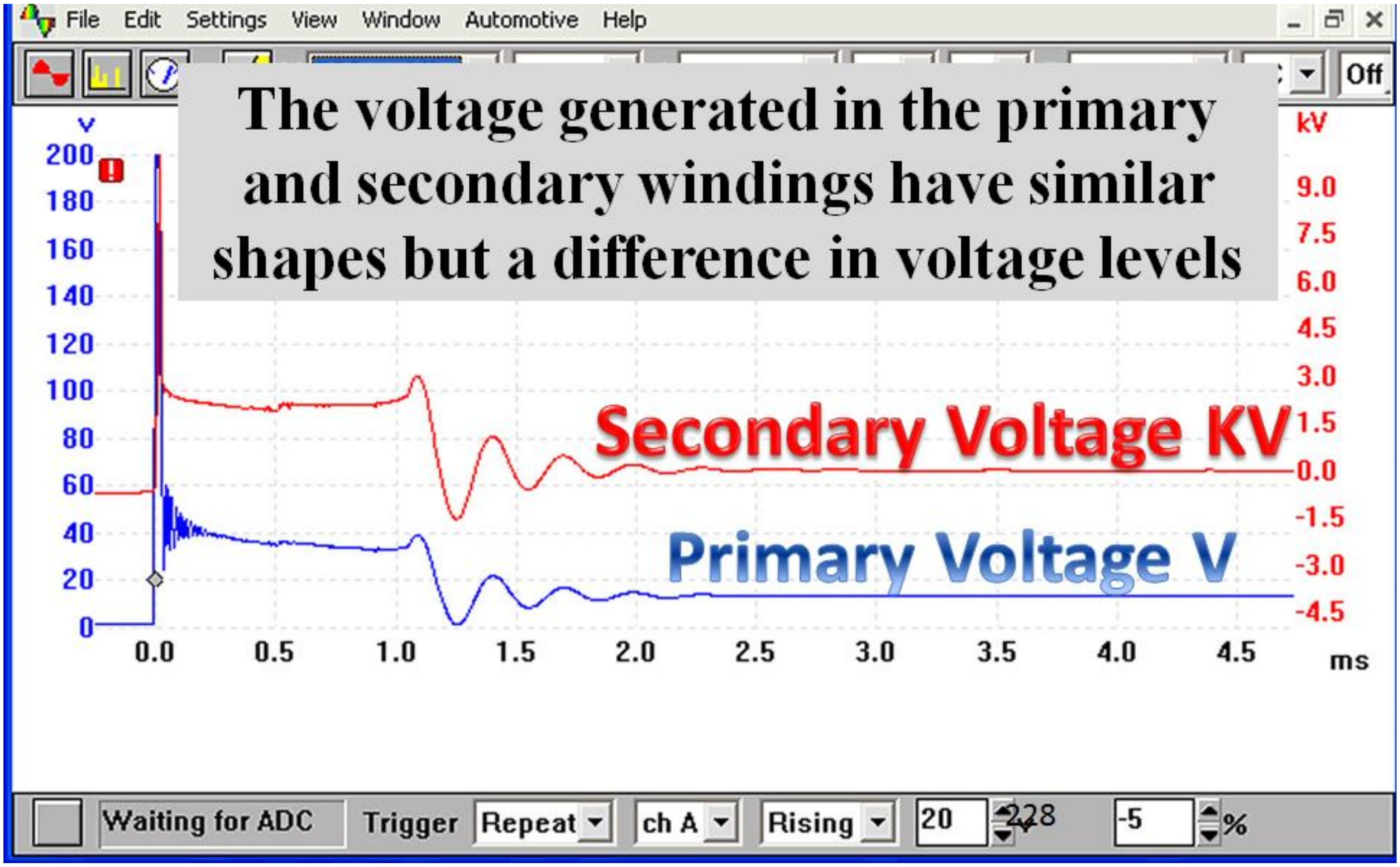
You need a lab scope to display the secondary patterns.

Typical 2 wire COP unit

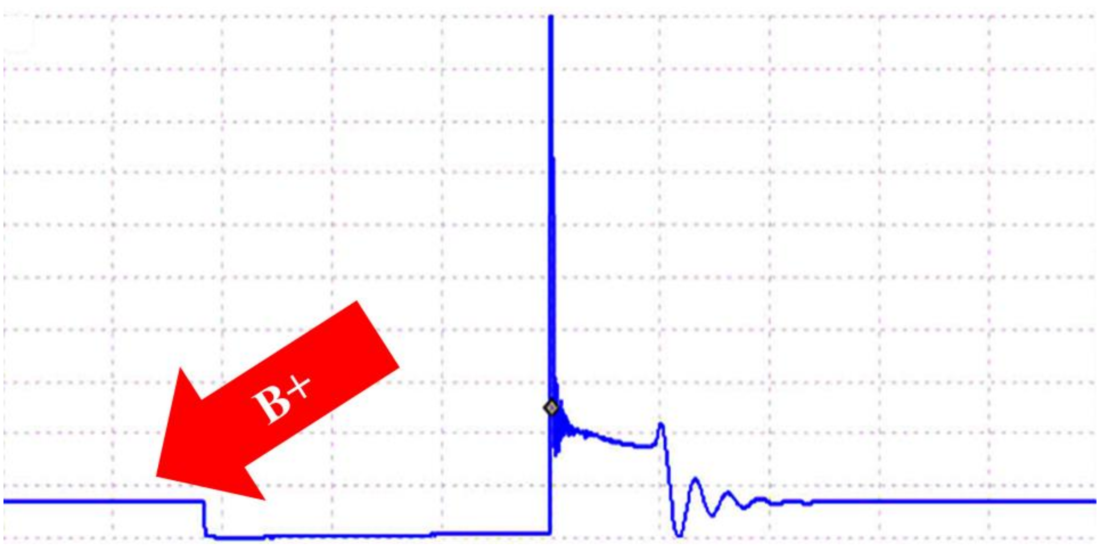
This is the most basic system. There is a power (B+) and a control circuit. The B+ comes through a fuse and supplies power to each COP unit. The control circuit supplies a ground to complete the circuit. The control is connected to a driver in the PCM. The PCM grounds the driver supplying a ground for the COP unit turning it on. Current flows through the primary winds. When the PCM needs to fire the spark plug it opens the driver, primary current stops flowing and collapses into the secondary and current flows through the secondary to ground having to jump the spark plug gap. When the spark jumps the gap, the electrical arc ignites the air fuel mixture. The 3 and 4 wire COP units have these basic two circuits to create the spark. With the 2 wire units the PCM is the ignition module. It supplies the ground to control the COP's circuit.



Ignition coils are basically step up transformers. A transformer takes low voltage to create the high voltage to send an arc across the spark plug. The transformer has two coils a primary and a secondary coil. The primary windings have larger diameter wire and less winding. The primary has a low resistance value, between 0.5 and 2 ohms. The secondary has smaller diameter wire and a lot more windings. The primary has a low resistance value, between 7,000 and 16,000 ohms. The primary windings are shorter or have less turns than does the secondary. For every 1 turn in primary there are 100 turns in secondary. The primary and the secondary are the mirror image of each other. What can be seen in the primary voltage wave form can also be seen in the secondary voltage waveform.

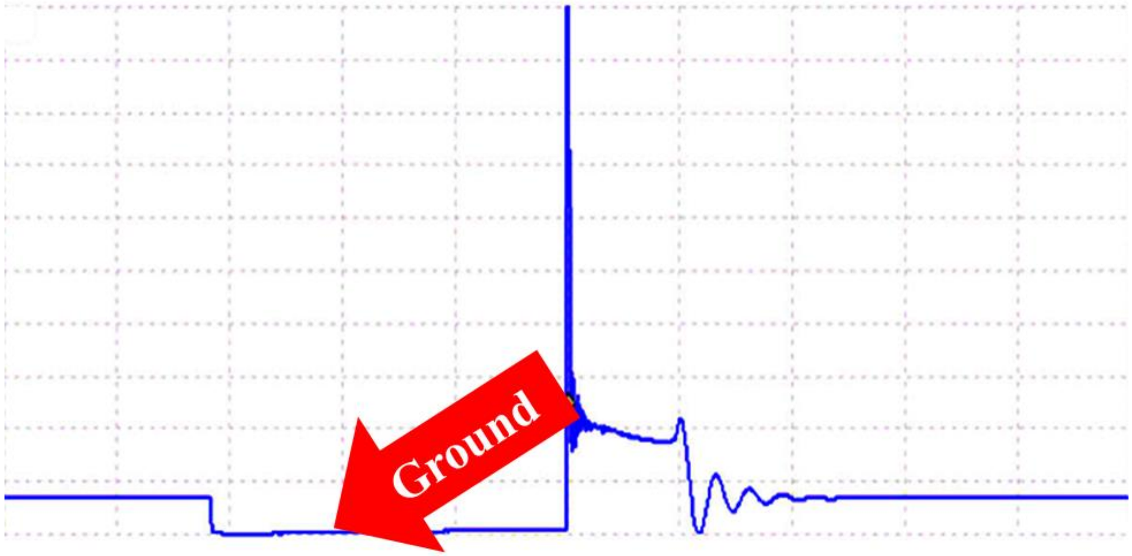


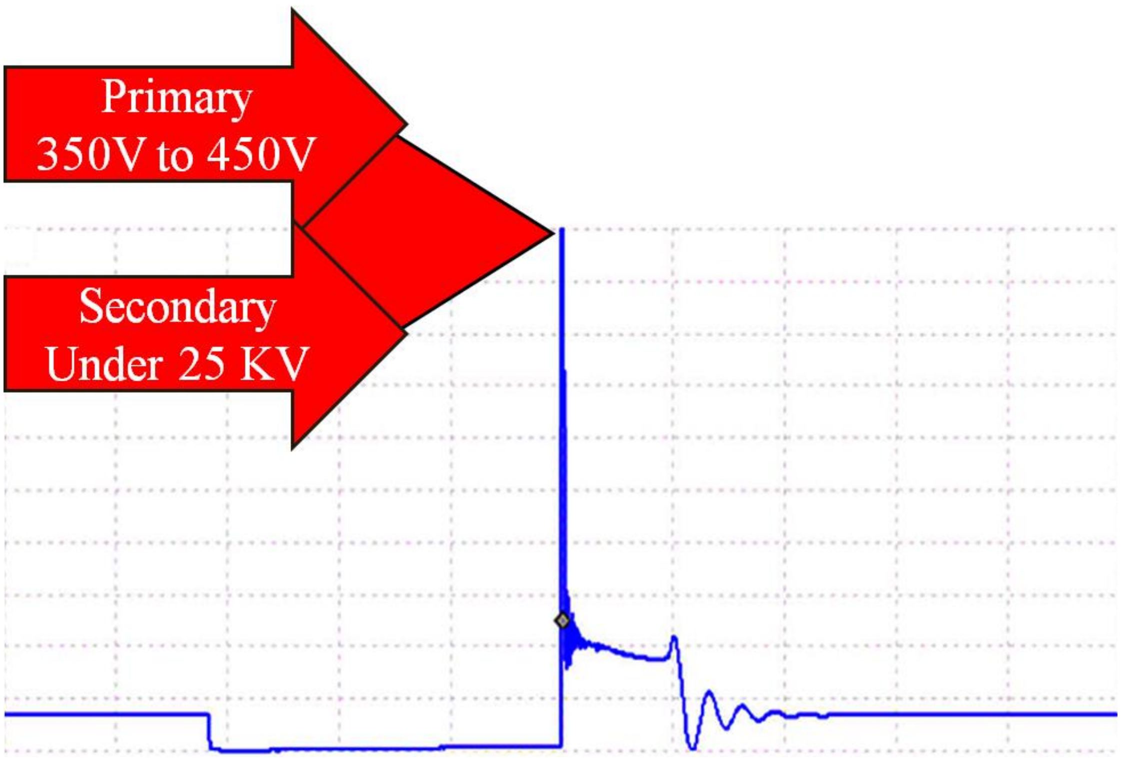
Primary Ignition Waveform Analysis



The primary is supplied B+ and is ground side driven, so the control or ground side reads B+ when the primary current is off.

The next change in the pattern is when current starts flowing to build a magnetic field around the ignition coils. This is ground enabled or low side driver, so the control grounds the control circuit to start current flow.





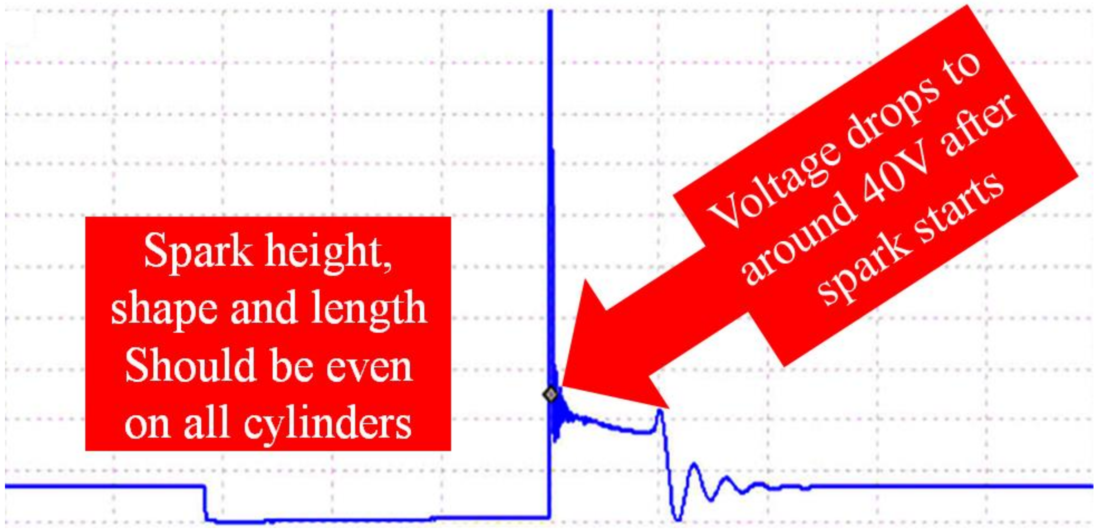
The control removes ground to collapsoe the magnetic field which grnerates a voltage in the windings. The primary voltage spike heigh is directly related to the coil windings and the current that created the magnetic field that collapsed to generate the voltage.

If the primary voltage spike is not as high as expected, check the current and coi primary resistance. The secondary will have reduced voltage available if this spike is low. It is smoetimes easy to blame the COP unit because they fail, but replacing COP units may not correct all ignition misfire problems. Be prepaired to go beyond swapping COP as a diagnostic. There are wiring, connector and PCM driver problems that can also be a problem.

If all COP primary voltges are low, check the B+ supply and the PCM ground. Remember, the PCM must supply the ground to start current flow. This type of diagnostic we are doing here is where you go after your "quick fixes" do not correct the problem.

The spark shape is the same in primary and secondary. There will be silghtly more ringing at the start of the spark in the primary signal, but the overall shape will be very close.

The shape of the spark line conveys a lot of information about what is going on inside the cylinder.



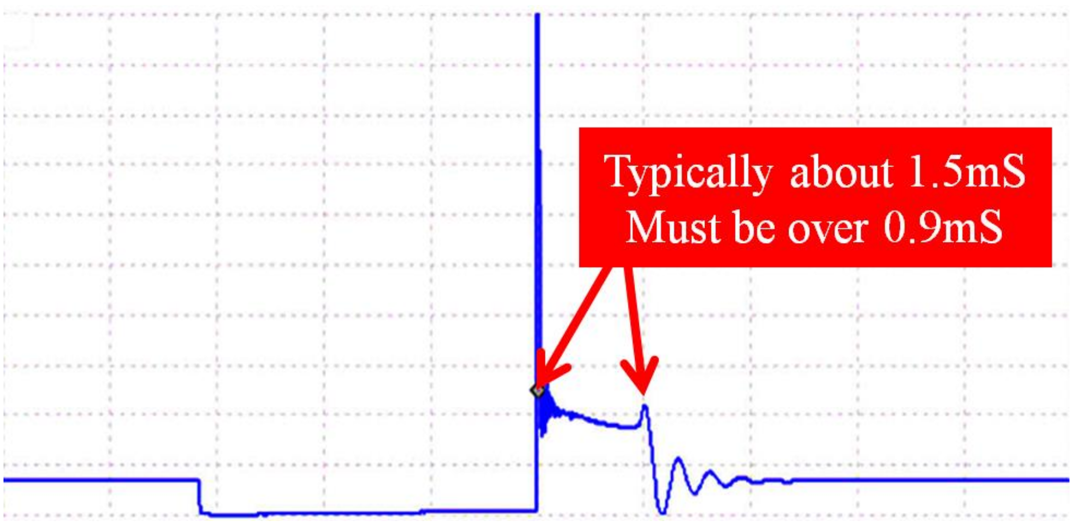
Spark Analysis

Factors that influence the start of spark;

- Temperature of electrodes
- The coil energy and its circuits
- The resistance to cross the spark gap (size of the gap and gases in the gap)
- Secondary leakage current that bypasses the air gap
- The concentration of the gas in the air gap (lean/Rich)

Spark Length

The length of the spark is directly related to energy the ignition coil stored in the magnetic field that collapsed to produce the spark.



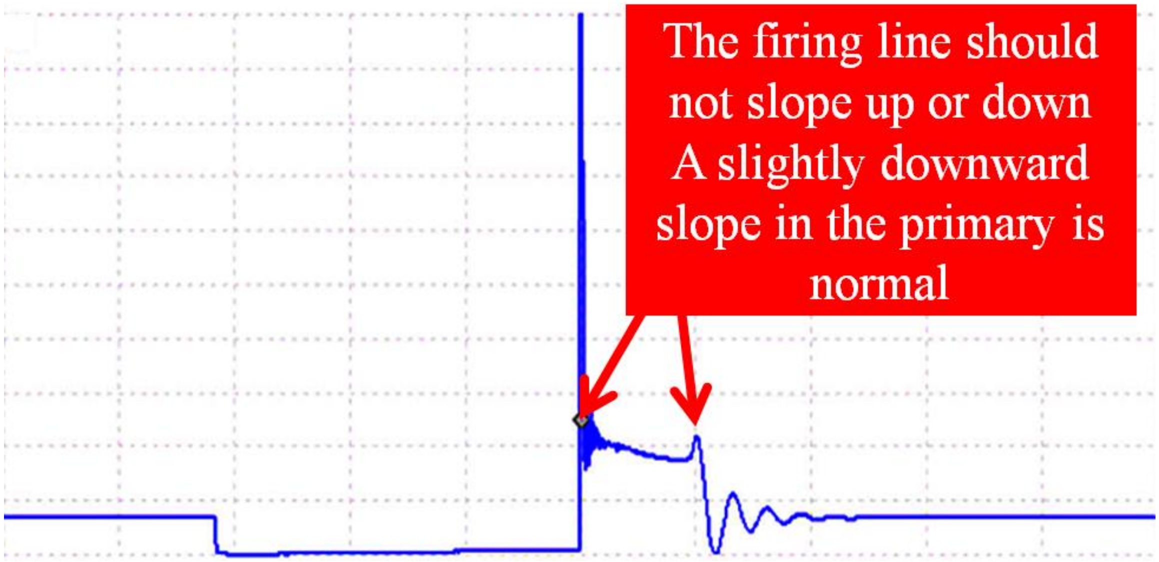
If the primary current flow is limited by a problem, it will reduce the energy stored in the magnetic field and result in a short spark.

Do not condemn the secondary without insuring the primary has normal current flow.

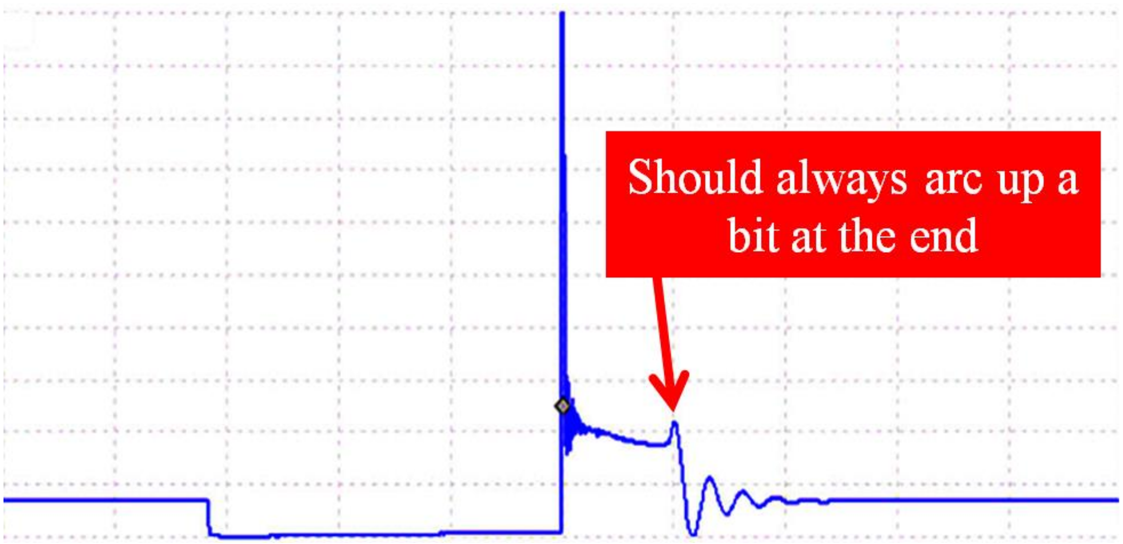
Spark Line Slope

The spark line should not have steep slope up or down. The primary is a low voltage scale, compared to KV, so a slightly downward slope is normal.

Steep slope is sign of resistance.



Spark Line Ending

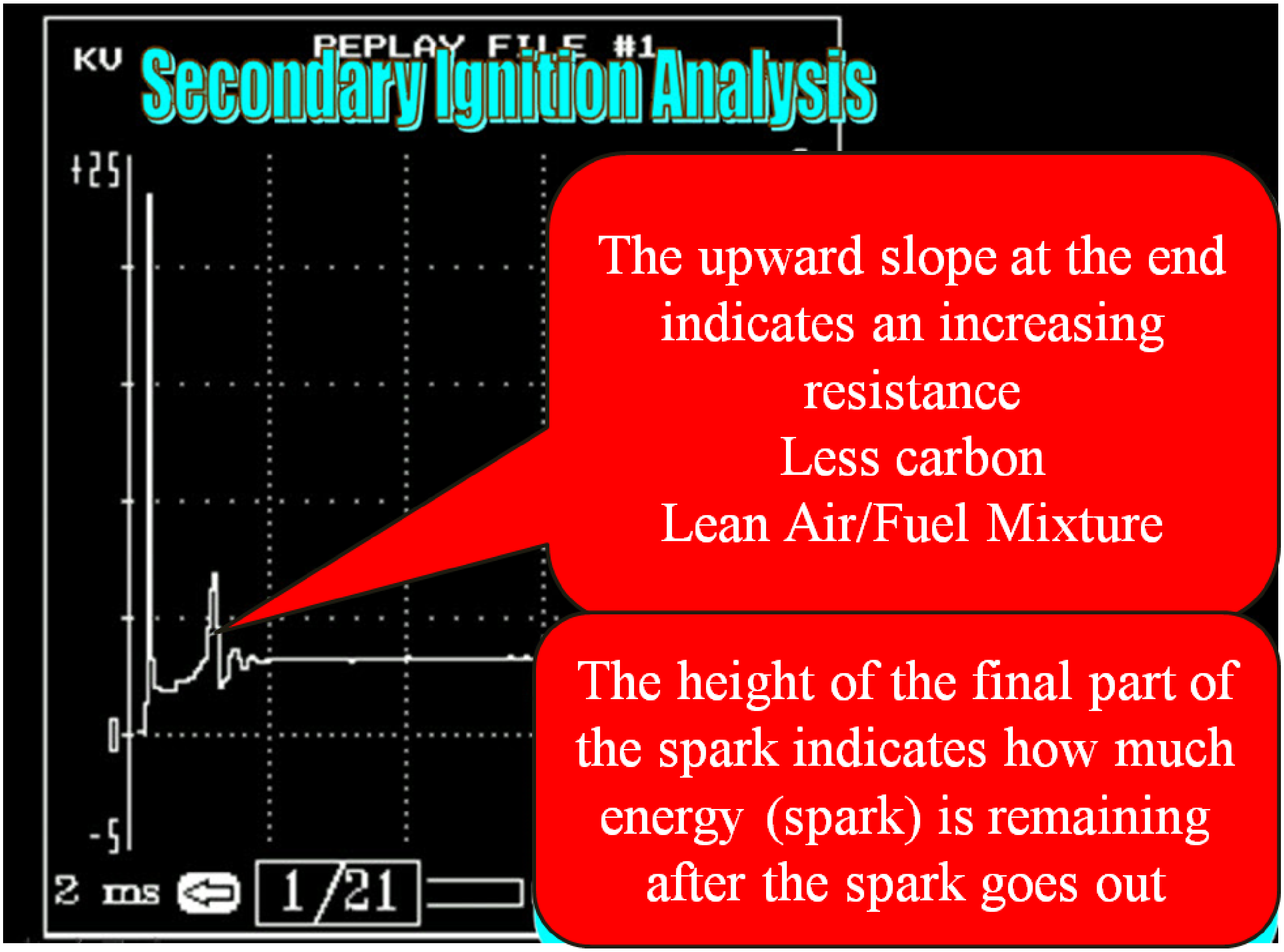


When the spark stops there should be a slight rise in the voltage, indicating there is a small amount of energy left in the coil.

Cylinders firing outside the cylinder will have little or no energy remaining because the spark is not being compressed like the gas in the cylinder.

Lean Fuel Mixtures

Lean fuel mixtures increases resistance as the fuel is used up. Fuel ions low the resistance to the spark, a lean mixture consumes much of the fuel before the spark goes out which causes resistance to be higher than it was when the spark started. This increasing resistance causes the spark line to slope upward. The higher resistance

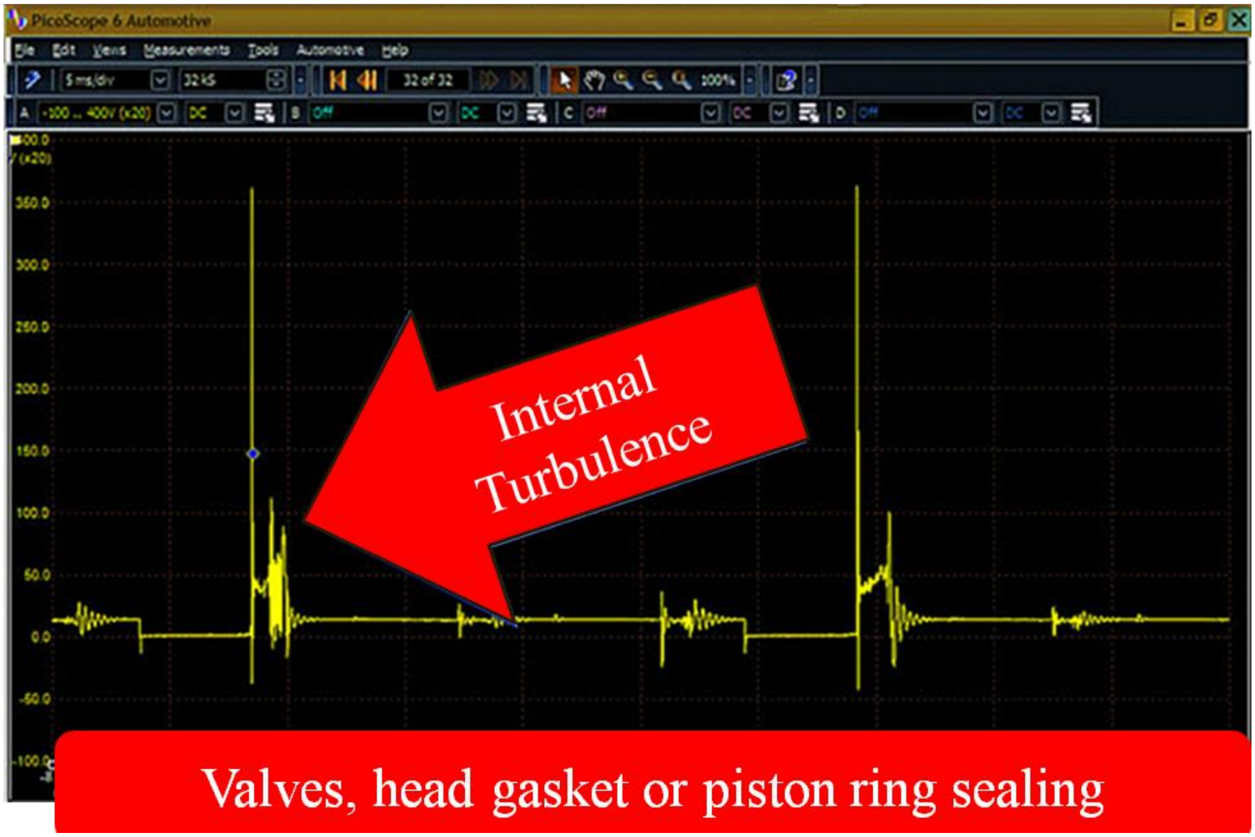


also causes the spark to go out soon than normal which causes the slight increase at the end of the spark to much higher. The is a classic example of fuel lean out in the spark line. Notice that the spark goes to About 25KV which puts stress on the secondary ignition components. Did you ever ask yourself why a spark goes down the side of a well insulated spark plug?

Detailed Analysis

A combination of worn spark plugs and lean fuel mixtures can combine to cause high COP unit failures.
Replacing the COP unit is a short term fix that does doesn't last (possible comeback).
The lean condition must be fixed or early COP unit failure is likely.

Internal Cylinder Turbulence



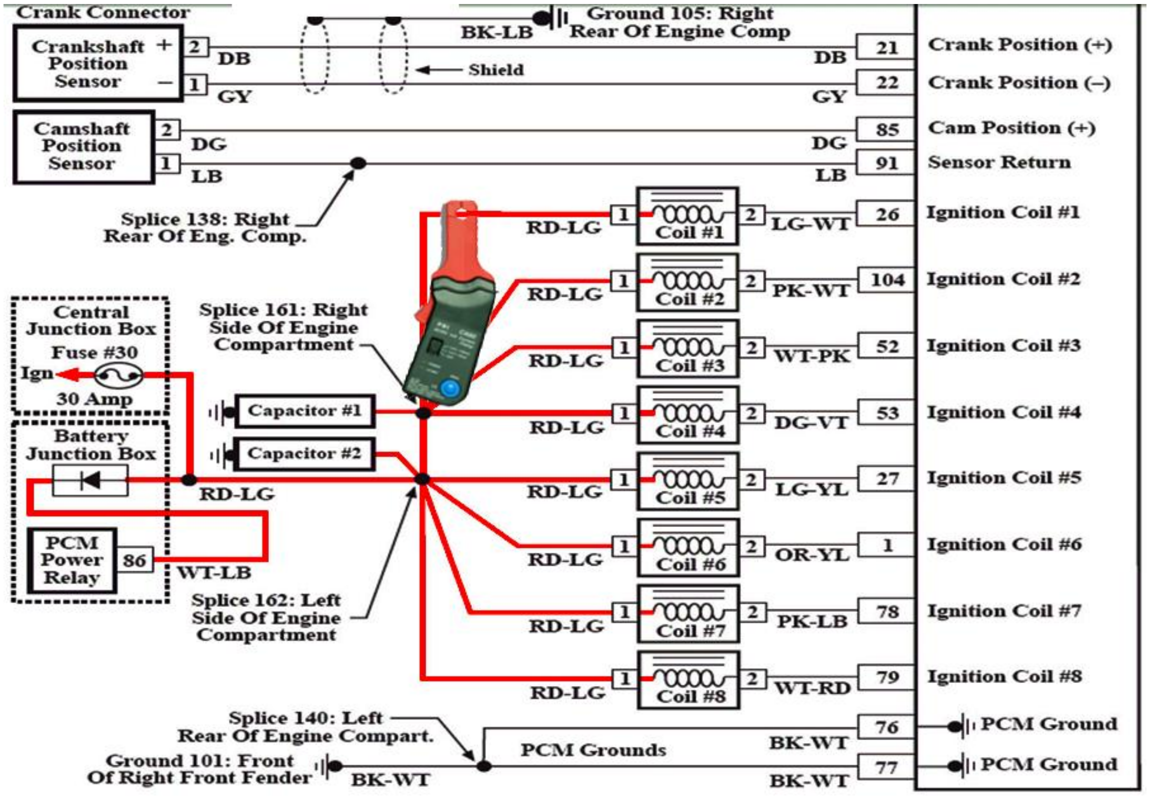
Turbulence causes the mixture to vary wildly which produces noise in the spark line. This can be cause by EGR, but EGR will impact all cylinders. Off idle operation shows this type noise to a slight extent when EGR is opened, but it should not be excessive.

Detailed Ignition Analysis

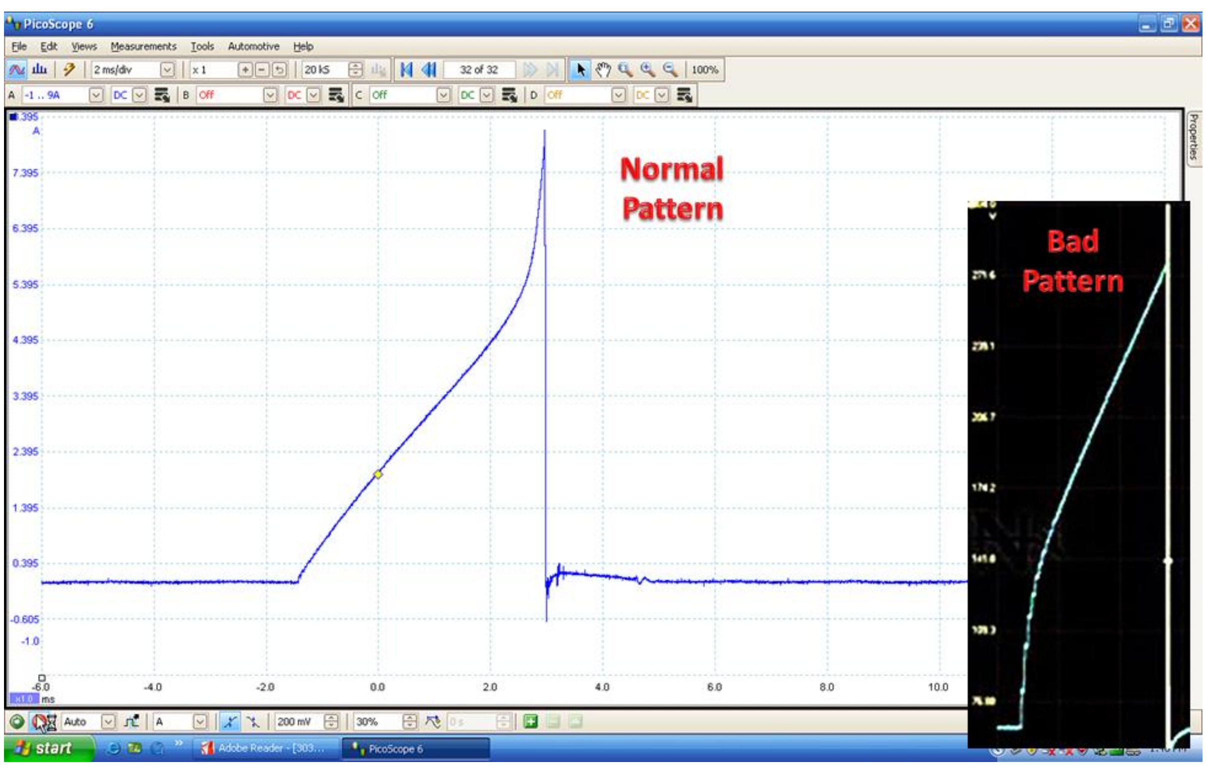
Use a scan tool and perform a cylinder contribution test or cylinder balance test on some vehicles.
Perform a relative compression test on newer vehicles.
The scan tool only identify problems in the coil primary circuit, it does not identify secondary ignition problems.
Check the EGR or block it off to check for EGR problems.
Now it is time to move beyond scan data to identify the root cause of the problem. Remember, from the examples earlier, we saw lean fuel mixtures that accelerated the failure of COP units. Replacing a COP unit that must create very high voltage to fire a lean mixture will cause secondary insulation; like the spark plug boot to develop carbon tracks or cause early failure of the COP unit. It is easy to blame the manufacturer, and everyone knows we could use improvements in COP units, but the best COP unit designs need a reasonable fuel mixture to keep secondary voltage in a reasonable range.

Current testing of COP units

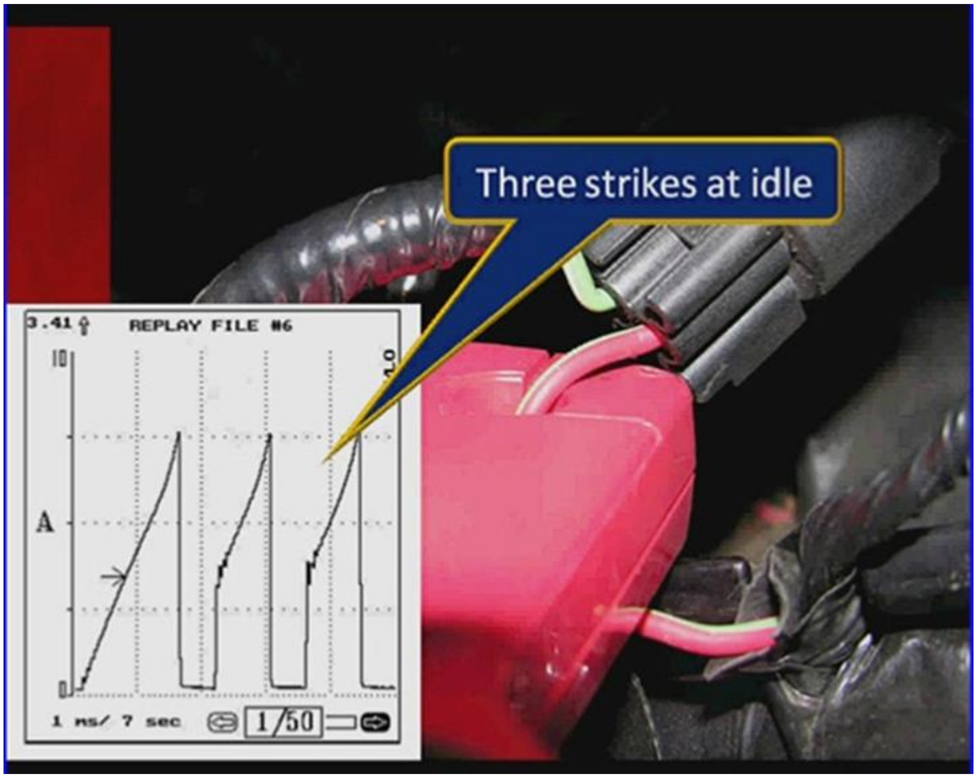
Connect to either side of the ignition coils with a low amps probe. You can test a single coil by using the wiring going to a specific COP unit or you test more COP units by connecting to the B+ supply to the 2-wire COP units. Normal and bad current waveforms are shown for your analysis.



It is this opposition that causes the high voltage spike in the secondary when current is turned off.Coil are inductors, an inductior opposes ANY change in currret flow. The ressoe for this opposition is the magnetic field created by changes in current move to try to keep current flowing. Notice the normal has a gradual slpope up while the coil with shorted primary winding increases quickly. The other difference is the maximum current goes higher on the bad coil.



Multi-spark ignition



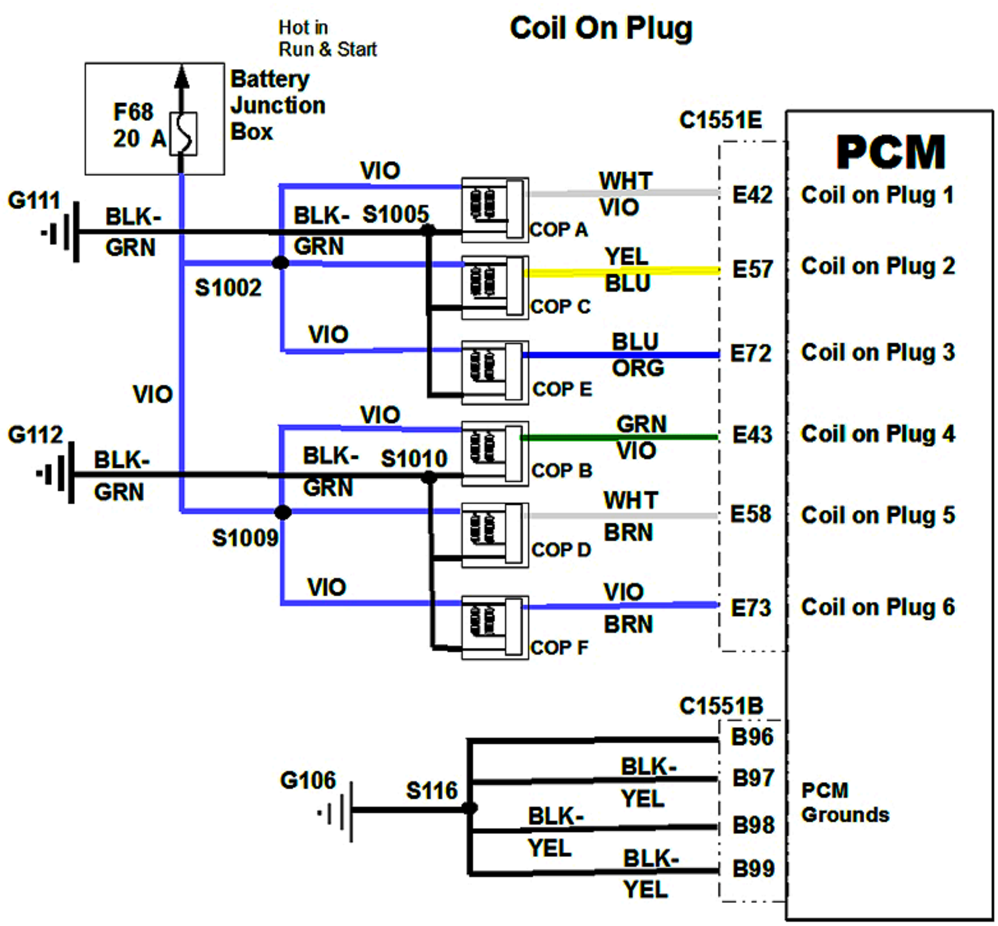
Some manufacturers fire the spark plug several times during idle operation to improve emissions, the system reduces the number of sparks as engine speed is increased.

We measue the maximum current on the first strike.

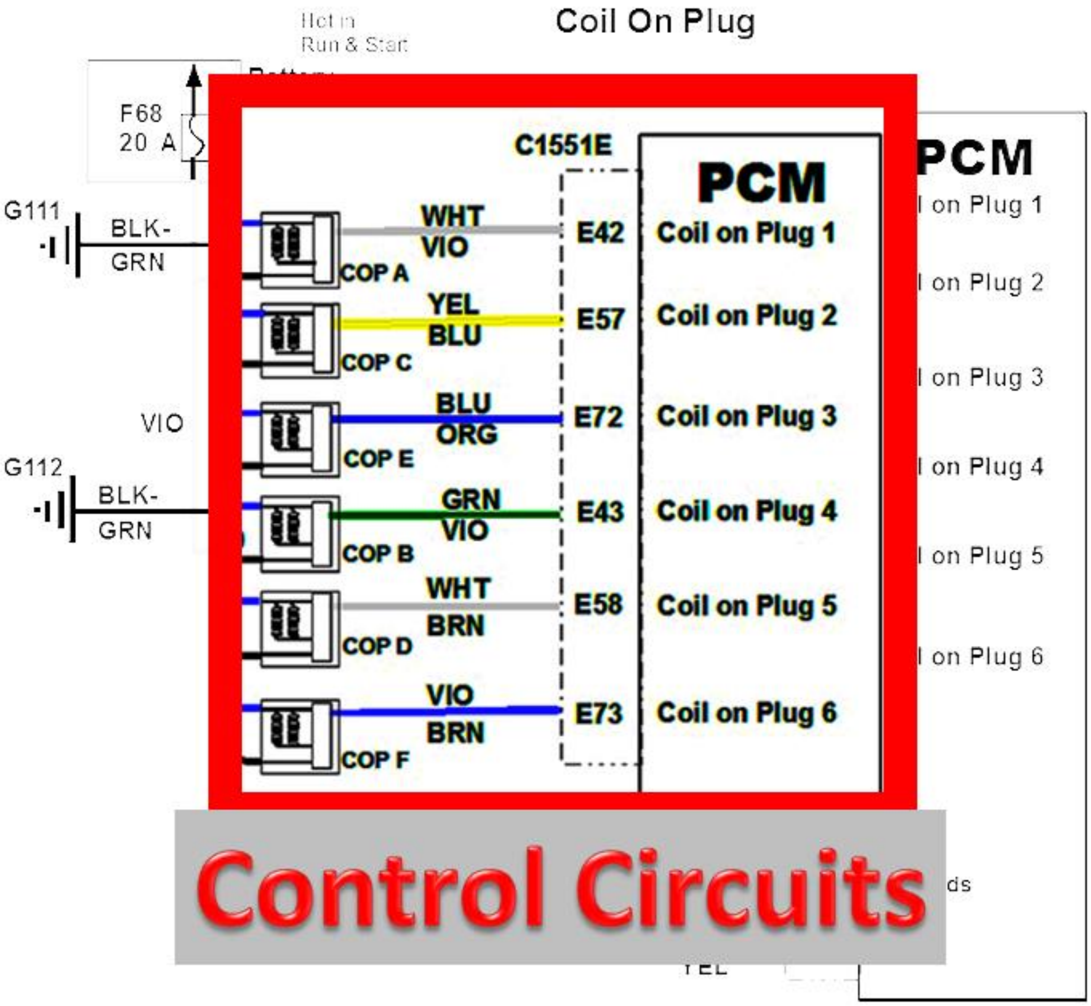
Typical 3 wire COP units

COP units with wires have electronic switching inside the COP unit for primary coil current and are controlled by a digital signal from the PCM.

Notice in the example diagram, that B+ and ground are to the left of the COP unit with a single wire from the PCM.



3 Wire Control Circuit

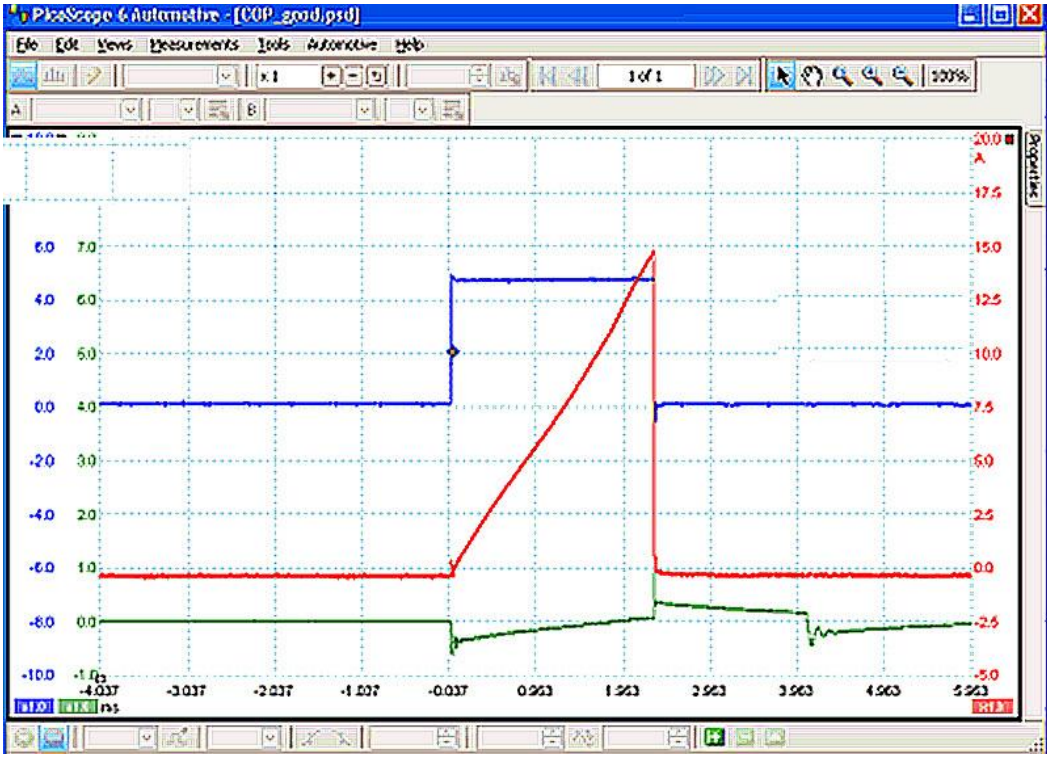


The control circuits from the PCM are highlighted in this example.

3 wire units have an additional circuit from the PCM to the COP unit for control.

- The COP unit has its own power switching for the primary circuit (Functions as an ignition module)
- It controls the primary current for the ignition coil (Closes and Opens the primary circuit)
- The third wire is a signal to command when to open the primary circuit (and fire the coil)

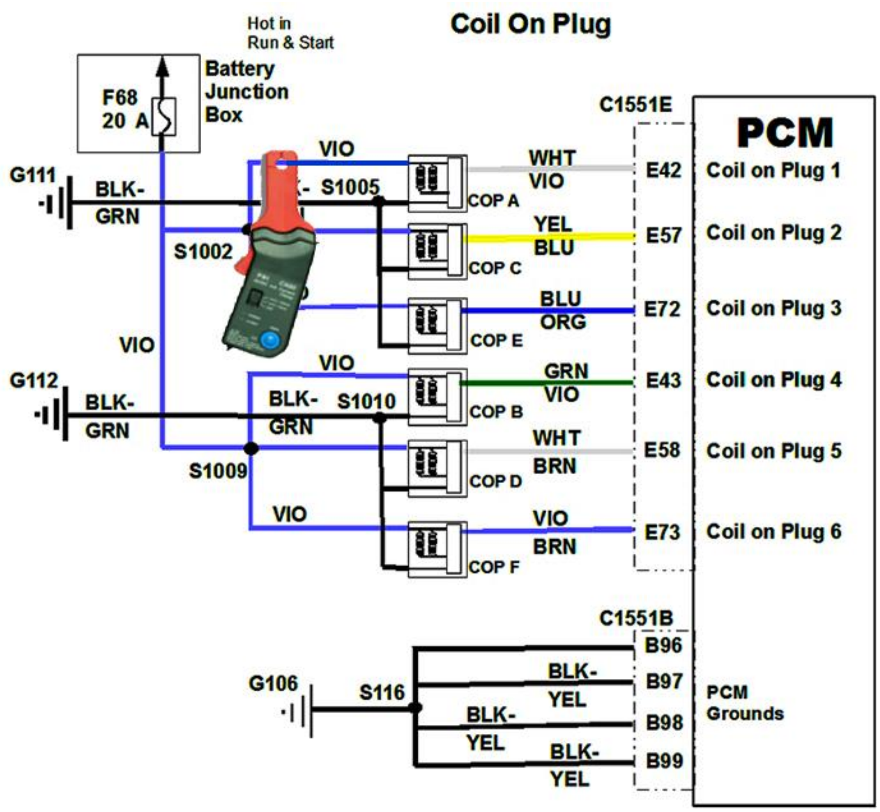
Lab Scope Pattern of 3 wires



The lab scope pattern will show the current flow, the secondary ignition pattern and the digital signal from the PCM.

Control Signal Blue'
Current Flow Red,
Secondary Ignition Green.

Test Connection for Current



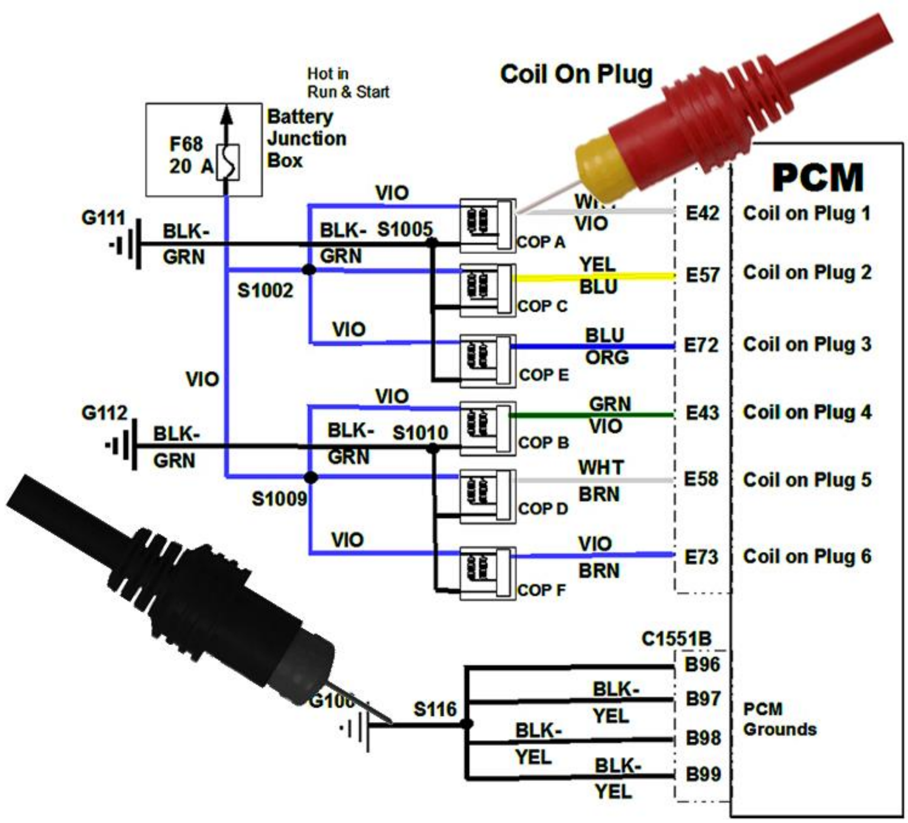
Test Connection for Secondary

Move the COP pick up to a position that gives you the best pattern, but don't expect the perfect patterns like we see from plug wires.

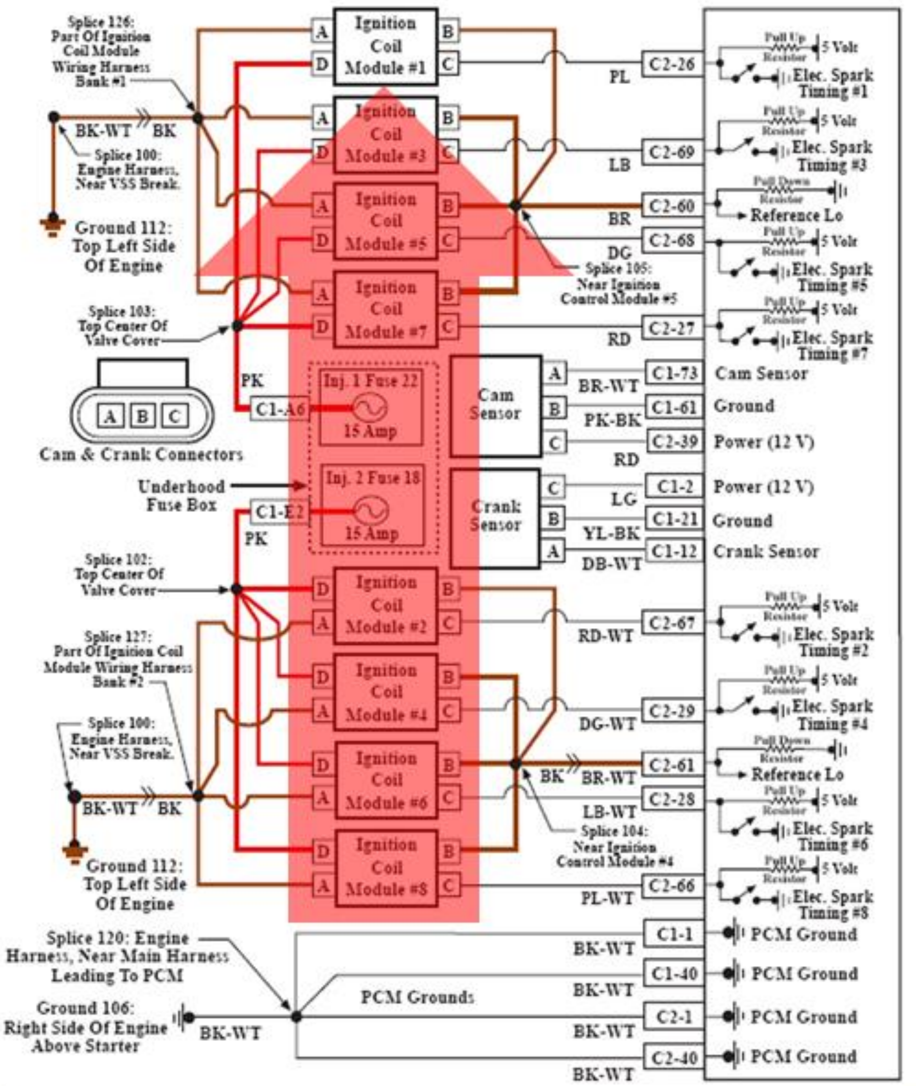
You will have inverted the scope pattern because the true voltage direction is negative.

Test Connection for PCM Control Signal

Connect the red lab scope lead to the signal circuit and the black lead to the ground.

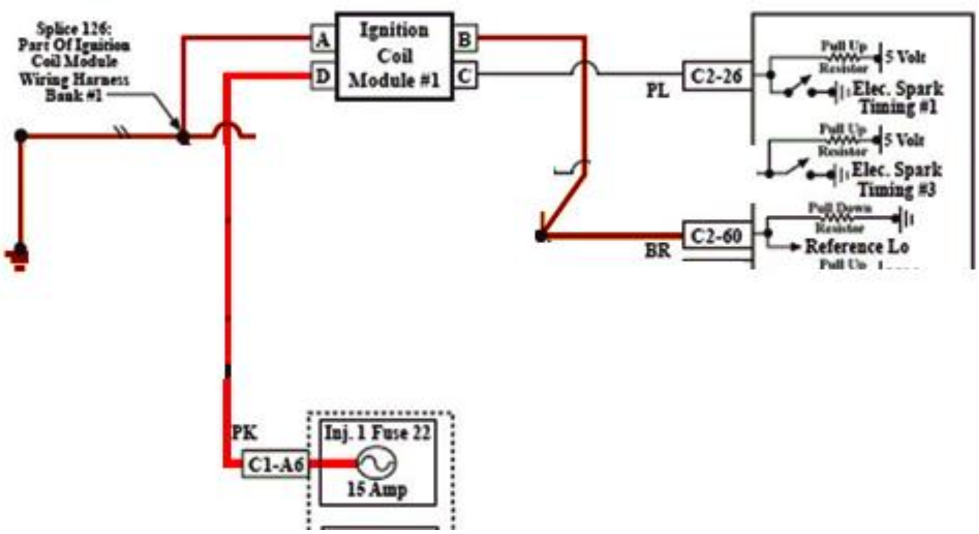


Typical 4-wire COP Unit

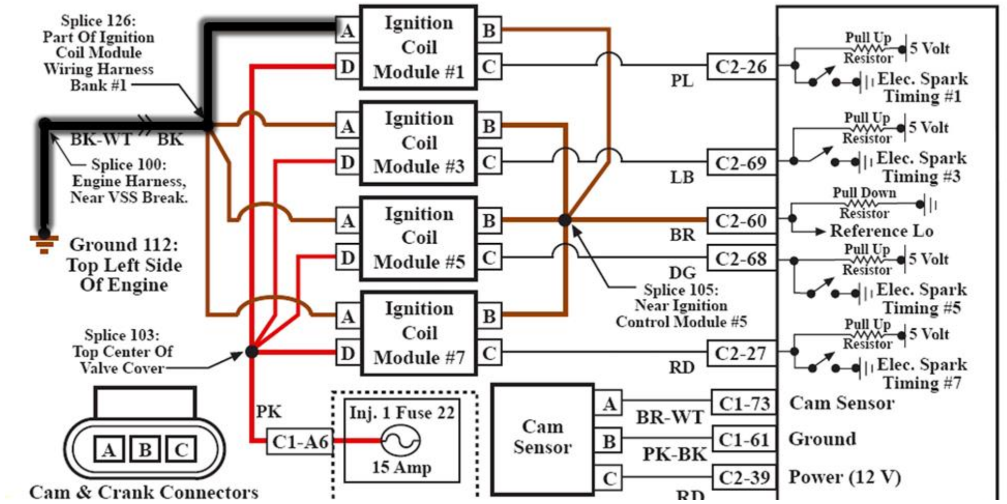


Operation is similar to the operation of the 3-wire COP unit. The control signal has a ground reference called reference low. This isolates the digital signal from the power ground for the control signal.

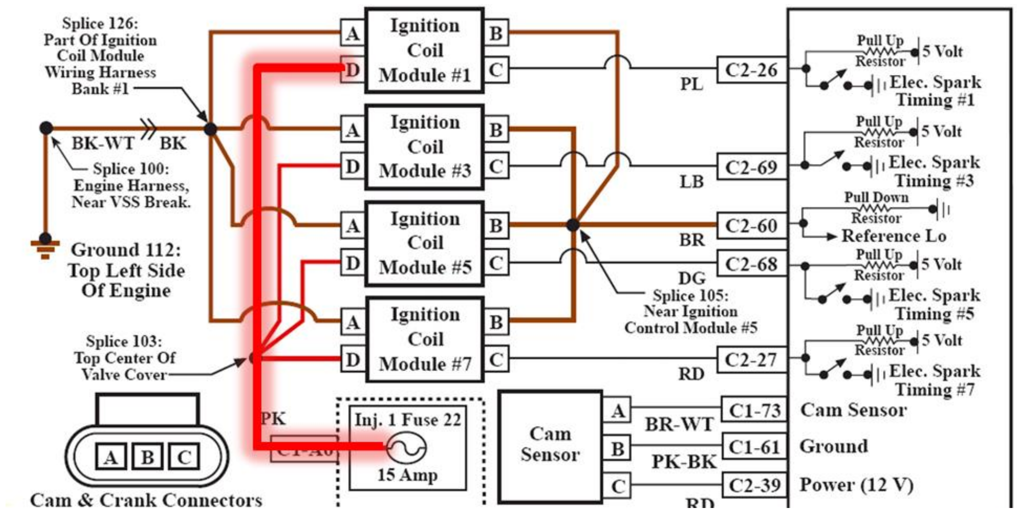
Most manufacturers have gone to the 3-wire version.



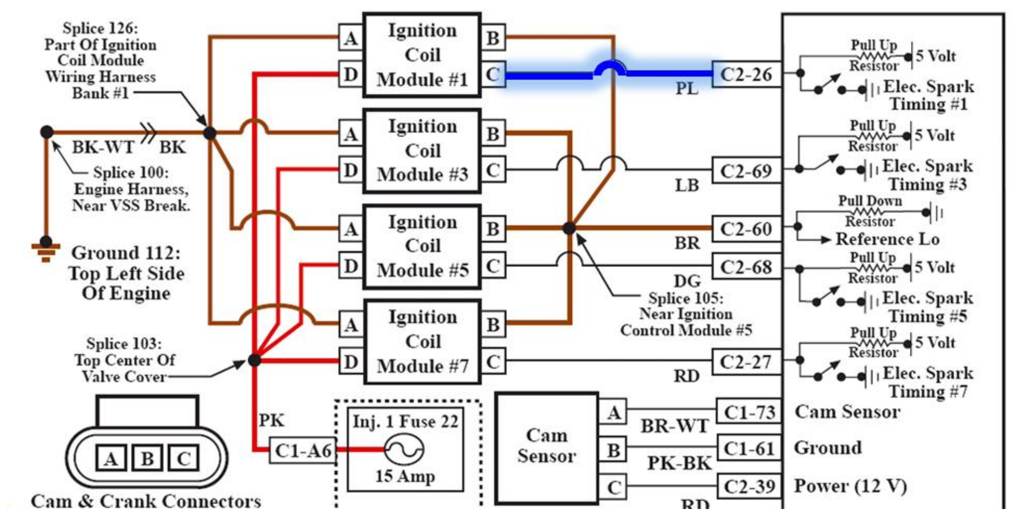
These are the circuits for a single COP unit.



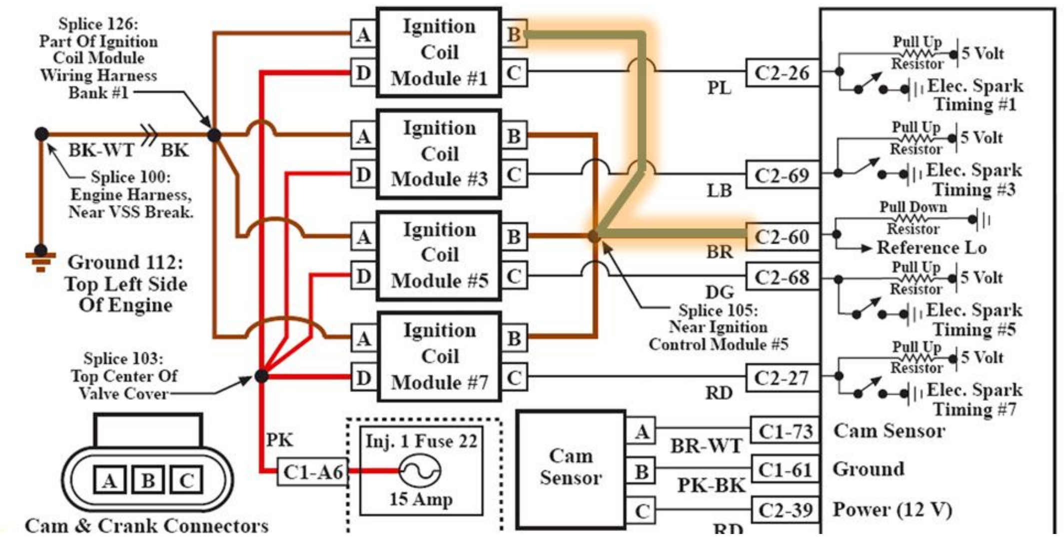
The power ground is shared by the COP units.



B + is shared by the COP units.



The PCM controls individual COP units for ignition control.

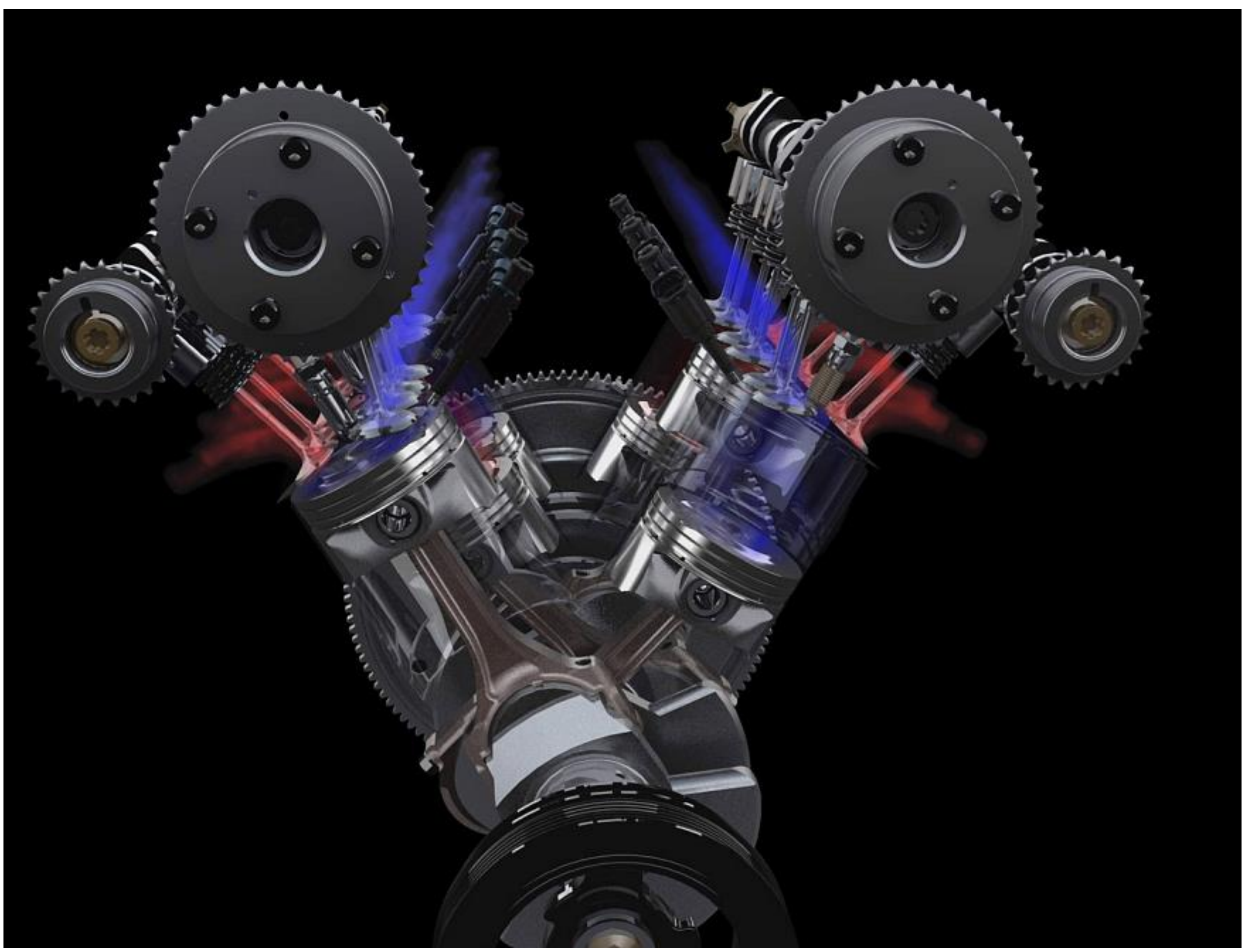


The reference low is used by the PCM and COP unit a ground for the control signal from the PCM.

This added ground reference is the only difference in 3-wire and 4-wire COP units.

The next system we will discuss is Independent Variable Valve Timing and Hydraulic valve lift that eliminates the mechanical connection between cams to valve operation.

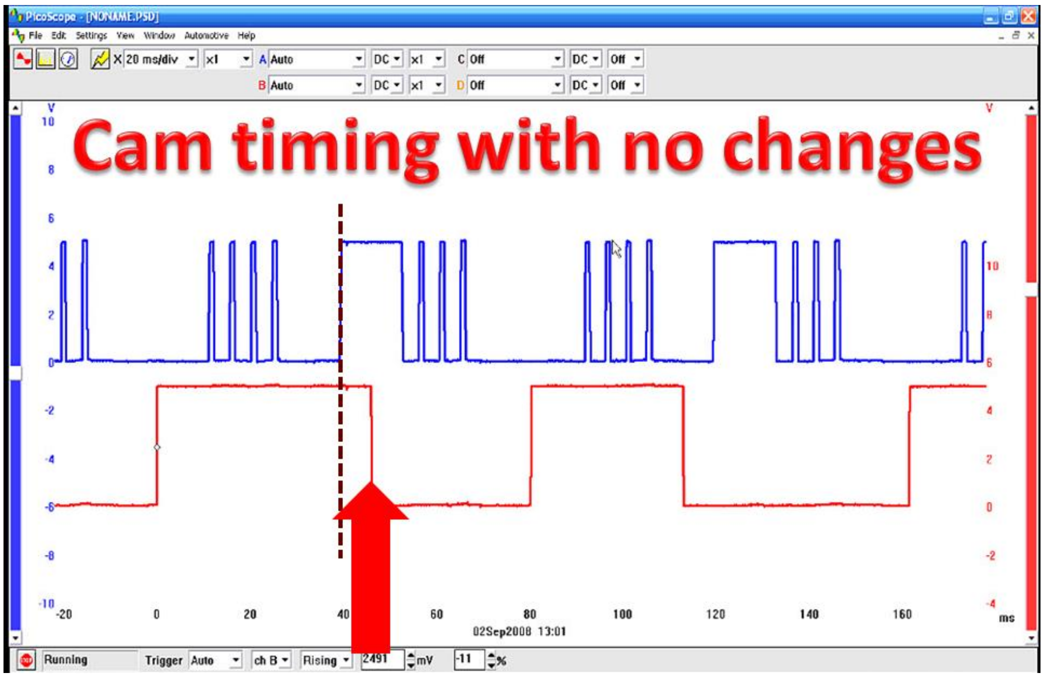
Independent Camshaft Timing



Variable Camshaft Timing

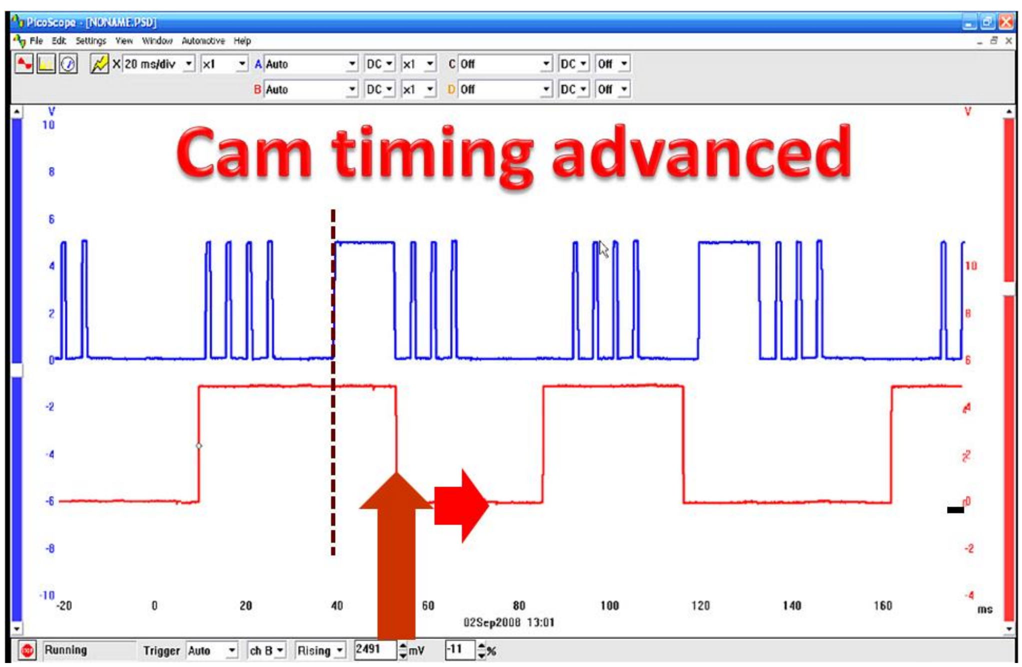
Variable camshaft timing uses oil pressure to adjust valve opening and closing events, providing improved off-the-line acceleration over non-VCT-equipped engines. One method of doing this is camshaft (CAM) phasing, which controls the angular position of the CAM relative to the crankshaft, allowing changes to the timing of valve lift events.

Scope Patterns of Valve Timing Changes



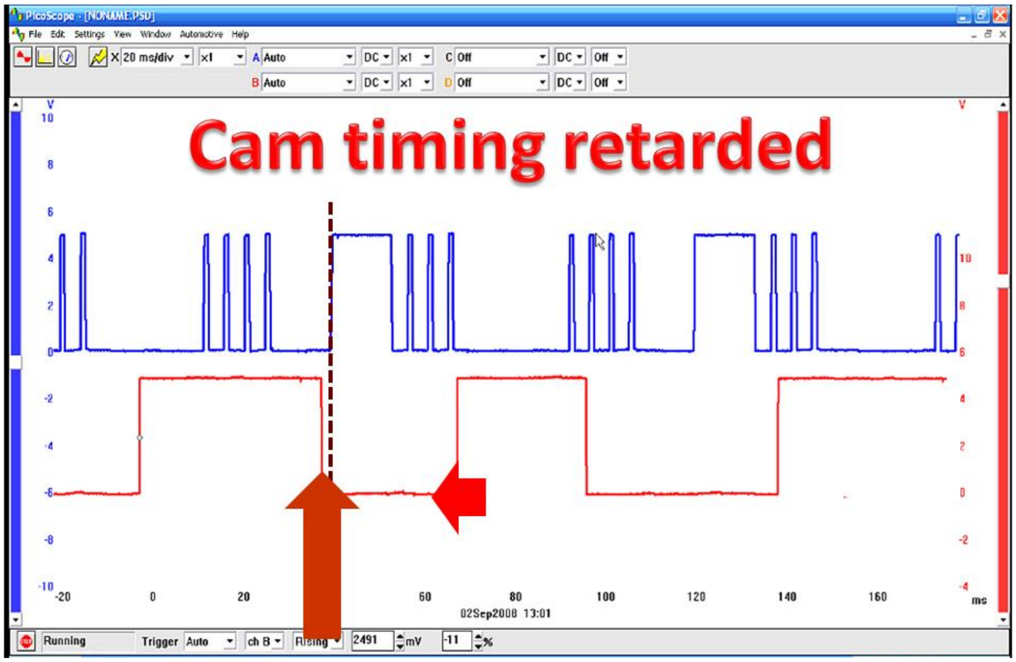
The crankshaft pickup signal is blue and the camshaft pickup signal is red.

The starting point in this timing study is when the cam is in normal operation before timing is changed.



The cam timing is shifted right, indicating the cam is opening earlier in relation to the crankshaft position.

The amount of advance is determined by operating conditions. The PCM constantly calculates the best cam timing for conditions.



Cam timing is retarded when the cam opens later in relation to the crankshaft position.

The PCM determines the cam timing that is best for the current conditions. New vehicles have intake and exhaust valve timing. The result of varying both cams is improved performance with a wider torque band.

Some modern V-engines have four cam timing phasers.

This engine is a Ford V-8 introduced in 2005, eight years ago.

VVT For Power and Torque

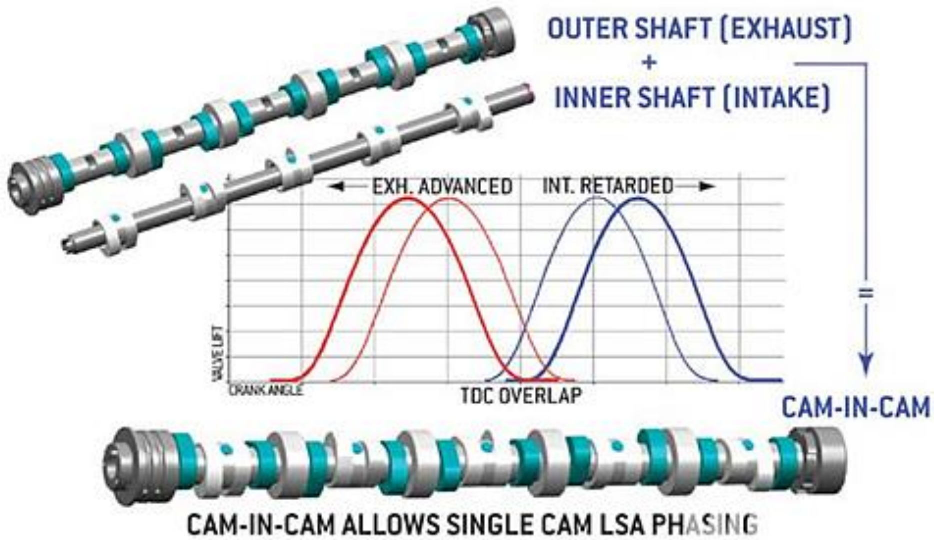
At any specific speed and load, increasing the intake of air into the combustion chamber allows us to burn more fuel, thus resulting in more power being produced. This is measured in terms of an engine's volumetric efficiency (the actual volume induced / the static cylinder volume).

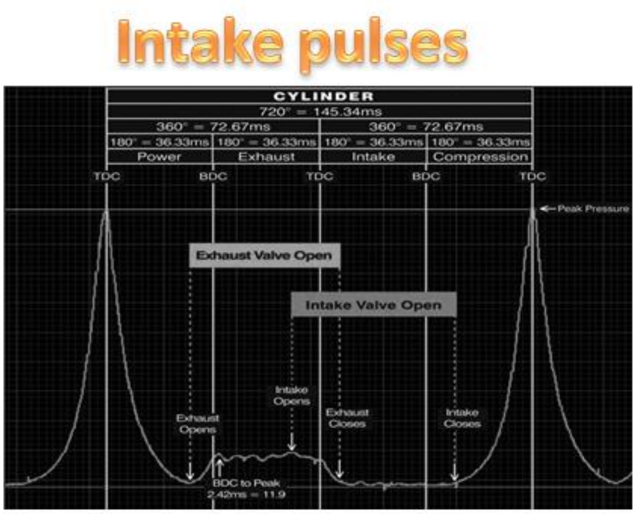
During normal engine operation, pressure pulses are set up within both the intake and exhaust manifolds from the continuous opening and closing of the valves and the intermittent motion of the gasses into and out of the combustion chamber.
To get the best volumetric efficiency at a particular operating point, one must tune the valve events to be in-sync with these pulses. Unfortunately, the frequency, magnitude and timing of these pulses varies with speed, so the volumetric efficiency of an engine with fixed valve timing will only be optimum at one speed.
With dual-independent VVT, however, the engine can be optimized at all speeds. This will yield significant improvements in low speed torque and top end power.

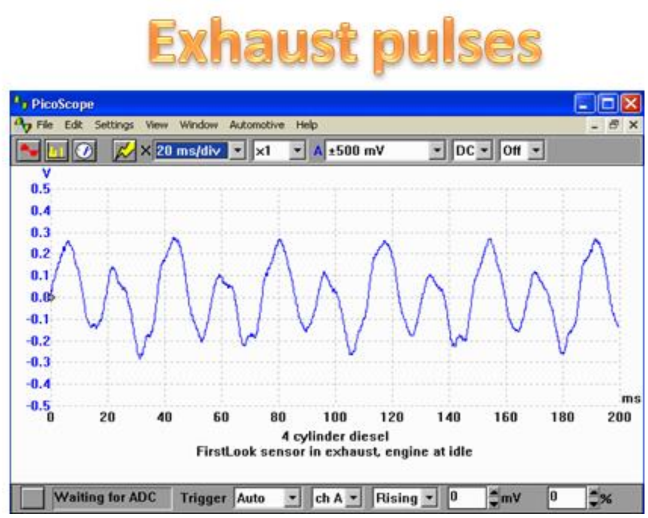
This is an example of the type of cam-in-cam design used to control valve timing with a push-rod cam design.

This design is used when cylinder deactivation and variable cam timing are used together.

During engine operation, there are pressure pulses in both the intake and exhaust manifolds from opening and closing of the valves

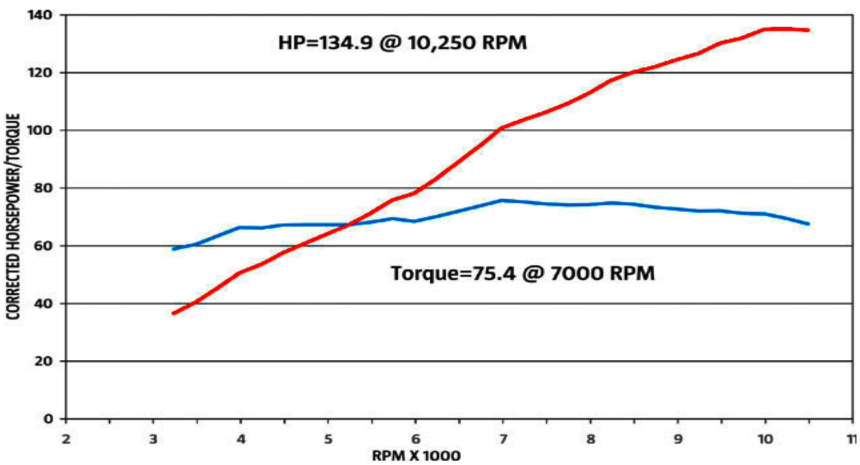






During engine operation, there are pressure pulses in both the intake and exhaust manifolds from opening and closing of the valves. These are pressure waveforms of the intake manifold and exhaust that show the pressure changes. These pressure changes effect volumetric efficiency and compensating for them is part of improving torque and power.
To get the best volumetric efficiency at a particular operating point, the valve events to be in-sync with these pulses.
Unfortunately, the frequency, magnitude and timing of these pulses vary with speed.

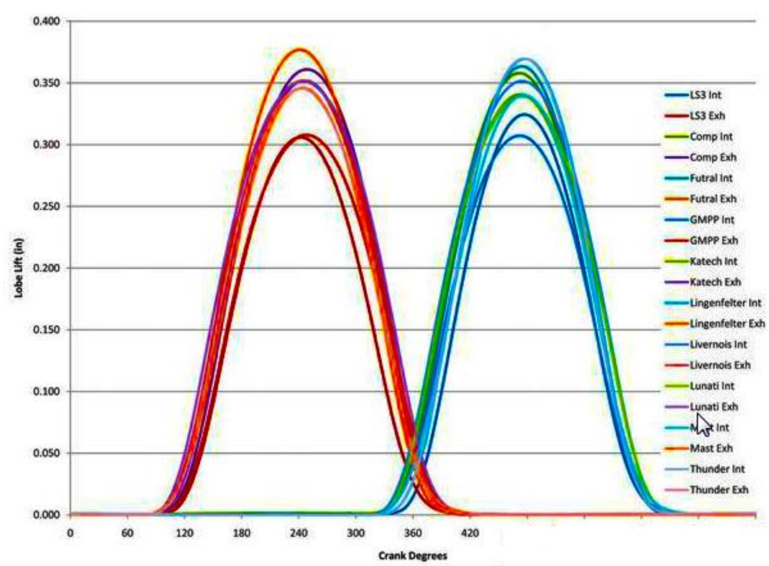
The volumetric efficiency of an engine with fixed valve timing will only be optimum at one speed.
With dual-independent camshaft timing the engine can be optimized at any speed.
This gives us improvements in low speed torque and top end power.
There will be flatter torque curve.



Horsepower is the red trace and the torque is the blue trace. This is the output of a small economy engine with VVT.

VVT For Fuel Economy and Emissions

Control of valve overlap is a key factor in improving engine fuel economy and emissions. Valve overlap is the point near piston TDC in the 4-stroke cycle where both the intake and the exhaust valves are open at the same time.
At low speed, the effect of valve overlap is to re-introduce exhaust gasses into the combustion chamber. This is known as generating internal exhaust gas re-circulation or internal EGR. The benefits from internal EGR are two-fold:
Firstly, internal EGR benefits part load fuel economy by diluting the charge within the cylinder, thus restricting output without the need for increased throttling and its associated pumping losses.
Secondly, internal EGR also reduces hydrocarbon and NOX emissions by the re-circulation of un-burnt exhaust gasses. The retained exhaust gasses tend to be very rich in un-burnt Hydrocarbons, as they typically come from crevice volumes that are expelled at the end of the exhaust stroke. This strategy can therefore be quite effective at reducing emissions.
Variable valve timing can also be used to reduce the work required by the piston to pump the combustion gasses into and out of the combustion chamber. This may yield further fuel economy benefits.



Eliminating the EGR

At low speed, valve overlap is used to intake a limited amount of exhaust gasses into the combustion chamber during the intake stroke.
This is known as internal exhaust gas re-circulation or internal EGR.
No EGR Valve required.

Independent VCT For Idle Quality

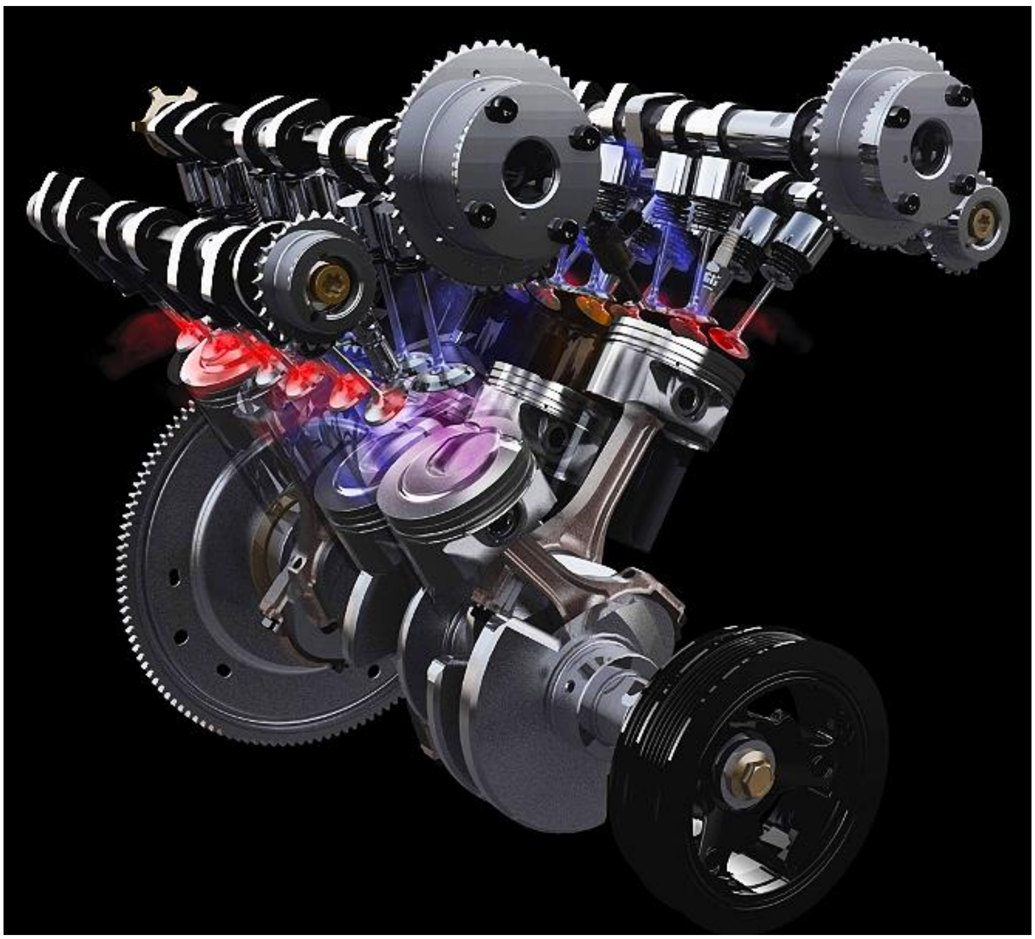
Control of valve overlap is also the key to good idle quality. While valve overlap improves mid-range performance it has the opposite effect at idle and light load.
The resulting internal EGR from high valve overlap tends to reduce engine stability at very light load (e.g. idle).
This increases idle emissions and fuel consumption, will make the engine sound and feel poorly tuned at idle.
Reducing overlap reduces the internal EGR which improves idle stability.
This can be a particular problem for high performance high-output pushrod engines. These engines often have long duration high-lift profiles, with more valve overlap than would be desirable at low speed. Idle performance can therefore be significantly compromised as a result.
With dual-independent VVT, these engines can now benefit from overlap control and significantly improved idle quality at low speed.

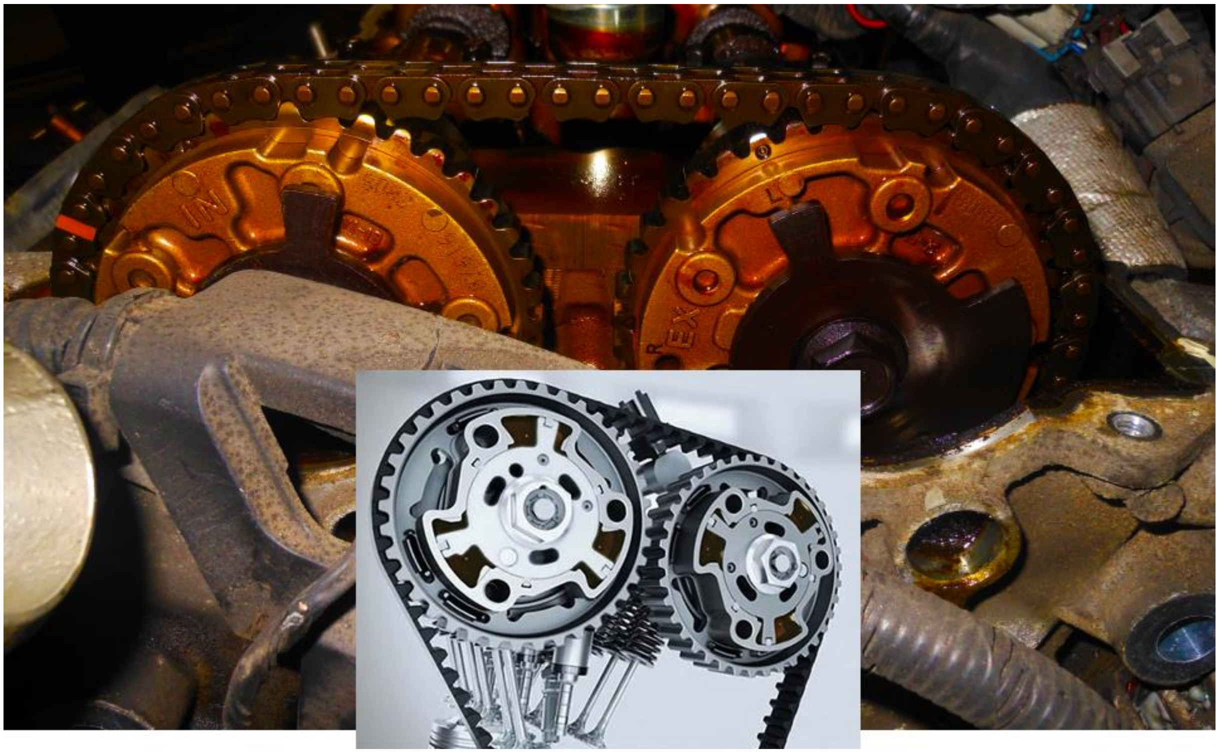
Independent VCT Operation

This is an example of two cams with independent cam timing. This is necessary of overhead cams.

Newer engine has variable cam timing for both intake and exhaust valves. This requires two independent cam phasers on inline engines and four cam phasers on v-type engine.

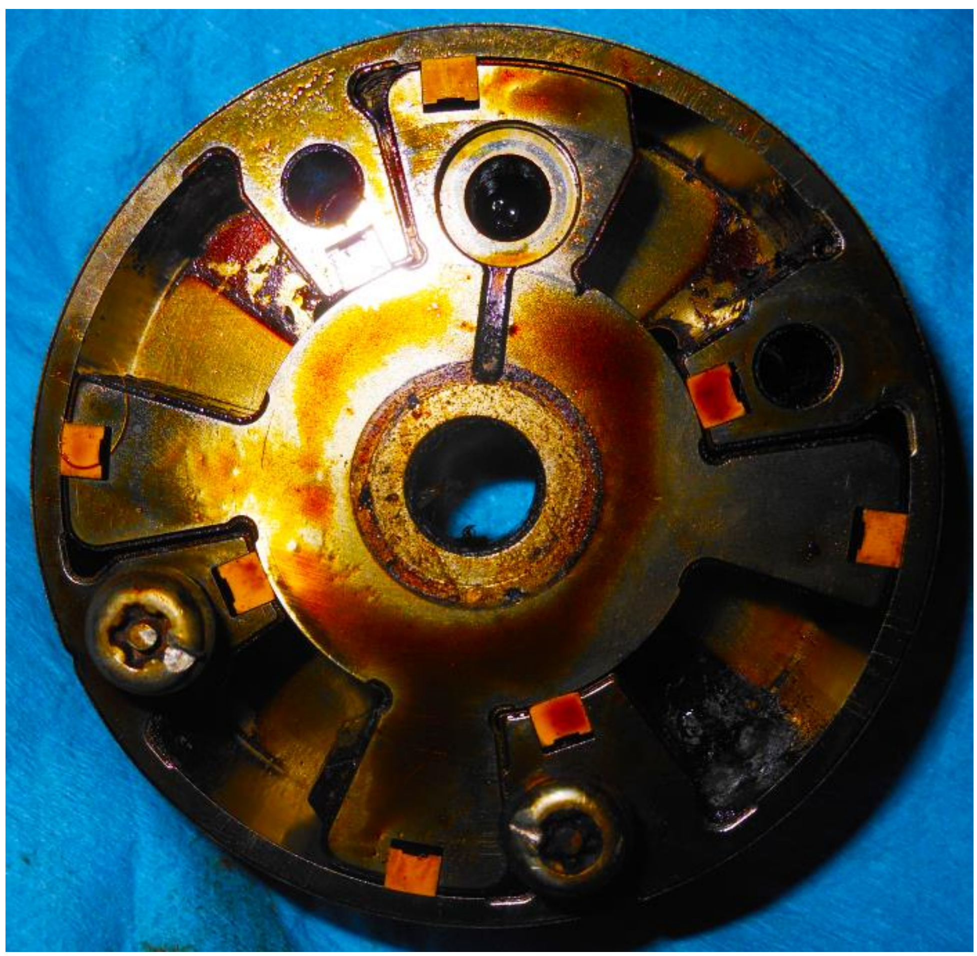
Poor lubrication is our biggest problem with variable cam timing.





We will give you an example for the engine in the background with the heavy varnish resulting for poor maintenance.

Dirty Cam Phasers



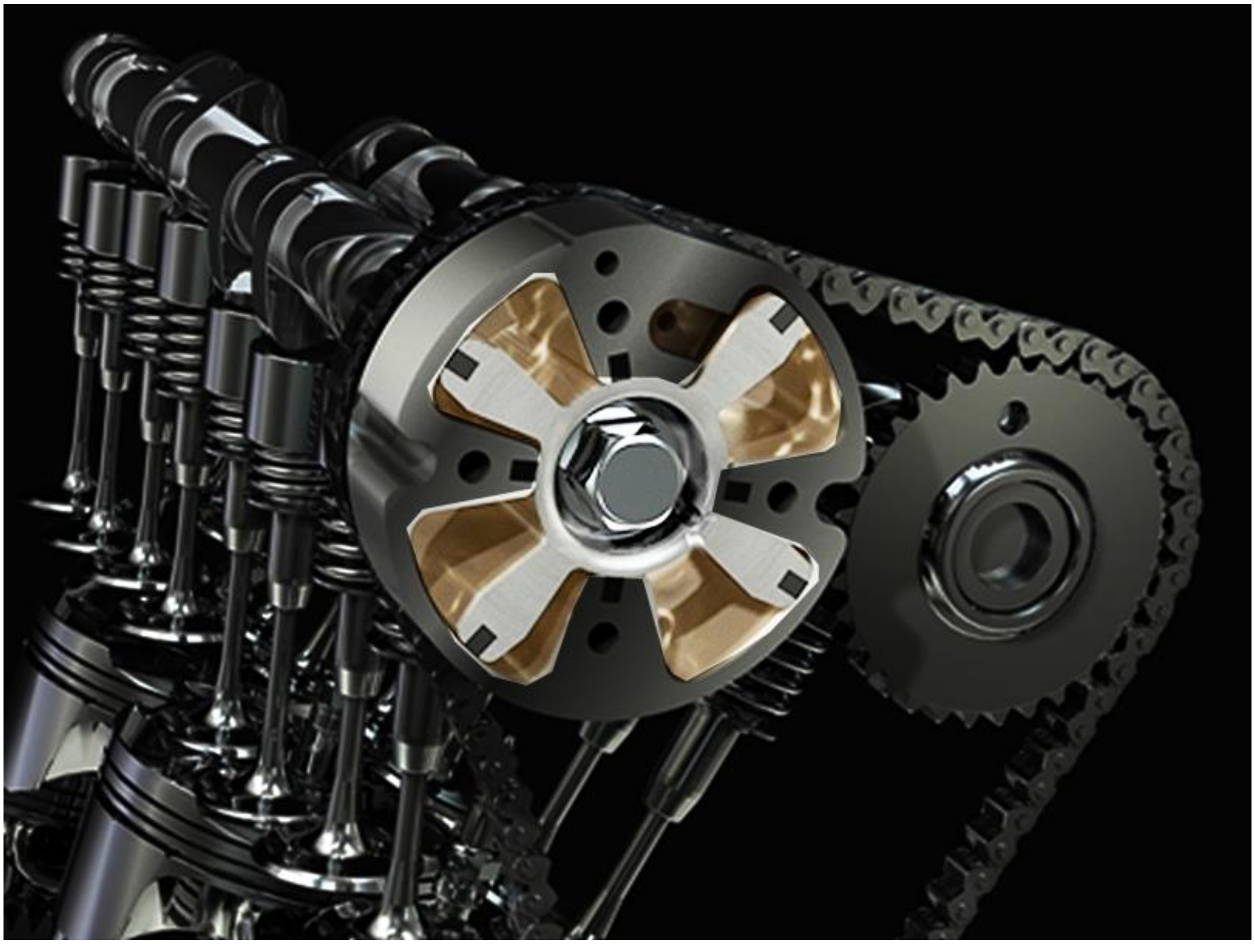
You can see the build of sludge and varnish in this cam phaser.

We will check out this phaser to show you the “dirty” details.

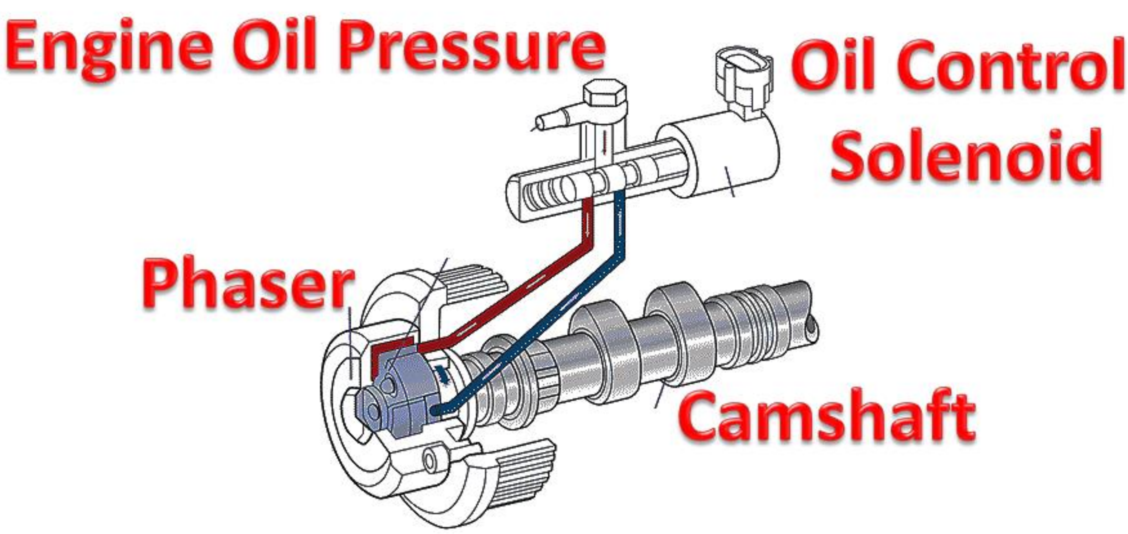
We cannot force the phaser to open fully with a screwdriver because of the heavy buildup of sludge and varnish.

One port is completely blocked.

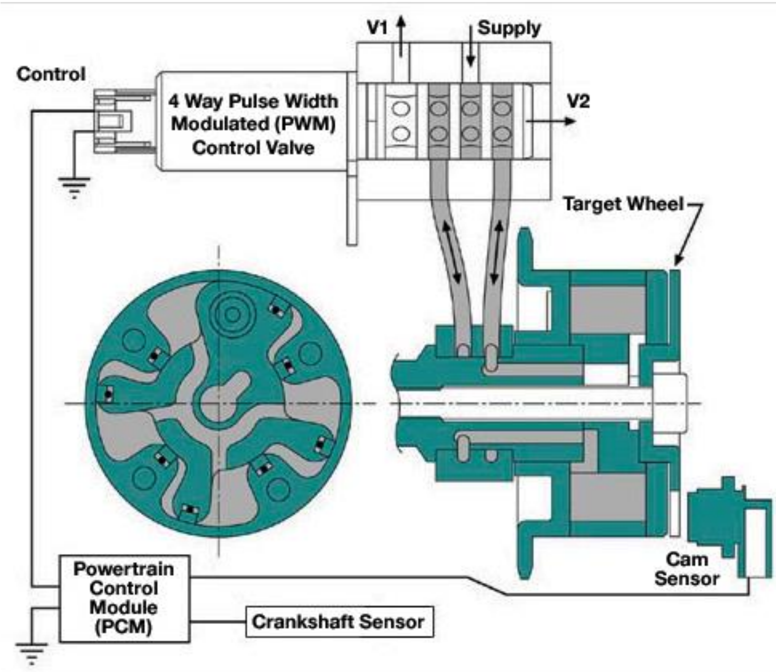
Phaser Operation



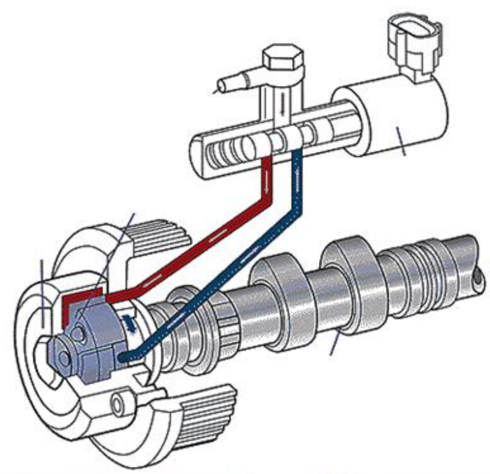
The phaser uses oil pressure to mover the phaser to control valve timing.

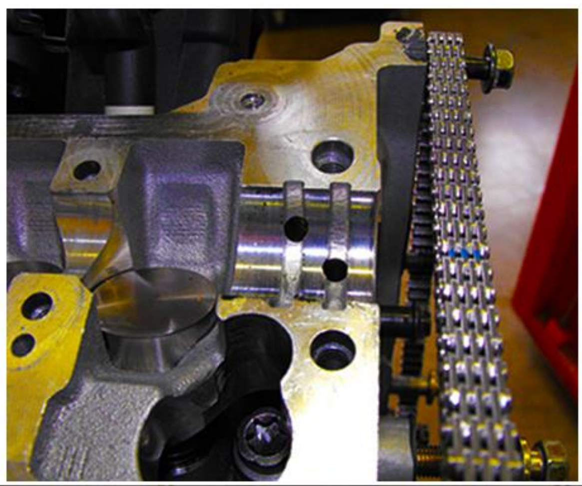


Engine oil is controlled by a solenoid to move the phaser vanes

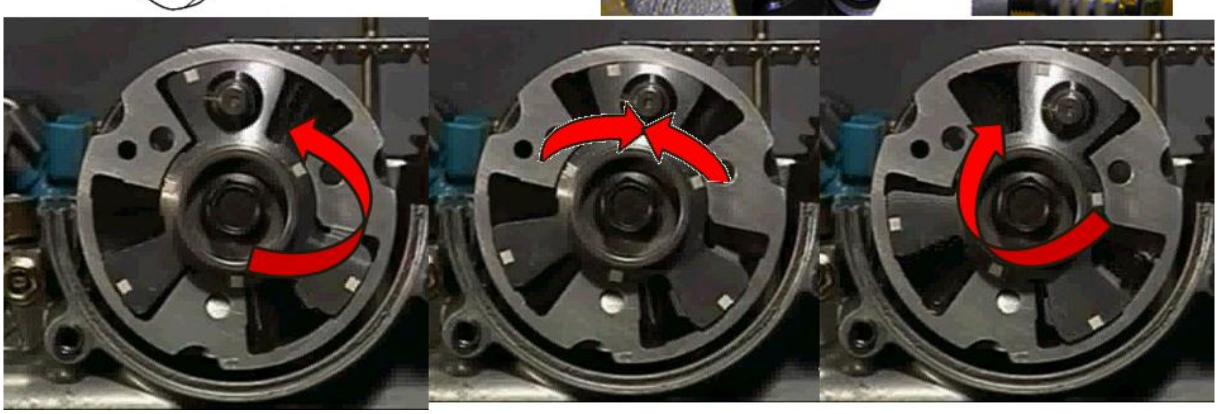


The solenoid changes the PCM commands into hydraulic pressure to move the phaser that varies cam timing.





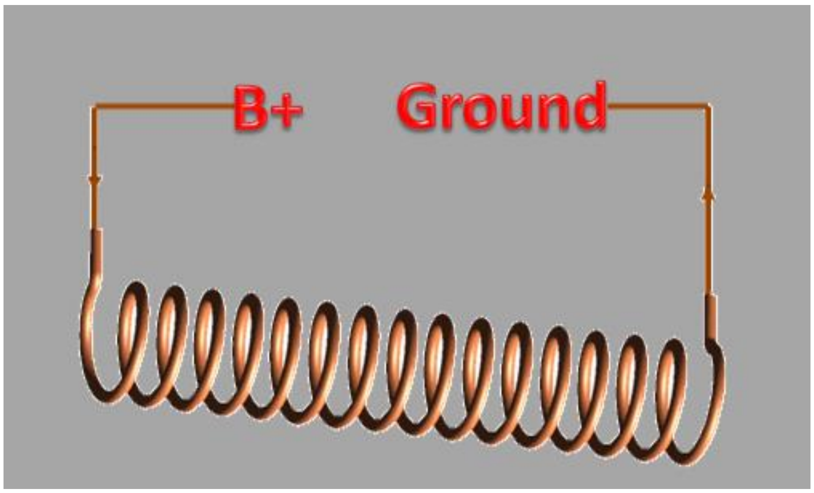
This is a cur away that shows the oil pressure ports to the phaser and the movement of the phaser when the PCM commands movements.

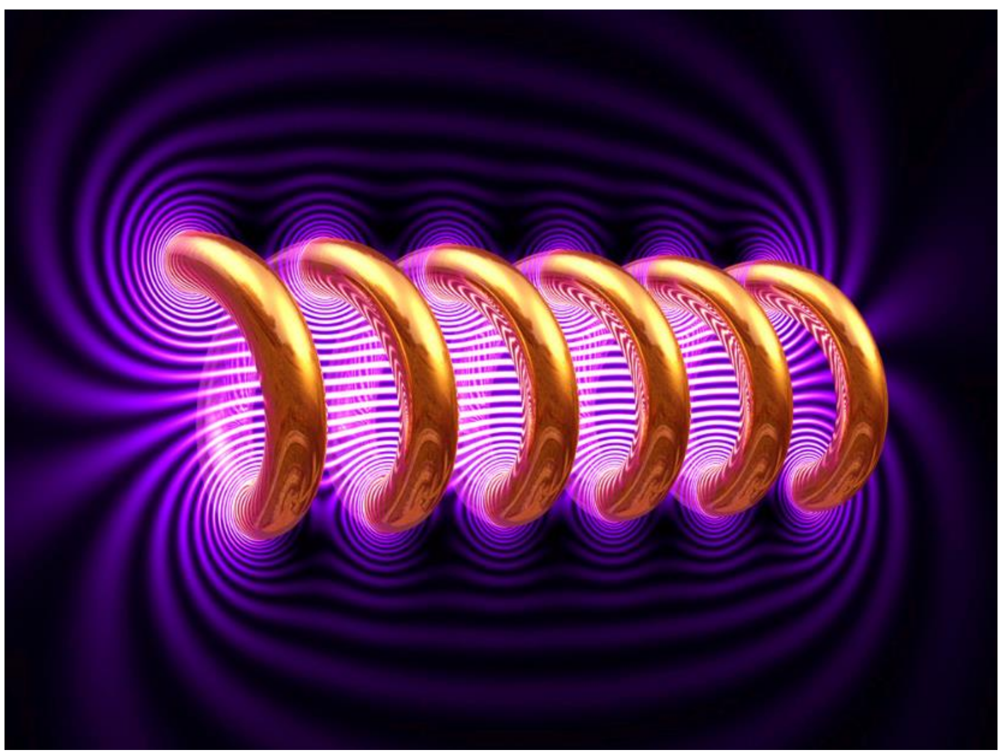


Solenoid Control

An electrical solenoid has two aspects, an electrical circuit to create a magnetic force the causes a mechanical action. Testing must include the electrical action and the resulting mechanical action. The dirty phasers we saw before cannot function properly when the electrical portion performs correctly.
A clean properly functioning phaser will not operate properly if the electrical portion does not create a good magnetic attraction for the mechanical attraction to operate the mechanical portion of the control.

- Solenoid: An electrical device that changes electrical energy into mechanical action.
- Test it like a long piece of wire wrapped into a coil.

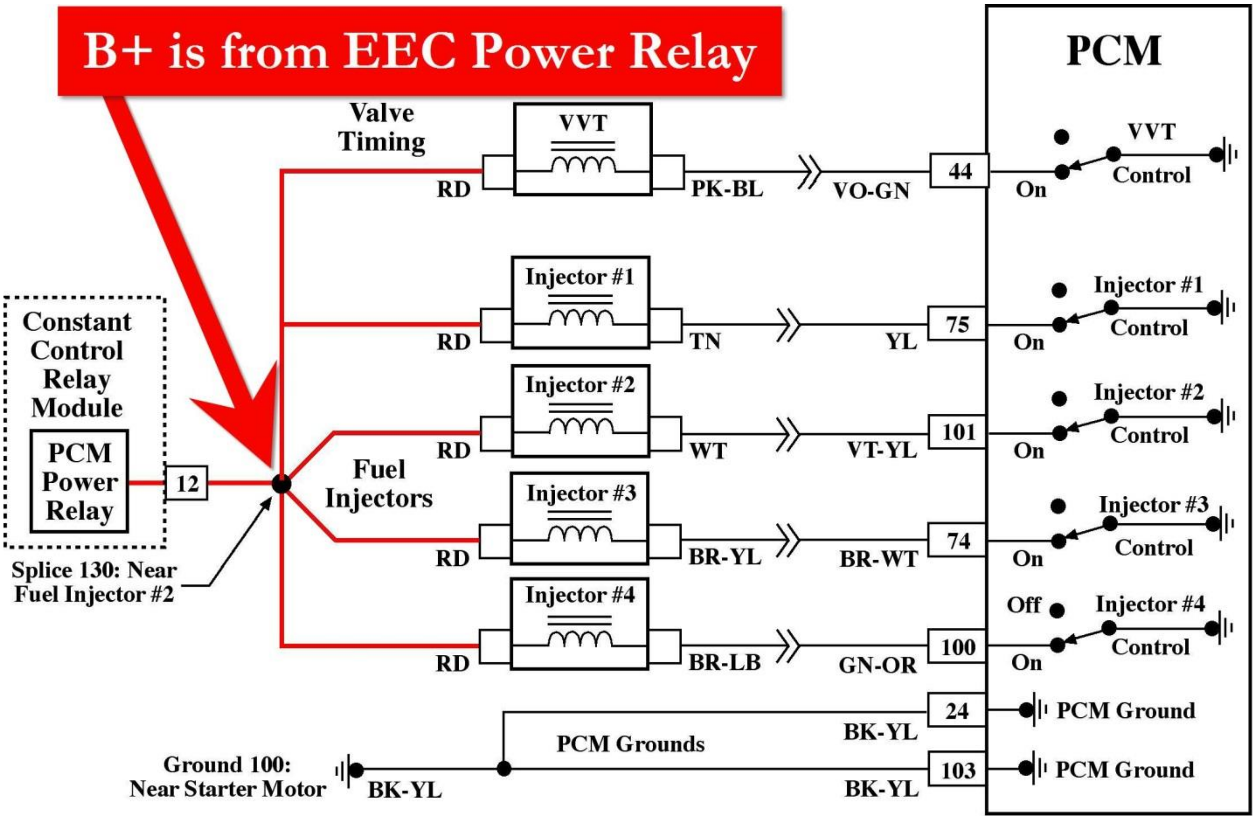




A Magnetic Field is created. This requires current flow to be normal and the coil to have good winging and connections.

The magnetic field should cause the expected mechanical action.

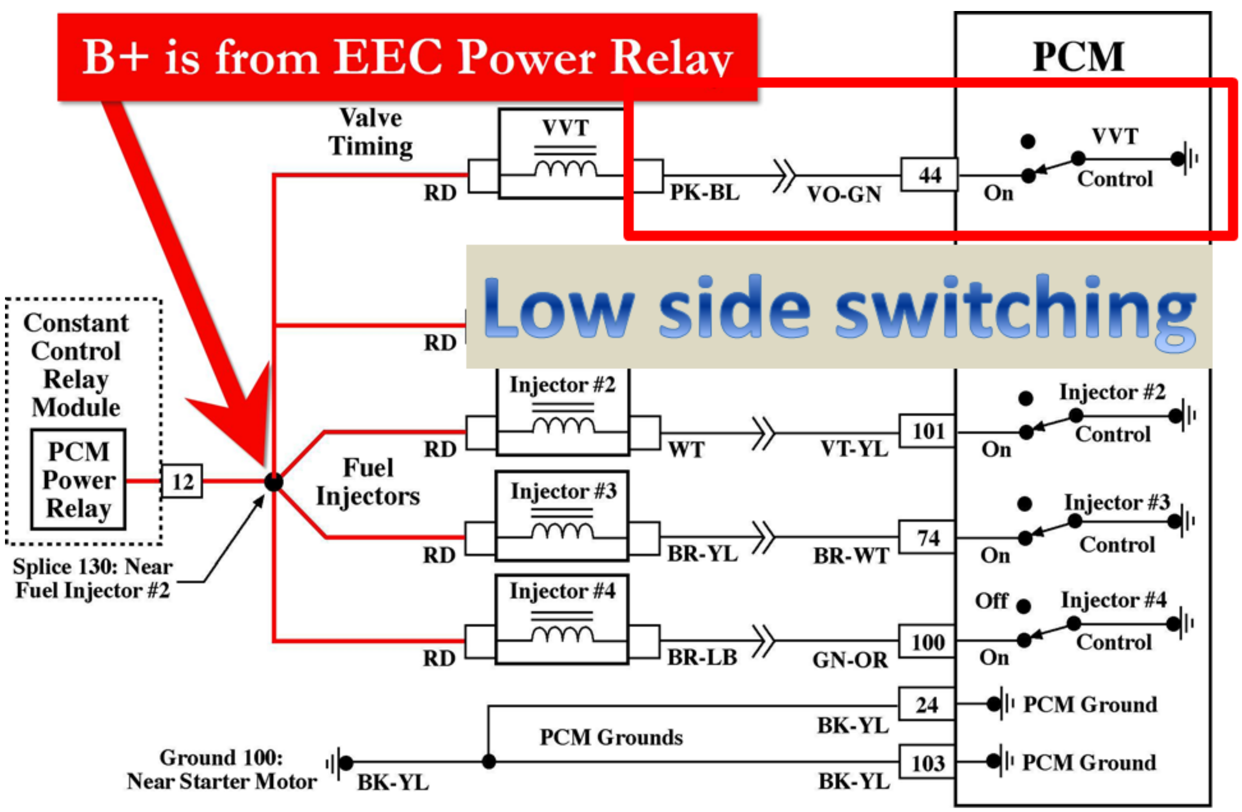
Electrical Testing



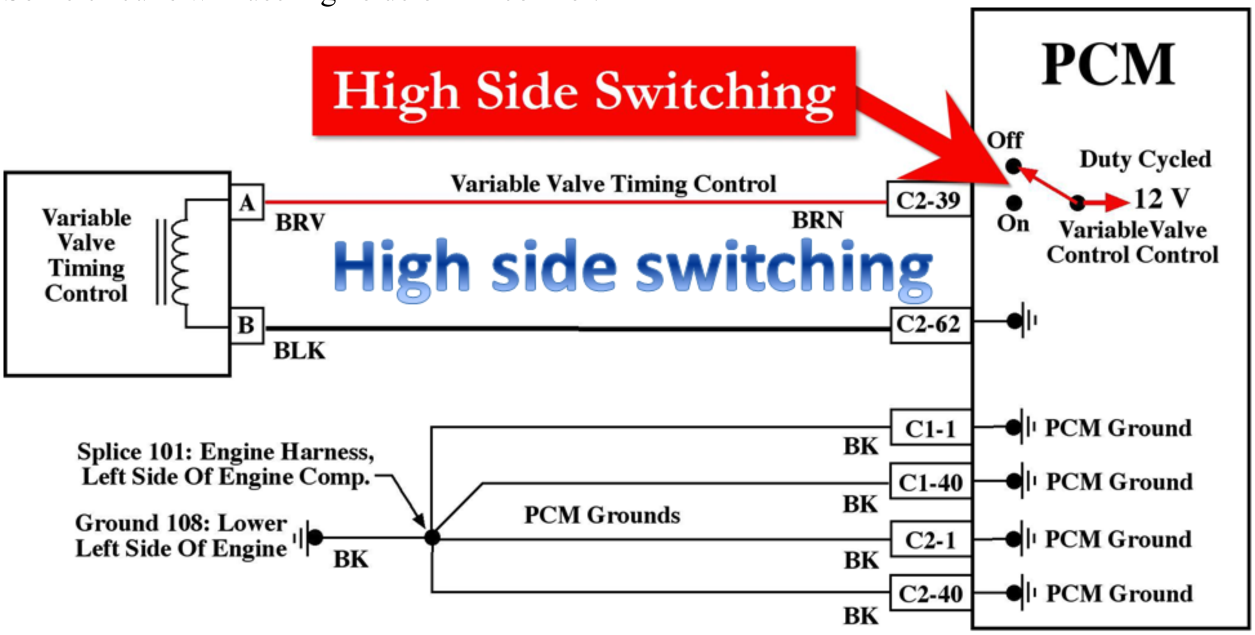
Use a diagram to identify the B+ supply for the solenoid.

This circuit must have B+ applied.

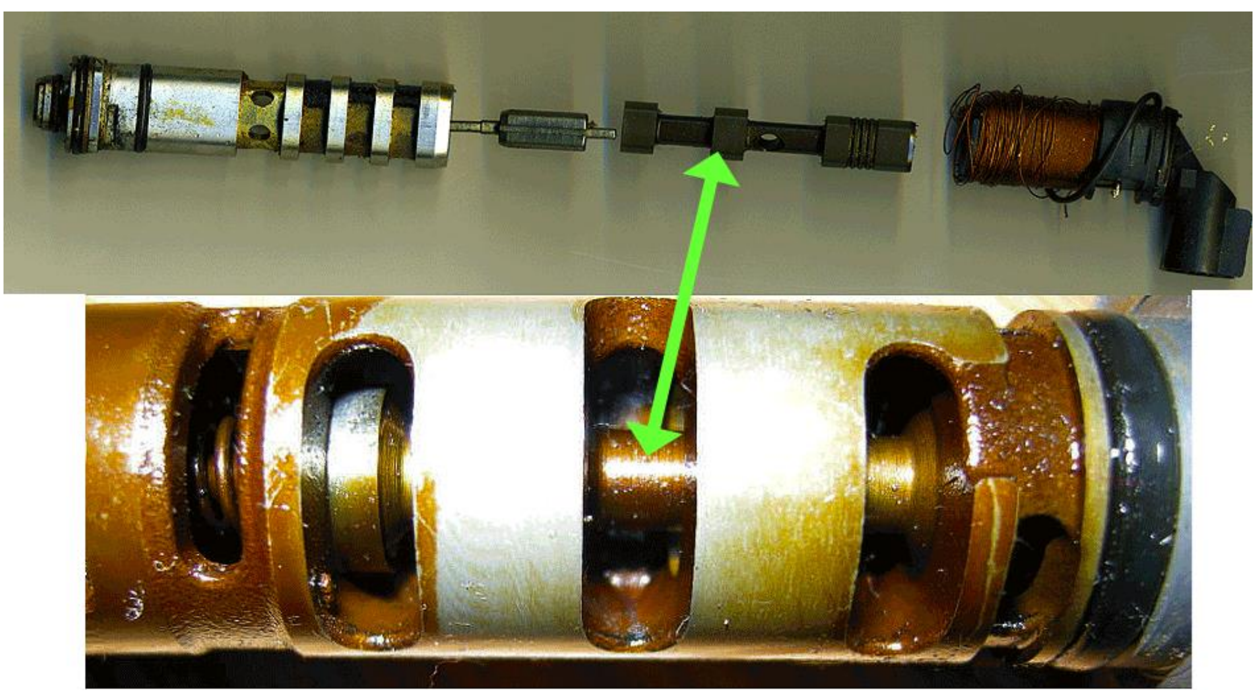
Next identify the control circuit. This example uses low side or ground control. The coil must receive a good ground from the PCM.



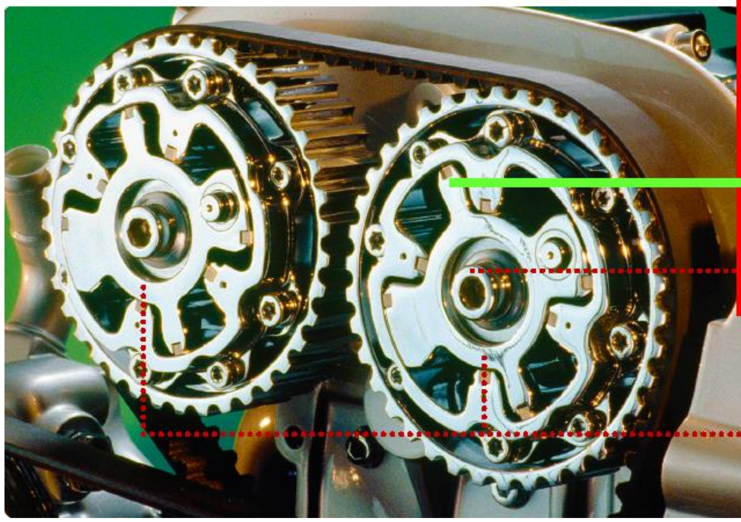
Some circuits will use high side or B+ control.



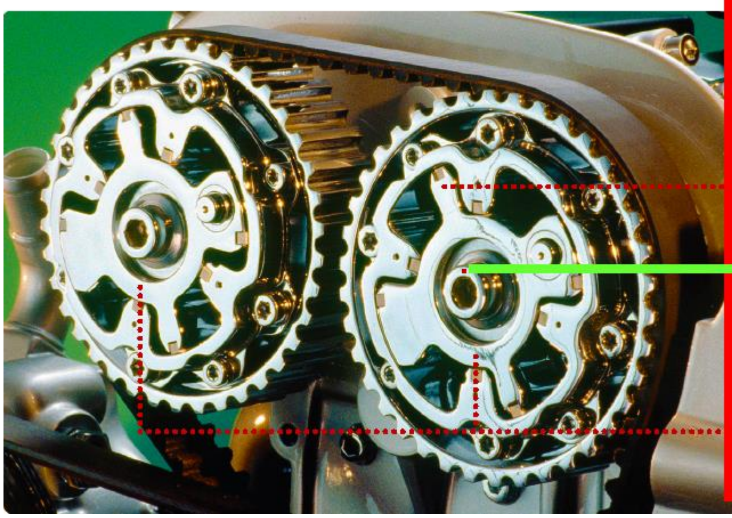
This circuit must receive B+ from the PCM toi energize the solenoid.
The ground is alo from the PCM but it is not switched.
The next step is to check the mechanical operation.



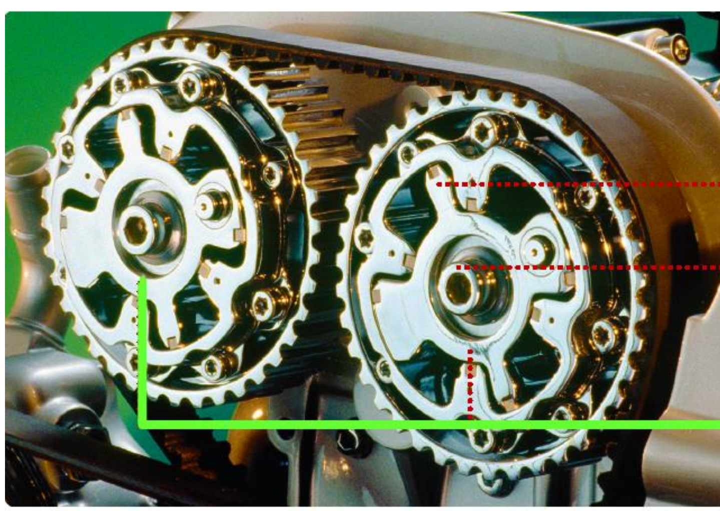
The spool valve is moved by the solenoid control in this phaser control valve.



Electronic solenoid valves direct high-pressure engine oil to control vanes in each of the camshaft sprocket housings



The camshafts can be rotated slightly relative to their initial position, allowing the cam timing to be advanced or retarded based from the oil pressure directed by the solenoid valves



By using one Phaser per camshaft, controlled by the Electronic Control Module (ECM), each intake and exhaust cam can be advanced or retarded independently of the other

Cam-Torque Actuated Variable Valve Timing System (CTA

The CTA system avoids those pitfalls by using Newton's Third Law of Motion—for every action there is an equal and opposite reaction—to move the oil in the cam phasers. The system uses the existing torsional energy in the valve train. When a cam lobe pushes a valve open, the valve spring resists that force and pushes back. Similarly, when the valve spring pushes a valve closed, it also pushes on the cam lobe in the opposite direction from the valve opening. When multiplied over an entire camshaft, there is enough energy from these back-and-forth forces to make cam phasing work.

The system also uses oil to move a spool valve. A center spool valve, controlled by a solenoid inside the cam-phasing rotor, directs the flow. With the valve open in one direction, oil flows into only one side of the oil pockets and can't leave. By sliding the valve back and forth, the system can mete out the precise amount of oil flow on either side of the rotor lobes.

The key advantages of the CTA system are that it responds quickly even at idle and can operate using a standard engine's oil pump. But there are downsides. As engine speeds increase, the CTA system becomes less effective. This happens because the valve events occur more frequently, reducing the time available to move the oil. Conversely, Oil Pressure Actuated only systems work quicker as oil pressure increases and are better at high rpm. The CTA system improves performance and efficiency in all areas of the engine RPM range. Also, CTA cam phasing is at the mercy of the natural oscillations of those forces on the camshaft. Valve openings and closings in an inline-six are spaced too closely for the system to work well. But a V engine is perfectly suited because there isn't as much overlap between each valve event. CTA is used on the Ford's 3.0-liter Duratec V-6, beginning with the 2009 Escape and the 2010 Fusion. The 3.7-liter V-6 uses the CTA system, as do the 2010 Edge and Lincoln MX. You can also find it on the Mustang's 5.0-liter V-8 as well as the V-8 engines used in Jaguar and Land Rover vehicles

Cam Phasing Advantages

- Cam Phasing increases mid-range engine output and torque
- CAM Phasing has good idle quality with improved fuel economy
- Inexpensive, simple and eliminates the external EGR

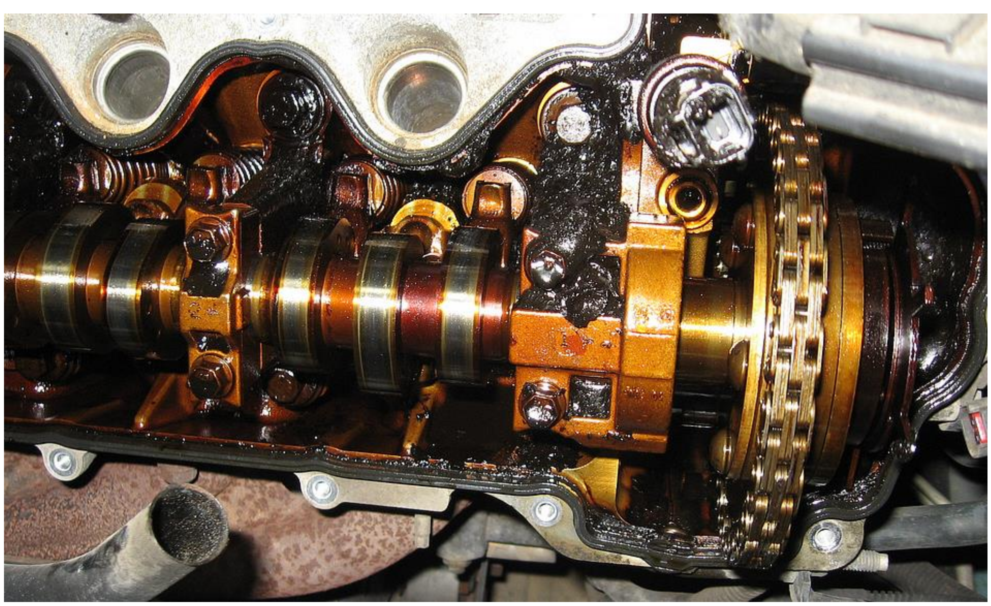
Cam Phasing Disadvantages

- Poor maintenance and dirty oil can cause problems
- Valve lift is not changed

Valve lift is the next step we will see on newer vehicles

Sludge is the enemy of VVT

This problem started long before the camshaft saddle wore in half. Everyone who was involved with this vehicle thought the problem was the lack of maintenance (oil changes). The thought is that dirty (Sludge build up) would have affected the twin variable camshaft timing system first. The Phaser would have started sticking. It would have been slow to move causing a drivability

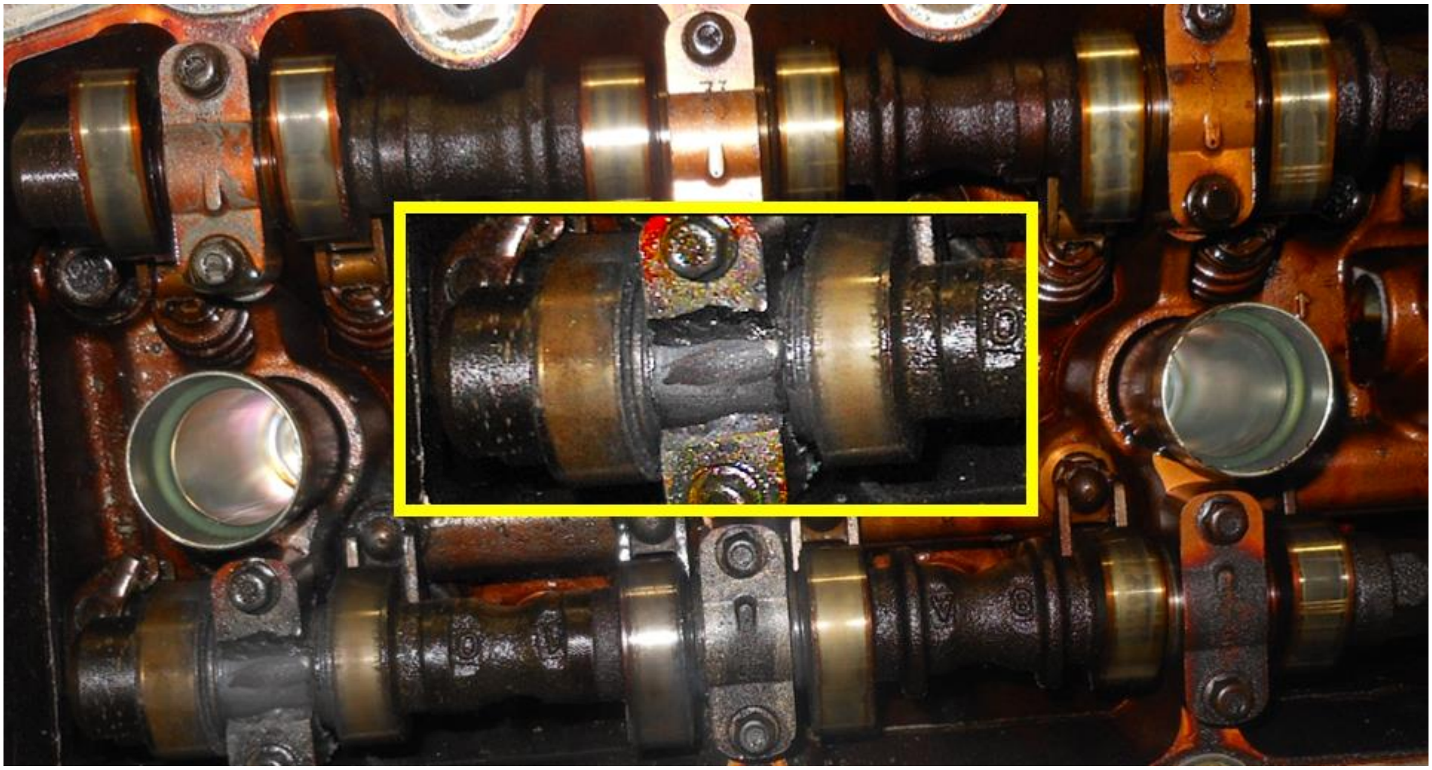


concern. The customer didn't feel it or didn't respond to it. This started long before any diagnostic trouble code was set.

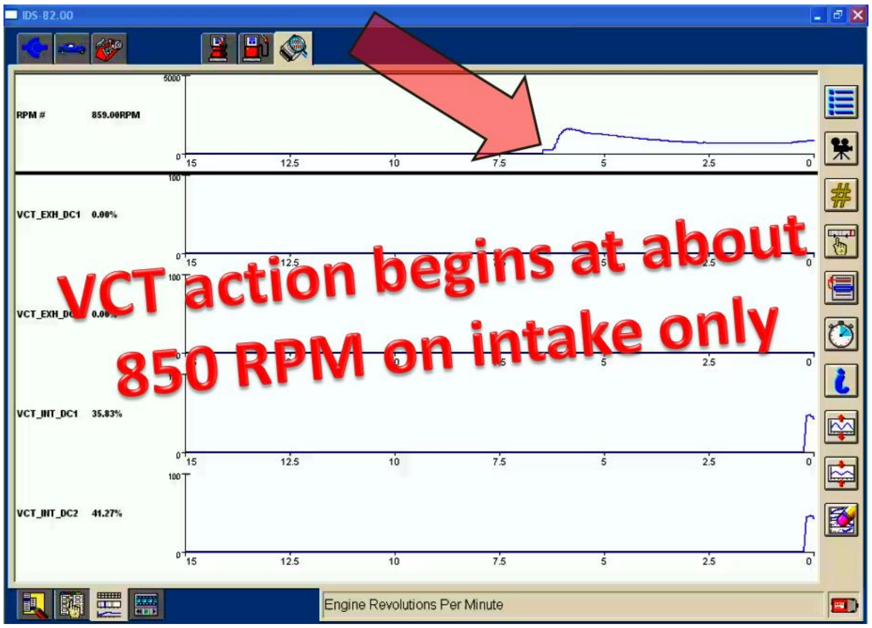
This was found by a technician that was diagnosing a noise in the engine. Anyone of us would have used our stethoscope, removed the valve cover and found this.

Let's look at another way. What if this driver was attuned to the vehicle's operation? They noticed that it drove differently when the Phaser first begins to stick, and brought it to your shop? The thing is sitting in your service bay and the only information is the engine feels funny sometime. Where would you start? What would you do first? There aren't any diagnostic trouble codes.

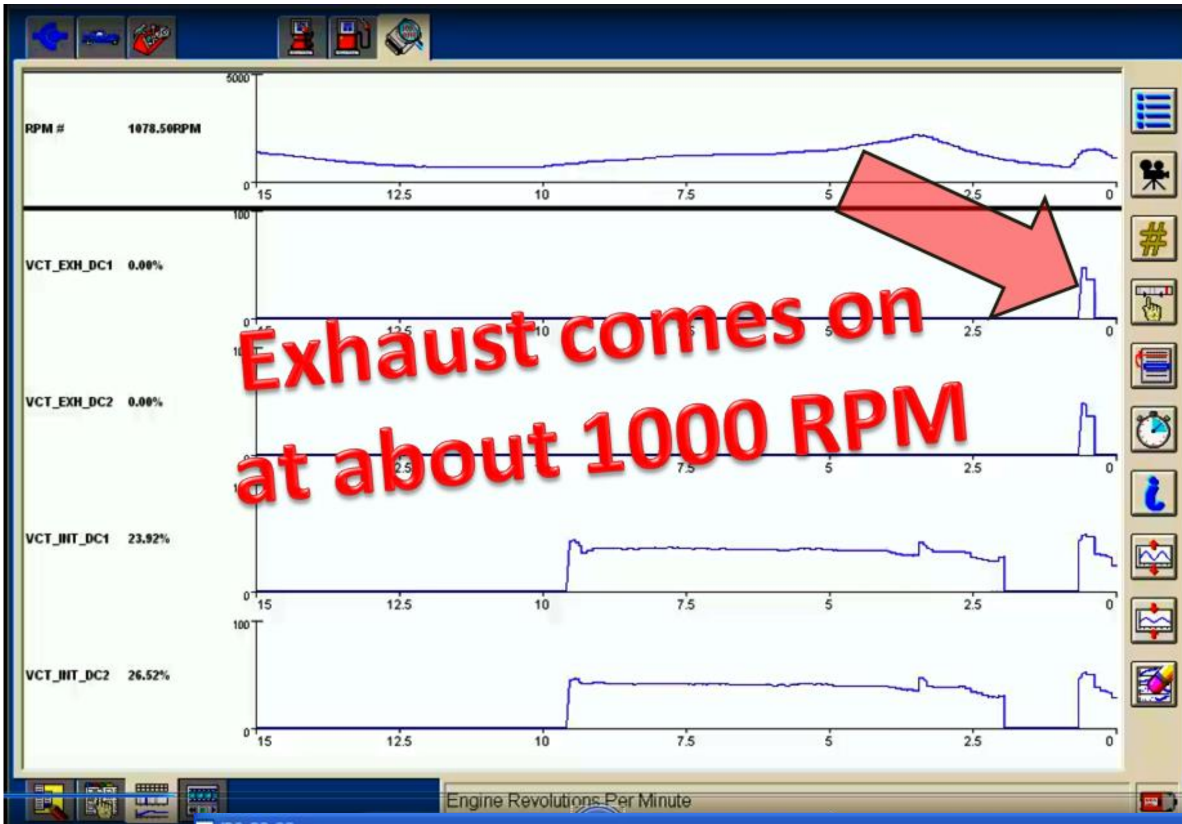
The answer is in DATA. Scan Data, would have indicated that this camshaft was responding differently than the others. Look at the Scan Data in the following examples and evaluate the data.



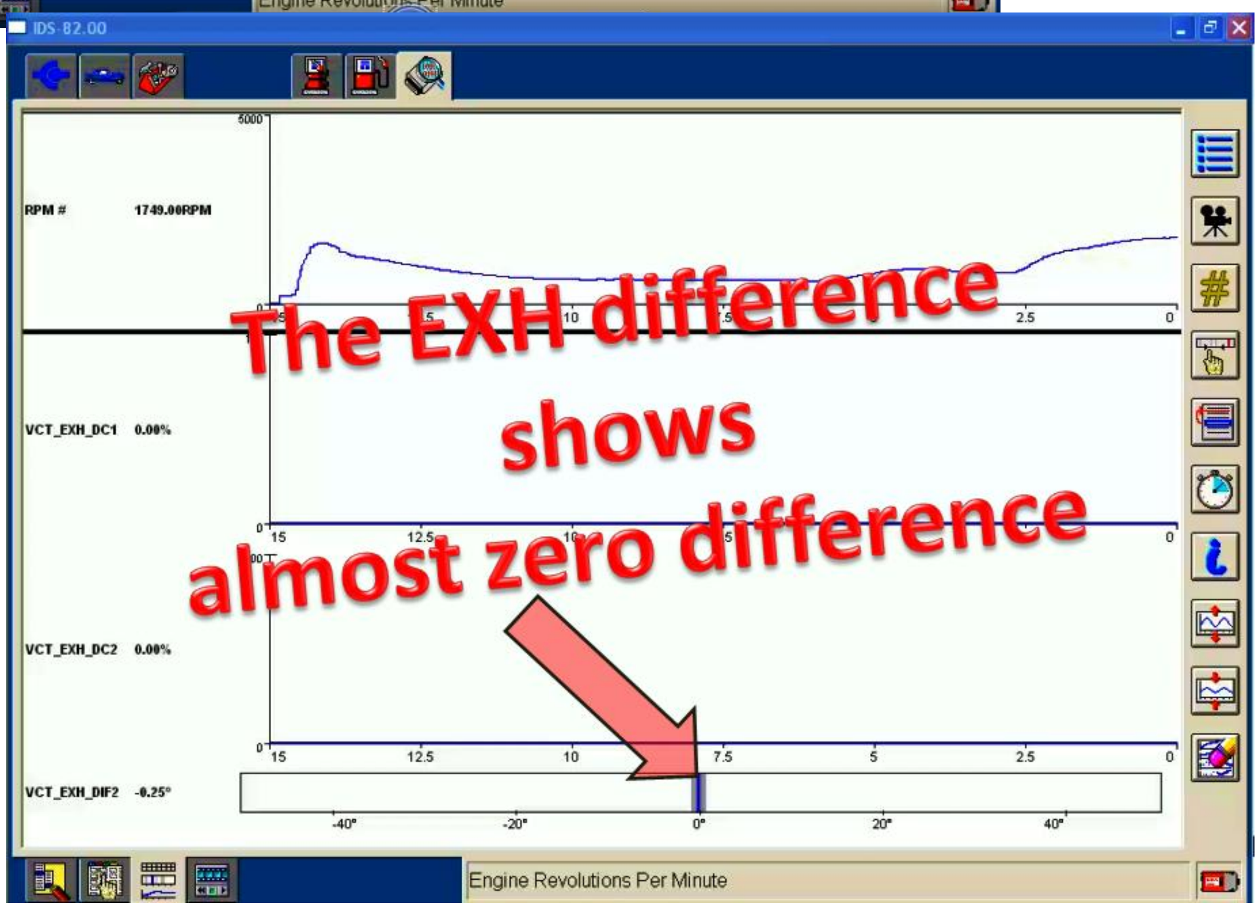
How do you find this quickly?



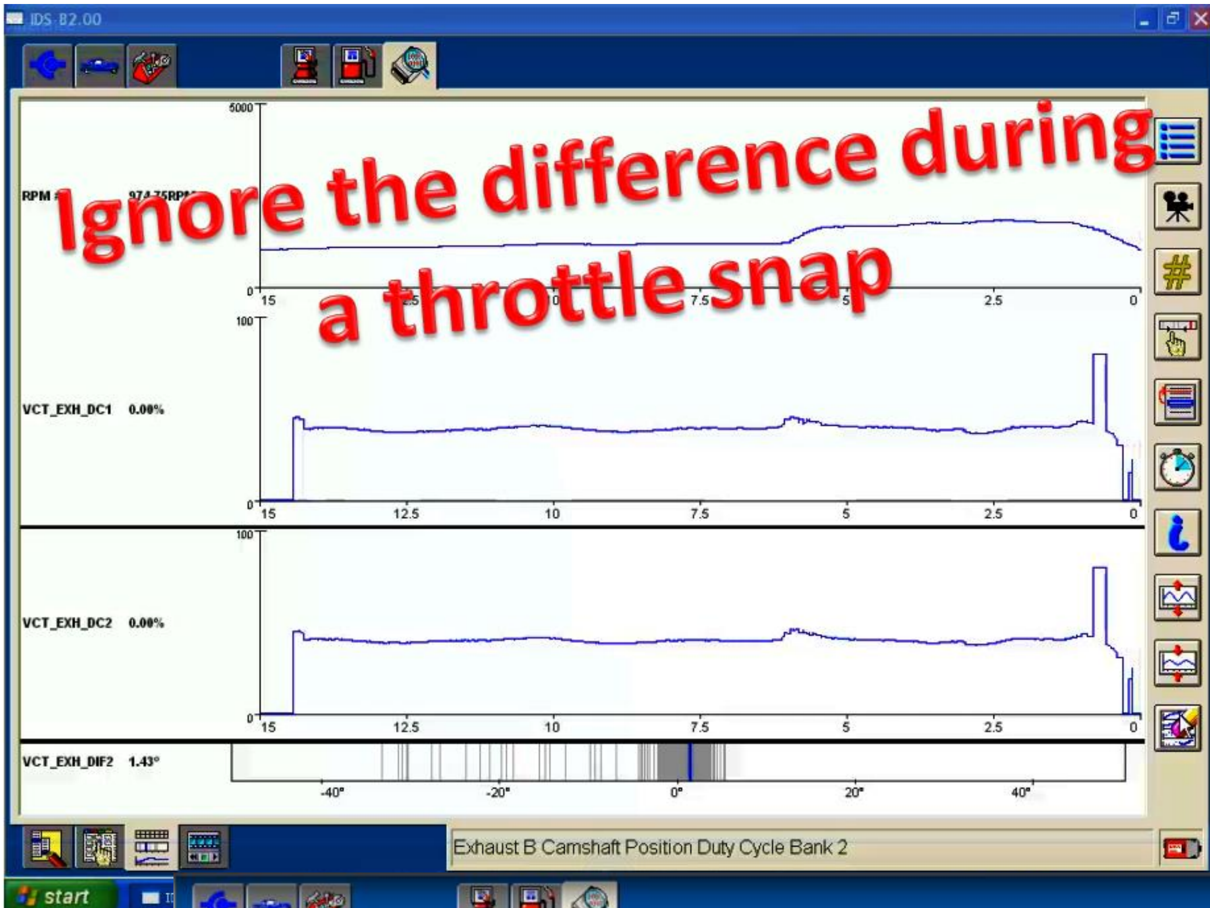
We will take a look at the scan data that really helps locate valve timing problems.



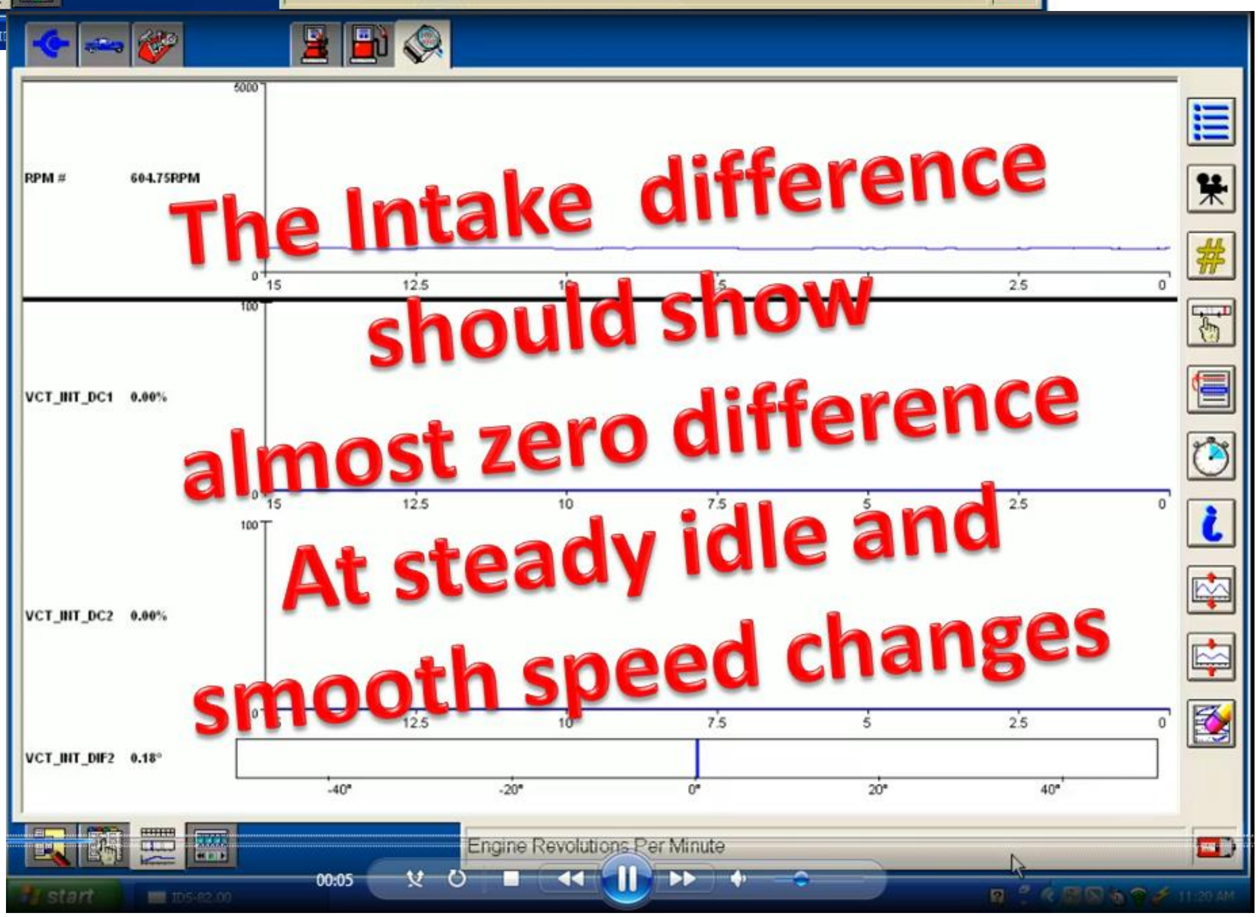
We use Smart-Spec to study valve timing during a test drive. If you know typical values, you can spot higher than normal duty cycle if the phasers start sticking. But we have other ways to help with diagnostics. We have scan data that shows the difference between the command and actual position. How easy is that?



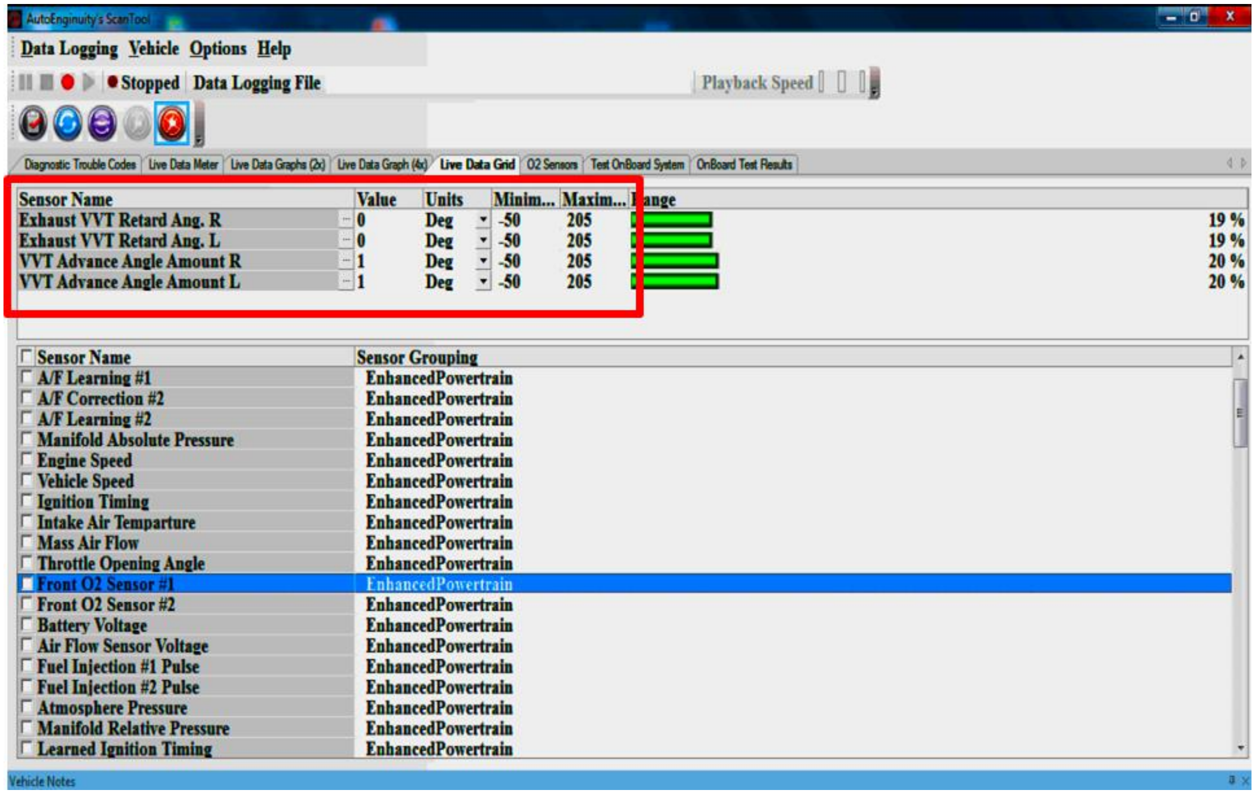
This indicates the phaser is not sticking, but it is not a complete diagnostic. It means operation was normal while we were testing the vehicle, it may be causing a problem during more demanding operation.



During snap acceleration and hard driving cycles, the error will indicate larger errors.

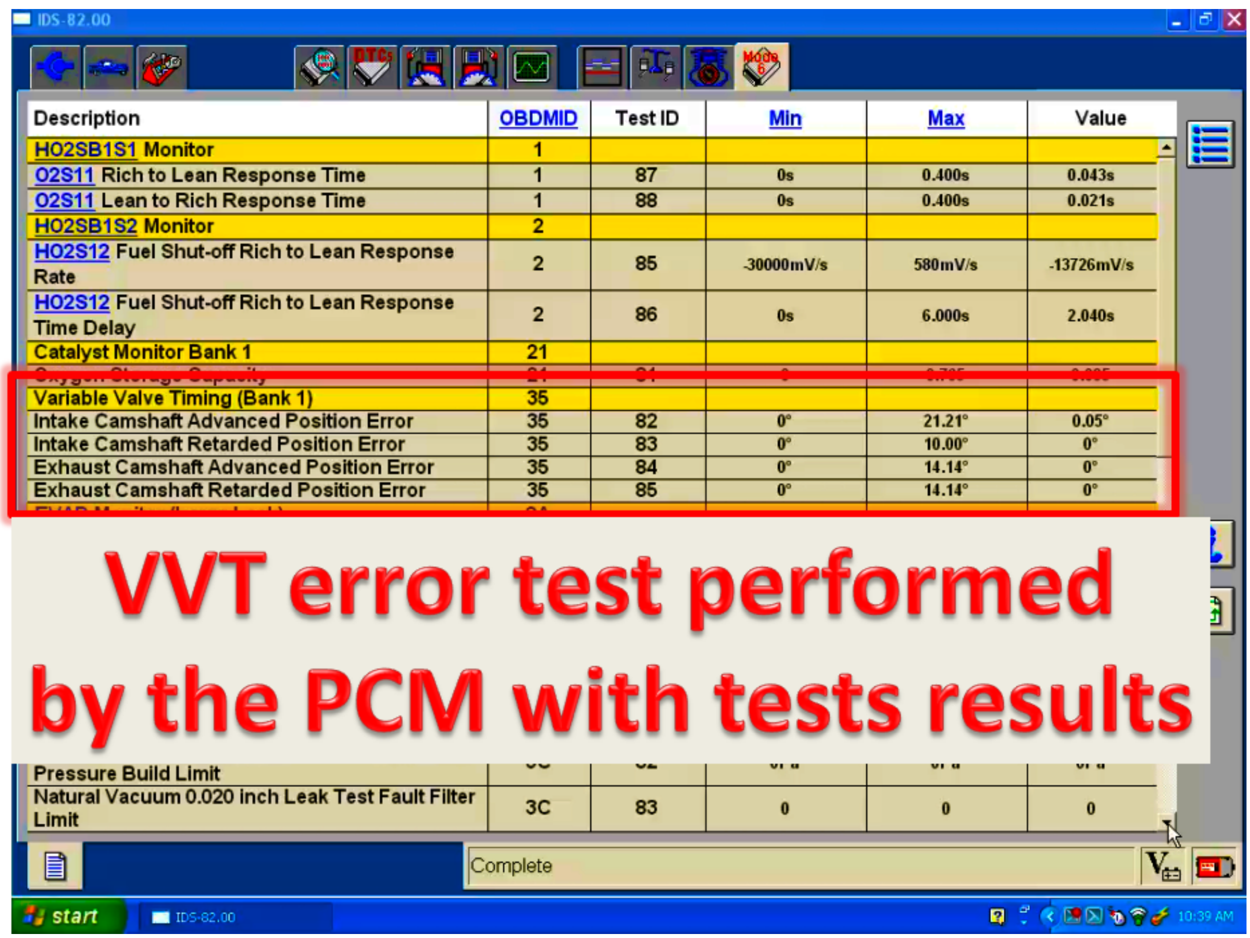


The difference here are very small, so be careful how you use this data.



You can watch live scan data to monitor the values.

The very bast test is to use Mode-6 where the PCM captures the error under controlled conditions.



Independent Camshaft Timing Summary

The two intake Phasers must stay in balance
The two exhaust Phasers must stay in balance
There isn't any normal engine operation where the banks would separate.
The PCM runs an error test to identify VVT position errors, watch this number; it detects varnish build up before it becomes excessive
You have seen the examples after it fails with too much varnish and sludge.

VVT Scan Data (GM)

CAM HI to LO counts [0 to 65534 (65535)]
CAM LO to HI counts [0 to 65534 (65535)]
Displays a count of the number of camshaft position sensor signal changes as voltage goes from Low to High or High to Low. Noise can cause the two ways of counting to be different.
CAM PHASE ACT (°) [0 to 25°]
The PCM's commanded camshaft retard in degrees, this is the actual position, what was the commanded amount.
CAM PHASE DES (°) [0 to 25°]
Indicates the PCM desired camshaft angle, this should match the actual degrees.
CAM PHASE DUTY (%)
[0 to 100%] (Advance/Retard)
Displays the duty cycle the PCM is applying to the solenoid, sticking phasers or valves will cause the duty cycle to very high or very low.
CAM PHASE VARI [0 to 25°]
Indicates the difference between desired and actual camshaft angle, watch this number, if starts to increase, you have a sticking phaser or control valve.
CAM REF MISSED [0 to 8]
Displays the number of cam/sensor pulses missed
0 is normal 1-8 not normal
For intermittent conditions only
If the signal is missing for a longer period it will read 0
CAM RETARD (°) [0 to 360°]
Display the number of degrees of retard between the camshaft position sensors and the crankshaft position sensor in degrees.
CAM SIG PRESENT [0 to 255]
Displays the number of the camshaft position sensor signal inputs into the PCM.
Resets to ZERO after reaching 255

VVT Scan Data (Chrysler)

CAM SYNC START [Yes / No]
YES indicates the camshaft agrees with data from the crankshaft position at start up.
NO indicates the camshaft did not agree with data from the crankshaft position at start up.
CAM TIMING POS (°) [0 to 127°]
This data displays degrees of variation in position from the *learned* camshaft position.
CAM /CRANK DIFF (°) [0 to 17°]
This data displays the amount of change in phase angle between cam and crank signals from initial set.

Indicates the amount of belt stretch, this is used mainly for fixed valve timing.

DTC sets at 17° or less (1 Tooth of Belt)

VVT Scan Data (Ford)

CAMDC 1
CAMDC 2

This data displays the duty cycle command to the solenoid to control valve timing.
CAMDC 1 is Bank 1
CAMDC 2 is Bank 2

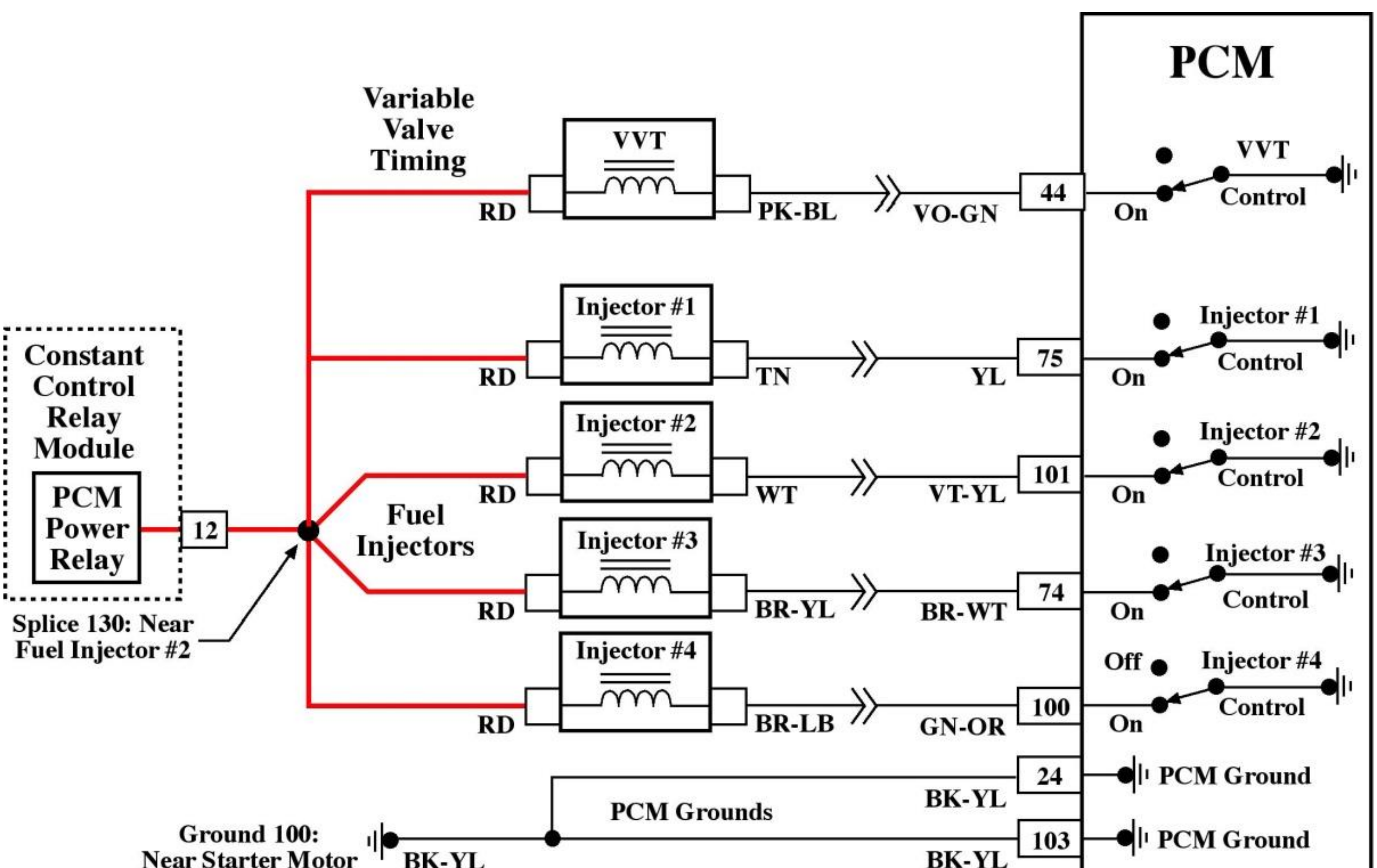
CAMDCR [0 to 99%]

This data displays the duty cycle of the solenoid; this is the PCM command to position the phaser. If this duty cycle varies over a wide range, you could have a sticking solenoid or phaser.
Warm engine at idle = near 0%
Off idle, varies with engine operating conditions

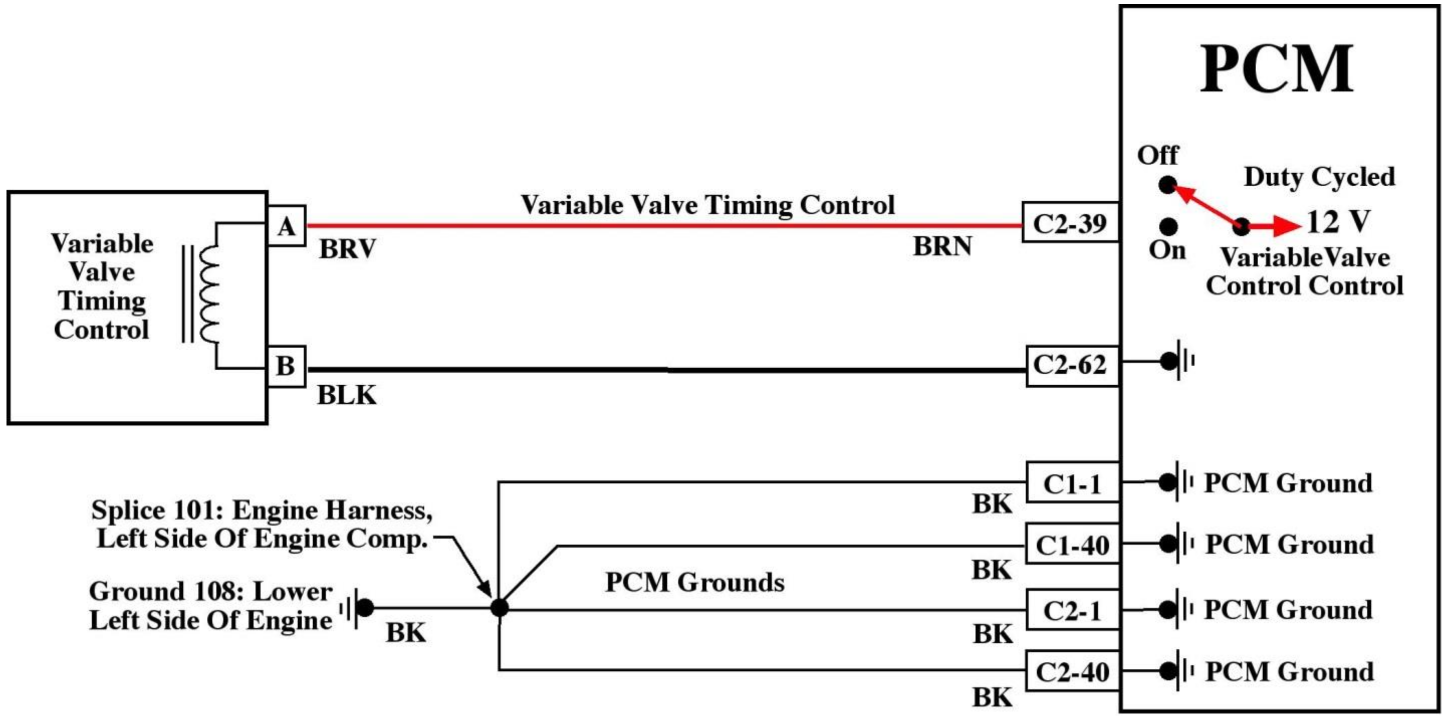
CAMERR 1
CAMERR 2

This data displays the variable cam timing error in crankshaft degrees; this is the data we saw in the scan data examples.
CAMERR 1 is Bank 1
CAMERR 2 is Bank 2

VVT Diagram (Ford)



VVT Diagram (GM)



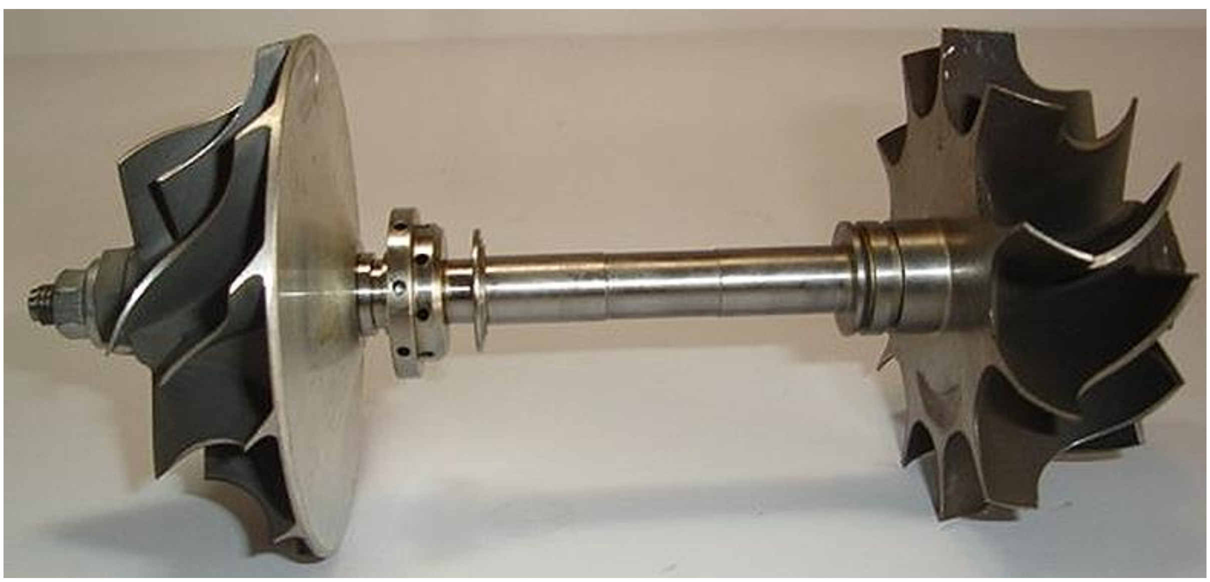
Turbochargers

Twin Turbochargers are used V-type engines.

Single Turbochargers are used on inline engines.

A turbocharger is a turbine that is driven by exhaust gases that compresses incoming air into the engine. The “hot” side of the turbo receives its energy from the heat and flow energy of the exhaust system. The “cold” side of the turbocharger pressurizes fresh air and forces it into the engine. The pressure generated by the “cold” side is called the boost. The “cold” side is driven by a shaft that is connected to the “hot” side.

The main drawback to a turbocharger, besides cost, is its fixed geometry. The Aspect Ratio (A/R) of a turbo, which is based on its geometry, has a direct relation to both the power increase generated and the motor speed at which the power increase is generated. A smaller A/R will produce boost pressure at a lower engine speed, but will be unable to provide a high enough flow rate at higher engine speeds. This leads to higher exhaust manifold pressures, lower pumping efficiencies, and lower power output. A larger A/R will create boost at higher engine speeds, and thus create more power, but it will be unable to produce boost at lower engine speeds. So an A/R must be picked to either; produce power at lower engine speeds for quicker acceleration, or for higher engine speeds to produce a greater total power.

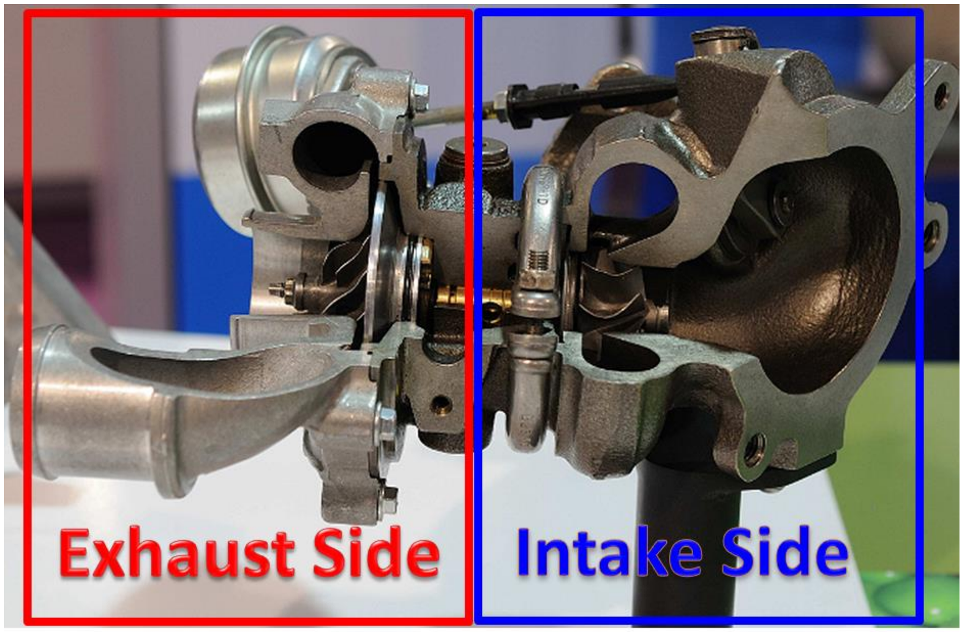


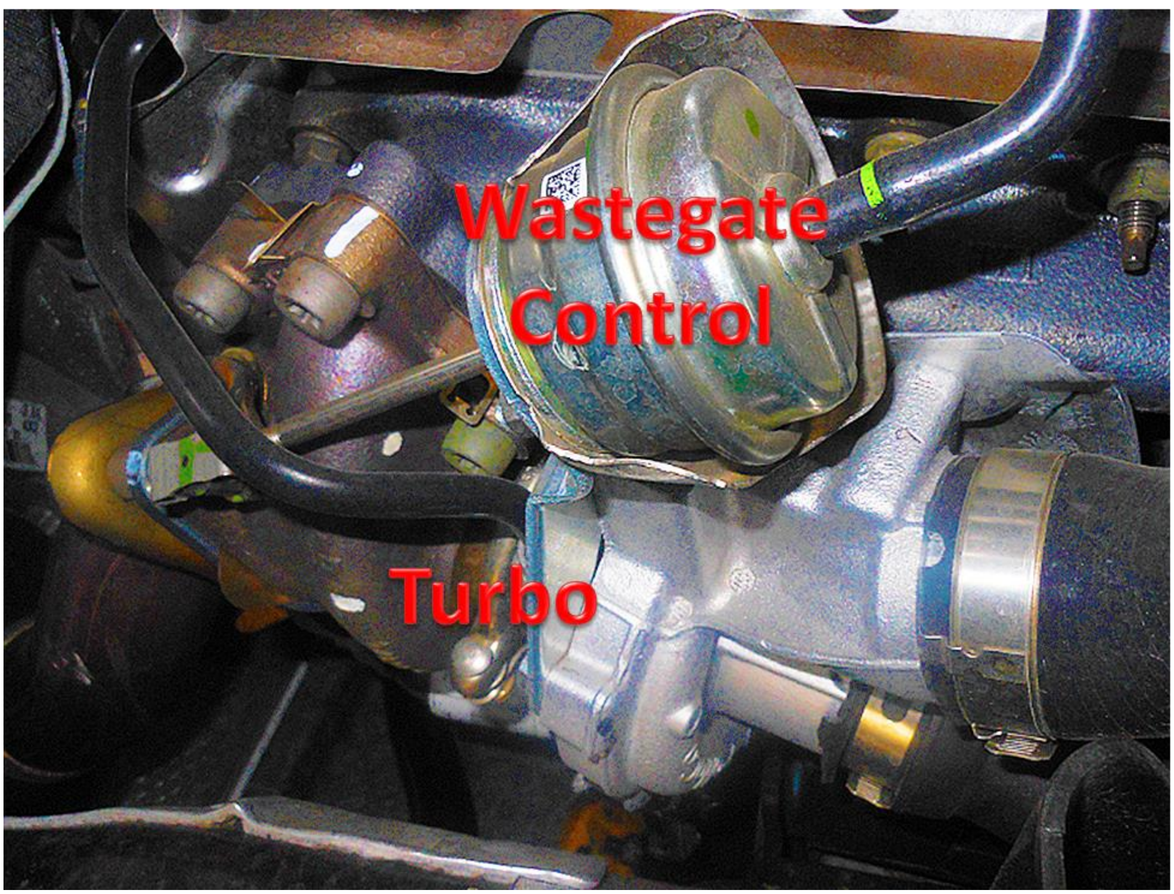
The time it takes for the engine to produce boost between transients is called lag. A large A/R turbo will have a longer lag time than a smaller A/R turbo due its larger requirement of energy from the engine to produce boost.

Turbocharger (VGT):

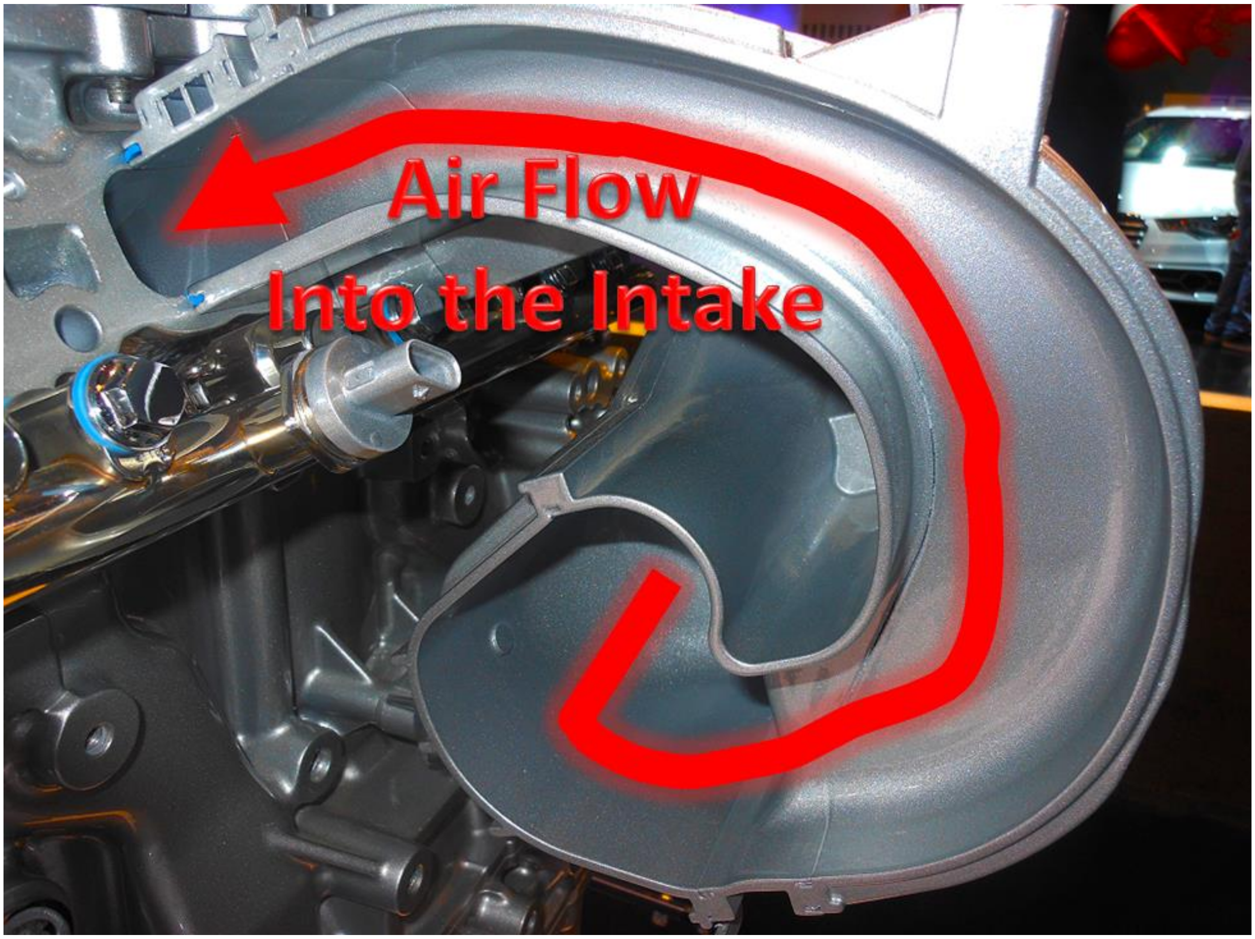
Variable Geometry Turbochargers are turbochargers whose geometry and thus effective A/R can be altered as needed while in use. The most common design includes several adjustable vanes around a central turbine. As the angle of the vanes change, the angle of air flow onto the turbine blades changes, which changes the effective area of the turbine, and thus the aspect ratio (A/R) changes.

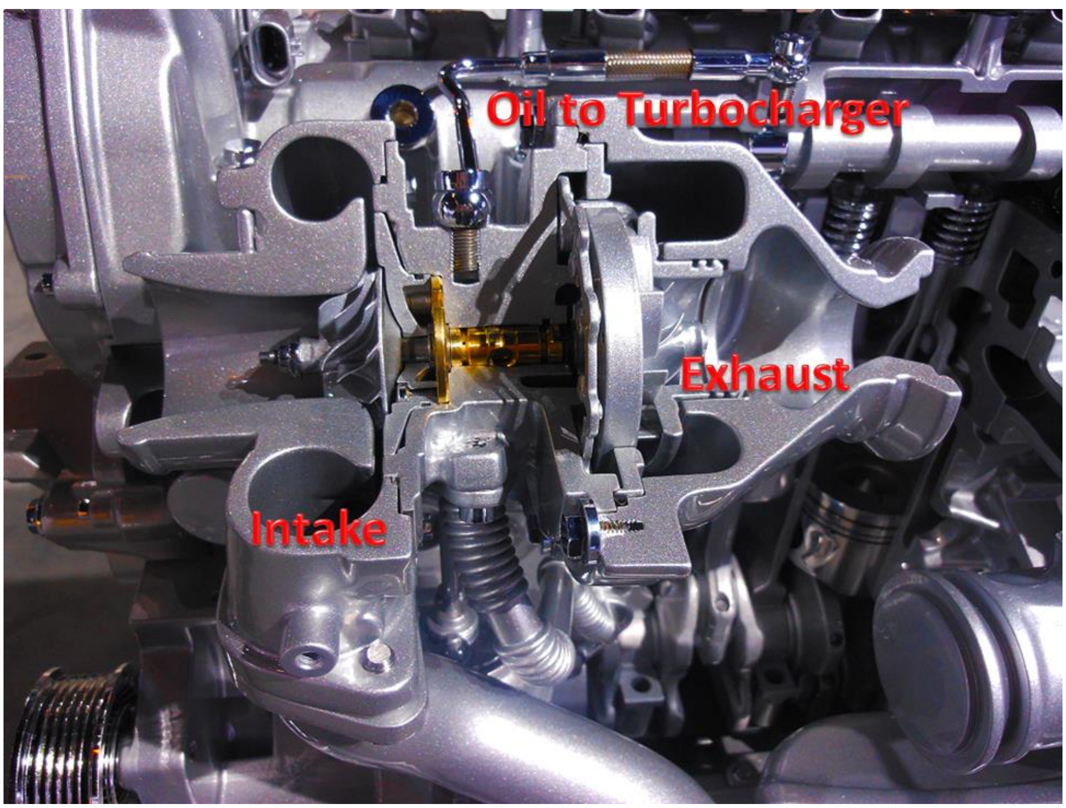
The area between the adjustable vanes works as nozzles. These nozzles are thus varied in size as a function of engine operating conditions. By opening the nozzles at high engine speed or closing them at low speed, effectively changing the A/R with engine speed or demands, the turbo can produce boost from a low speed without restricting flow at higher speed. Since they can produce boost at lower engine speed Lag time is decreased. Also since the vanes are remotely controlled the boost pressure can be altered without changing engine speed. By adjusting the vanes you can increase exhaust manifold pressure during transients (gear changes). Coming out of a transient with a higher exhaust manifold pressure allows this stored energy, in the form of pressure, to be used to drive the turbo to a higher boost level faster. By increasing the boost level faster Lag is once again reduced.





Some turbos use a wastegate that allows some of the exhaust to bypass the turbine when the maximum boost level is reached.



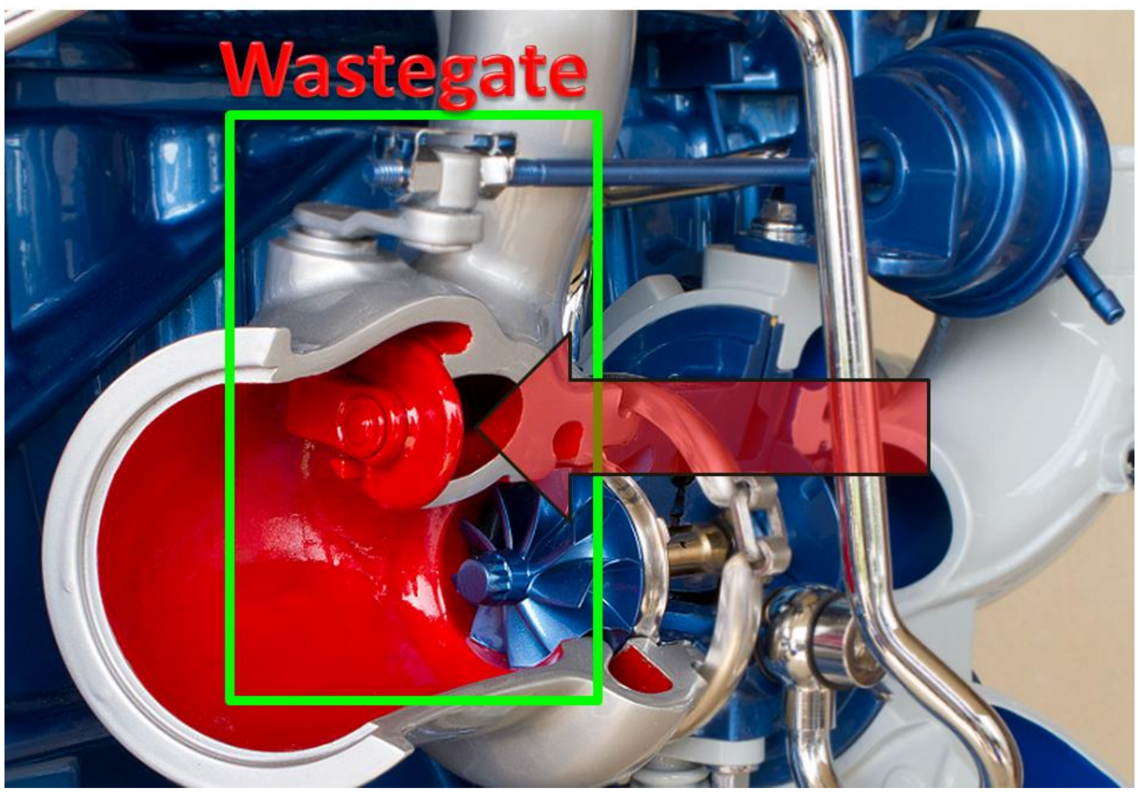


These pictures show you the inside of turbos.

The oil supply to the center of the turbo is critical.

Like VVT poor maintenance is the enemy of the turbo.

The wastegate is the simple control that has proven to be effective over the years.



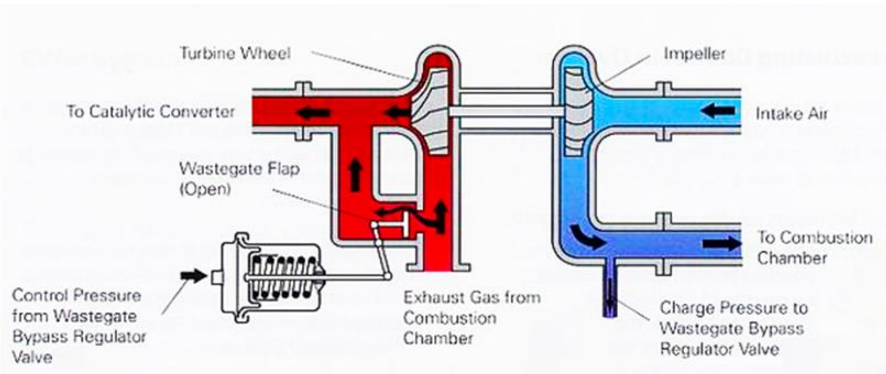
The wastergate opens under computer control to vary the amount of exhaust gas that is bypassed to control boost level.

Wastegate

The basic task of the wastegate is to vent exhaust gas away from the turbo inlet, the less exhaust gas that flows through the turbo, the less boost pressure the turbo can produce. Thus the wastegate "wastes" exhaust gas and lowers boost.

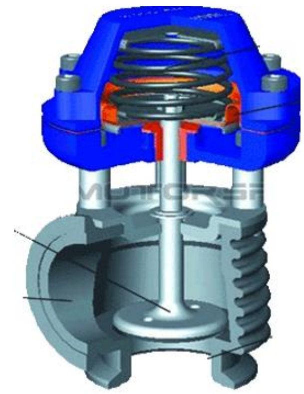
Wastegates are simply valves controlled by a spring and boost pressure. A diaphragm mounted between the spring chamber and the boost chamber creates an upper and lower control chambers.

Both the boost pressure and spring acts on this diaphragm. The valve is held shut by a spring inside the diaphragm chamber to keep the valve shut. The spring keeps the valve shut, and boost pressure forces it open



Wastegates are simply valves;

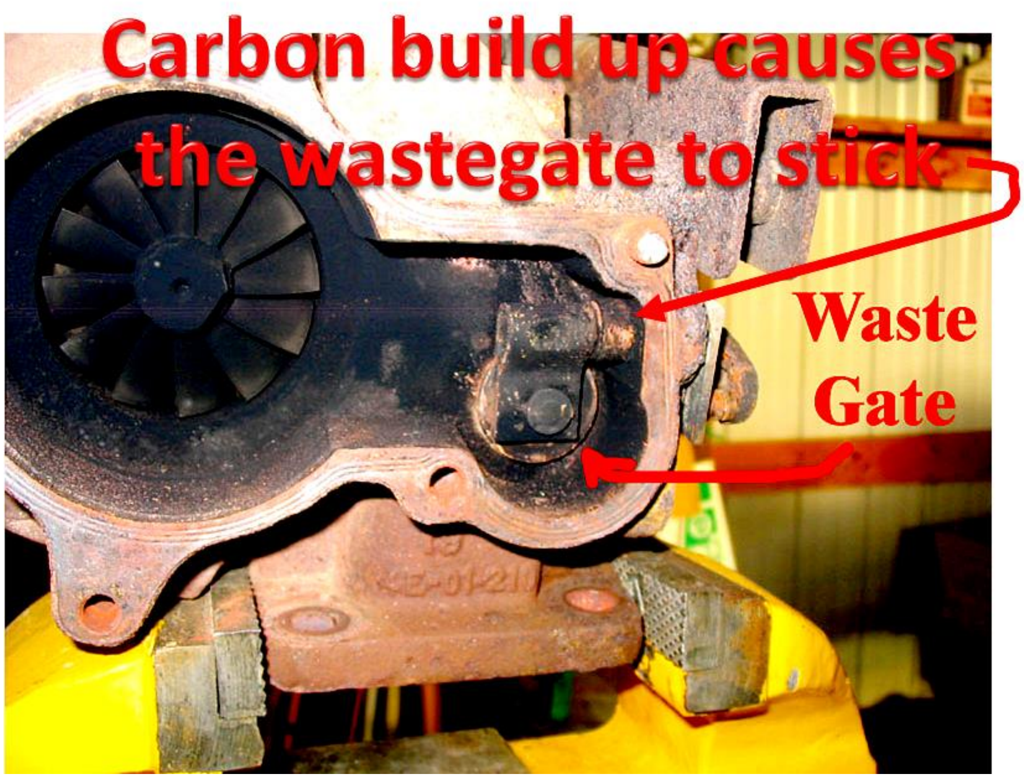
- A diaphragm creates an upper and lower control chamber



- Boost pressure acts on this diaphragm
- The valve is held shut by a spring inside the diaphragm chamber to keep the valve shut
- The spring keeps the valve shut, and boost pressure forces it open
- Controls boost pressure
- Prevents over-boost conditions
- Diverts the exhaust gas away from the turbine regulating turbine speed

Waste gates work on the exhaust side of the turbo.

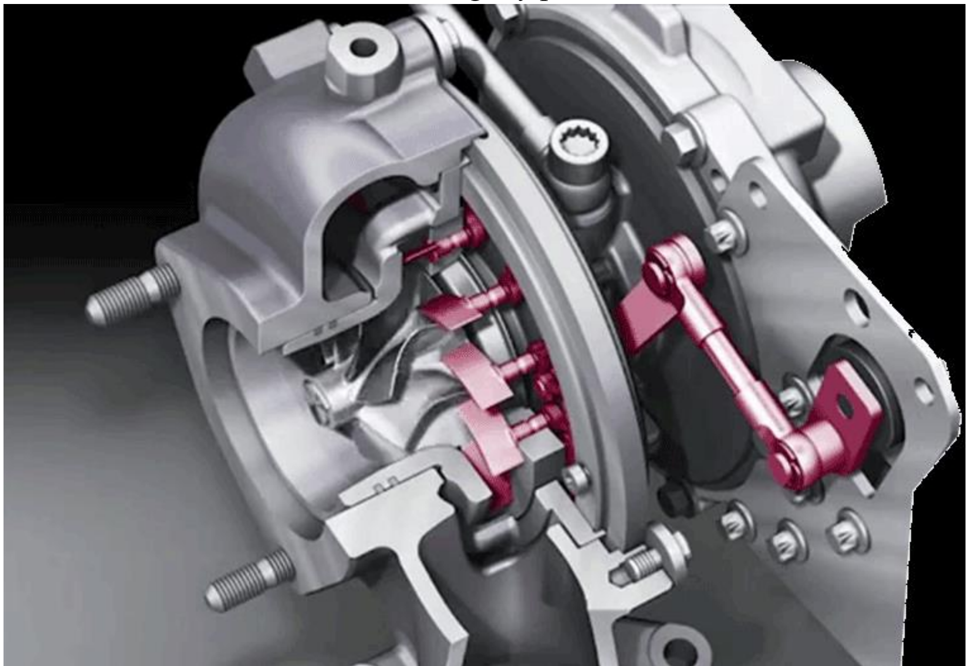
Carbon build up can be a problem for wastegate operation.



Vairable Geomerty Turbo Control

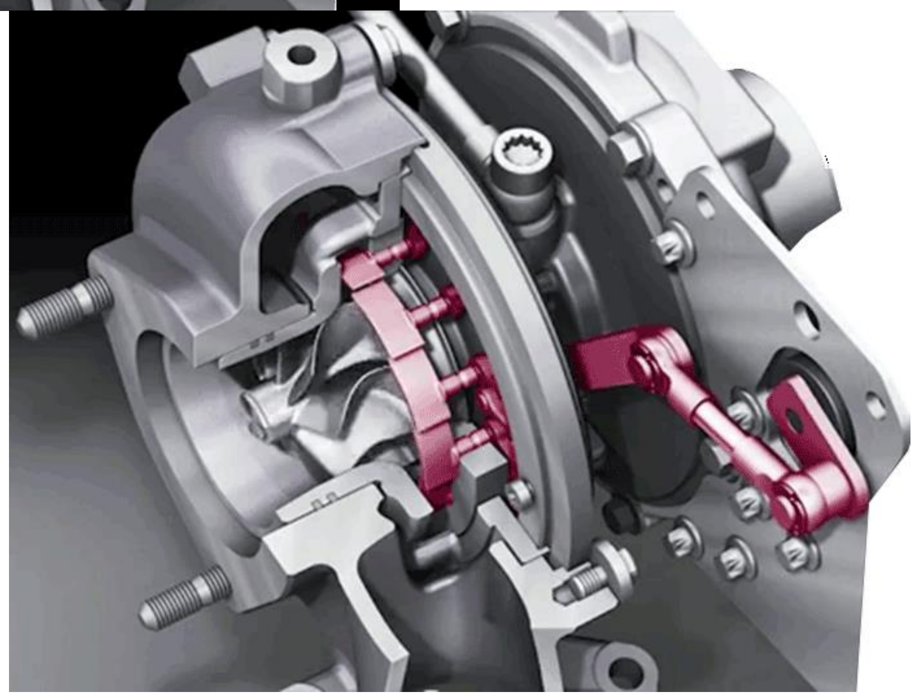
The vane actuator is controlled by hydraulic pressure. Engine oil is directed by an electrical solenoid to a spool valve which moves the actuator lever. The electrical signal sent to the solenoid is varied for precise control of the spool valve.

A solenoid is a coil wound into a tightly packed helix. The term solenoid refers to a long, thin loop of wire, often wrapped around an iron core, which produces a magnetic field, when an electrical current travels through it. Solenoids can create controllable magnetic field and can be used as an electromagnet.



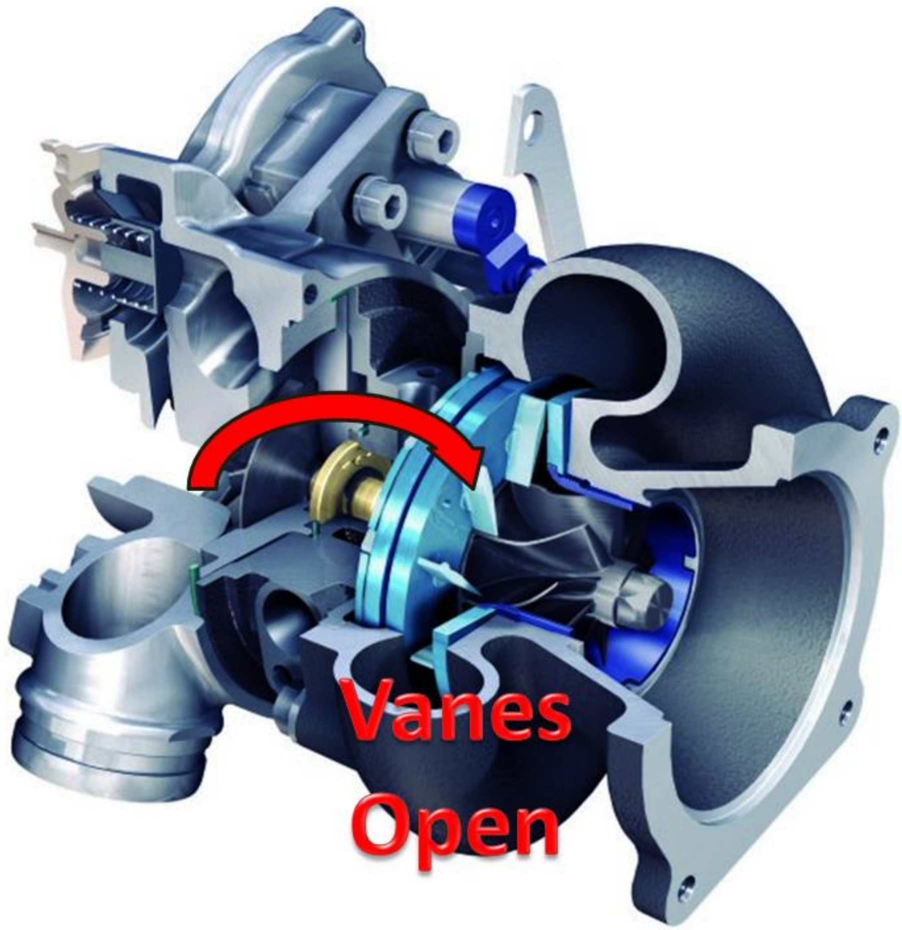
The VGT control valve is commanded by the PCM, based on engine speed (CKP sensor) and load (calculated value based on Mass Fuel Desired (MFDES) at a specified RPM). The PCM uses Exhaust Pressure (EP) for closed loop control of the VGT and to monitor its performance.

This picture shows the vanes open.



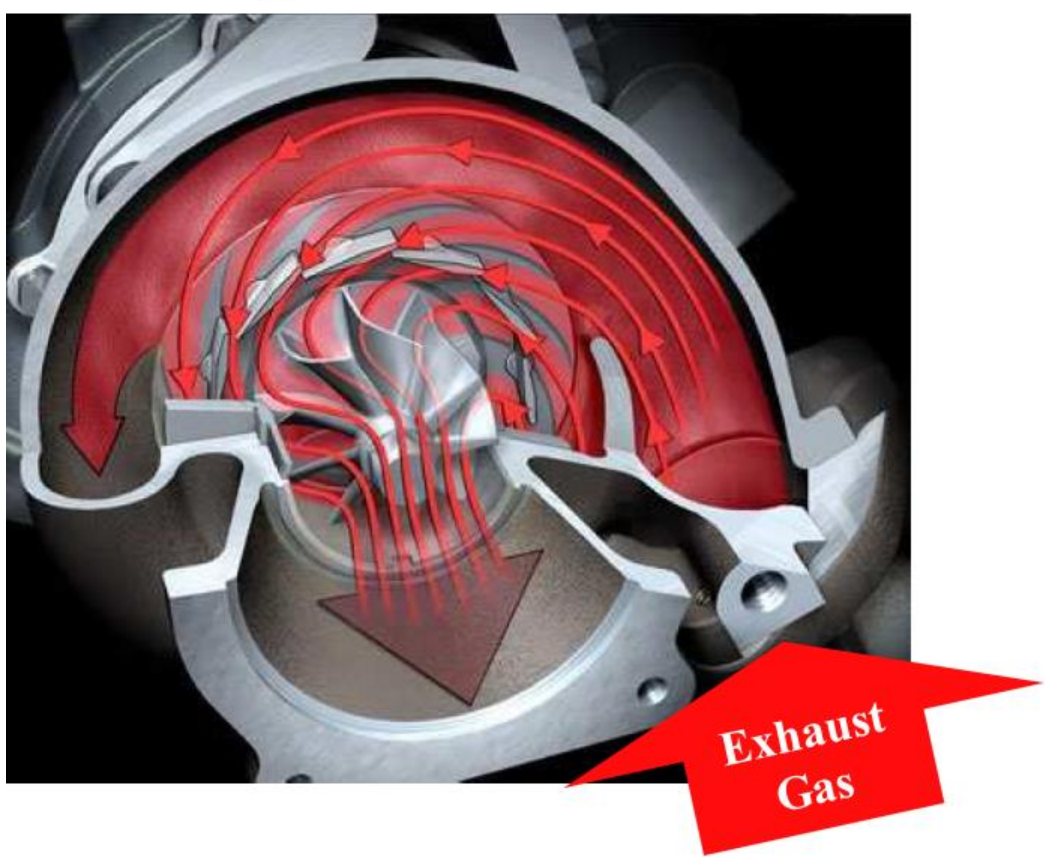
This picture shows the vanes closed.

The vanes are used on the compressor side of the turbo.



Maximum air flow is allowed to enter the turbine with the vanes open.

The wide passages slows the exhaust gas past the turbine blades with more volume at higher engine
 Speeds.

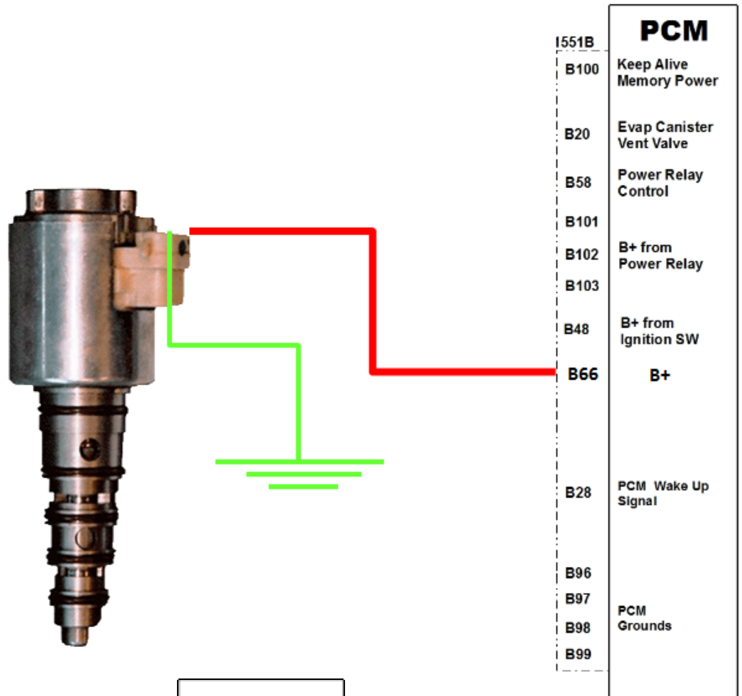


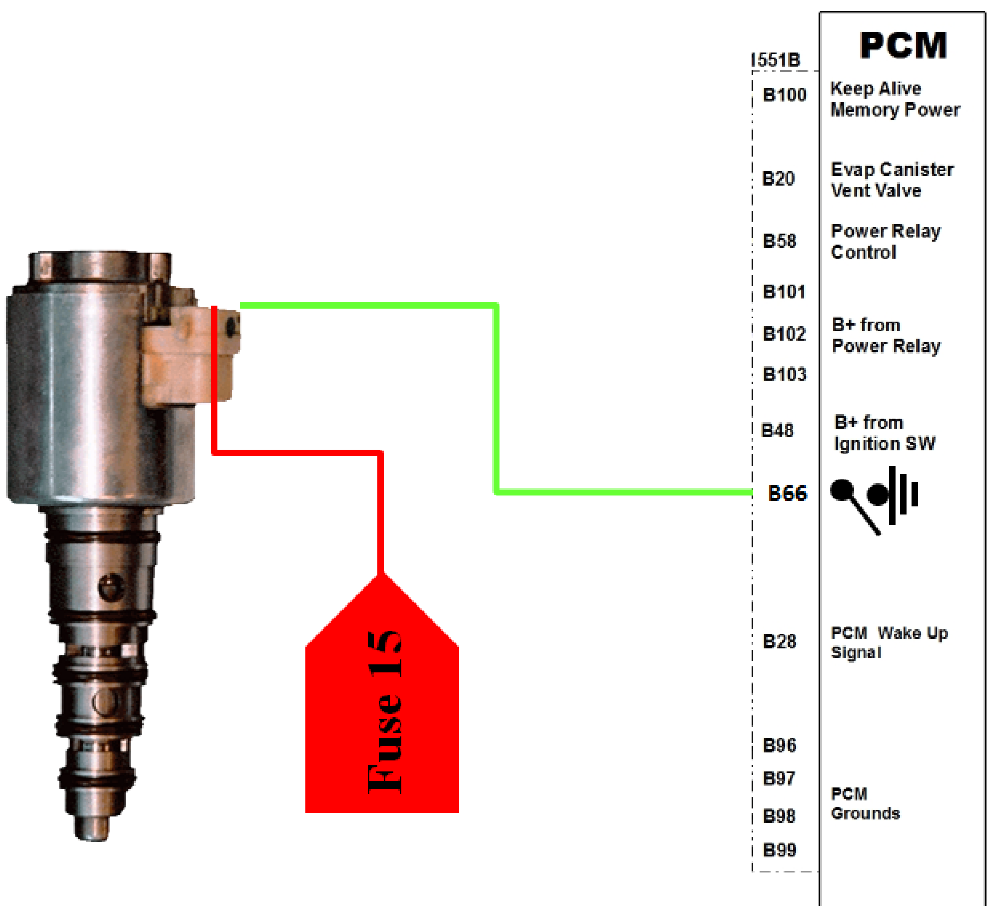
When the variable vanes are almost closed, the narrow passage between the vanes accelerates exhaust gas towards the turbine vanes at the proper angle making them spin faster creating large amounts of boost. When the variable vanes almost fully open the passages between each vane becomes wider. This slows the exhaust gas which slows the turbine by directing exhaust gas flow away from the vanes.

Vane Position Control Solenoid

The Vane Position Control Solenoid is a simple two wire solenoid that is controlled by the PCM with a pulse width signal. The PCM can position the VGT vanes in any position by controlling the signal sent to the solenoid.

This is an example of a high side driver that has B+ supplied by the PCM.

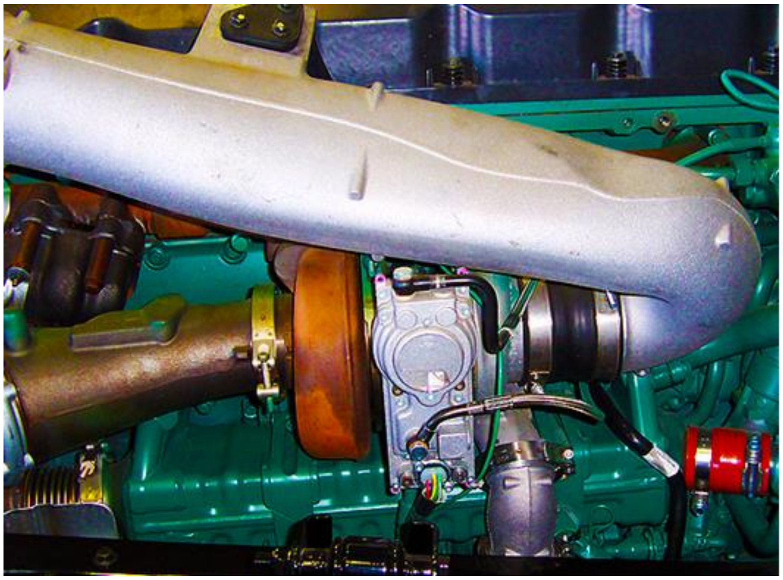


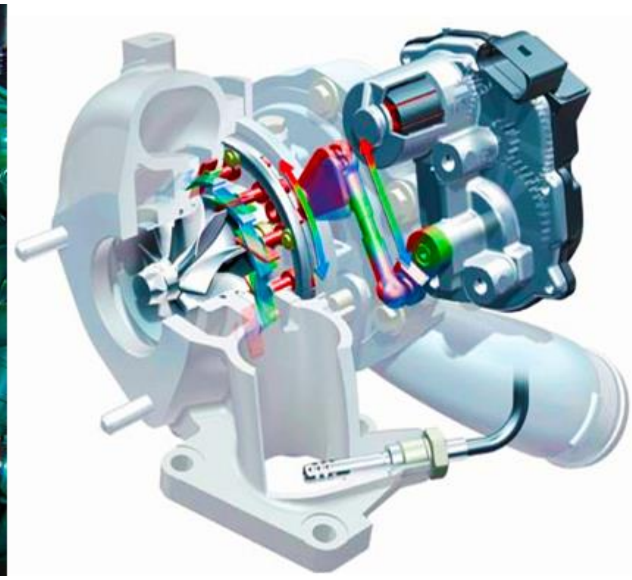


This is an example of a low side driver that has ground supplied by the PCM.

Vane Position Control Summary

This system is more complex than a simple solenoid, but does the same thing.



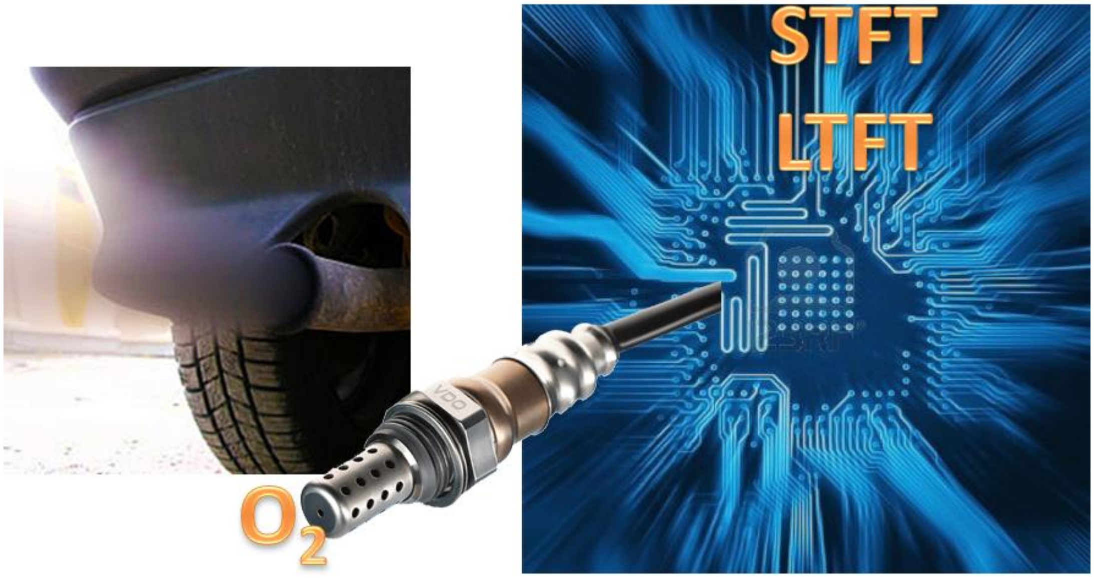


Fuel System

Fuel trim is a two part adaptive strategy that adjusts fuel injectors pulse width (open time) to adapt to any changes in the system. Such as carbon build up in the intake manifold, back of the valves, or a dirty Mass Air Flow sensor. Anything that reduces or increases the fuel or air entering the combustion chamber (vacuum leak) must be compensated for by changing the injector on time or air trim.
There are two parts to the fuel trim adaptive strategy are short term fuel trim (STFT) and long term fuel trim (LTFT). Short term fuel trim is a short temporary adjustment that is an immediate change to fuel control. Long term fuel trim is accumulated over time and stored in memory. If STFT moves too far or makes a continuous adjustment, LTFT adjusts to force STFT to return to zero.
The PCM tries to maintain a long term air/fuel ratio of 14.7:1. If it sees that the long term ratio is not maintained at stoichiometry (14.7:1) it will add or subtract from the injectors base pulse width “on time" to compensate for the incorrect air fuel ratio. Injector on time is the result of sensor input and learned adaptive strategies implemented by the PCM. If the PID on a Scan Tool for LTFT indicates a minus value the PCM is reducing the on time. If the PID on a Scan Tool for LTFT indicates a positive value the PCM is increasing on time.
On latter model vehicles there is an Air Trim value in the PIDs. Air trim is to by-pass air control what LTFT is to fuel control. It is adaptive learning strategy to compensate for a dirty engine that isn't breathing correctly because of carbon build up. When there is a vacuum leak, too much air enters the intake and must be corrected for.
Fuel system diagnostics start with Long Term, Fuel Trim (LTFT), and Air trim (AT)
O_2 Sensors drive STFT which drives LTFT

For diagnostics it is best to divide the fuel system into two separate systems. Fuel control and fuel delivery; Fuel control is the computer side of the fuel system and fuel delivery is the mechanical side. The computer side consists of the PCM inputs which report the engine operating conditions for the IPW on time. The mechanical side is the fuel pump to the injectors and their electrical circuits.

The long term fuel trim (LTFT) responds to STFT. If STFT shifts too far or remains out of normal for too long, LTFT makes its adjustment to the injector pulse width. The LTFT value is stored in memory. LTFT adds to or subtracts from the on time of the injector. The adjustment is a percentage of the on time. For example; if the injector on time was 10 mS and the value in LTFT memory was 3 percent, the injector on time would be, 10.3 mS, you would be able to detect the difference during normal diagnostics by looking at injector pulse width.



Air/Fuel Correction

Fuel control can be described as a computer program stored in memory. It is used to perform the calculations to command the correct fuel delivery during all engine operating conditions. The program uses the PCM inputs such as, temperature values, engine load values, and engine speed to command the correct amount of fuel (how much fuel to command). It uses engine speed, crankshaft position, and camshaft position to know when to command the fuel.

The Power Control Module (PCM) uses the oxygen sensors to determine if the injector pulse width (IPW) delivered the correct amount of fuel.
If the IPW was too lean the PCM will add time to it.
If the IPW was too rich the PCM will subtract time from it.
The time the PCM activates the injector determines how much fuel will flow through it. A longer time supplies more fuel than a short time.
The PCM follows an algorithm each time it activates an injector. (Basic fuel control)

1. Activates an injector.
2. Reads the signal from the fuel control oxygen sensor. If it activated an injector on the right bank, it reads the sensor on the right bank. If the injector was on the left bank, it reads the fuel control oxygen sensor for the left bank.
3. The PCM decides if the air/fuel mixture was too rich or too lean.

4. How much too lean or too rich the mixture was.
5. Calculates a new injector pulse width.

Advanced computer algorithm for fuel control performs the calculations for fuel control.

Computer software program, called Short Term Fuel Trim (STFT), responds quickly to the oxygen sensors information. If the sensor reports lean air fuel mixture STFT will signal a change to a richer fuel mixture. Short term fuel trim responds the rich or lean the oxygen signal by asking for changes to bring fuel mixture back to the ideal fuel mixture. The PCM then makes an adjustment to the injector pulse width to change the amount of fuel being injected.

Diagnostically, remember that STFT reacts to the oxygen sensor voltage. STFT always tries to get the fuel mixture back to the ideal mixture. It will request more fuel for lean conditions and less fuel for rich conditions. The adjustment is small and continuous. Long term reacts slowly to changes in short term correction. LTFT also tries to return the fuel mixture to the ideal mixture and then stored the correction in the PCM memory.

The STFT and LTFT is added together to come up with a value for Total Fuel Trim (TFT). TFT is the amount of the total correction for injector pulse width. It is total fuel trim that sets trouble codes.

The Power Control Module (PCM) uses the oxygen sensors to determine if the injector pulse width (IPW) delivered the correct amount of fuel;

- If the mixture was too lean the PCM will add time to injection pulse width
- If the mixture was too rich the PCM will subtract time from injection pulse width

Short Term Fuel Trim (STFT)

Short term fuel trim refers to adjustments being made in response to temporary conditions

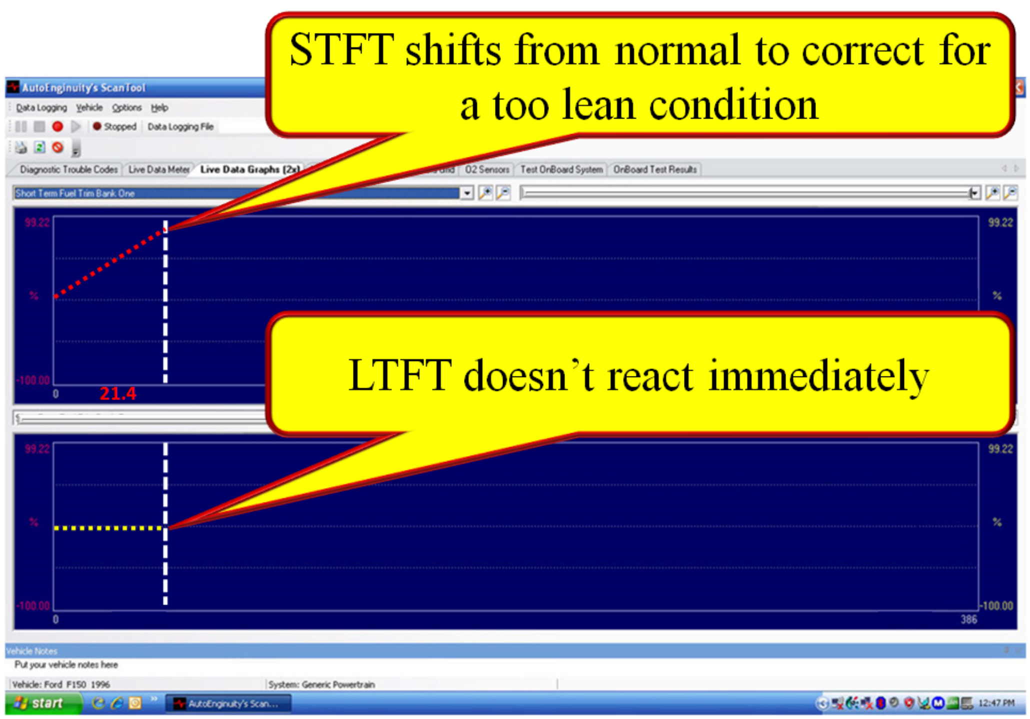
The STFT correction is in small amounts and continuous.

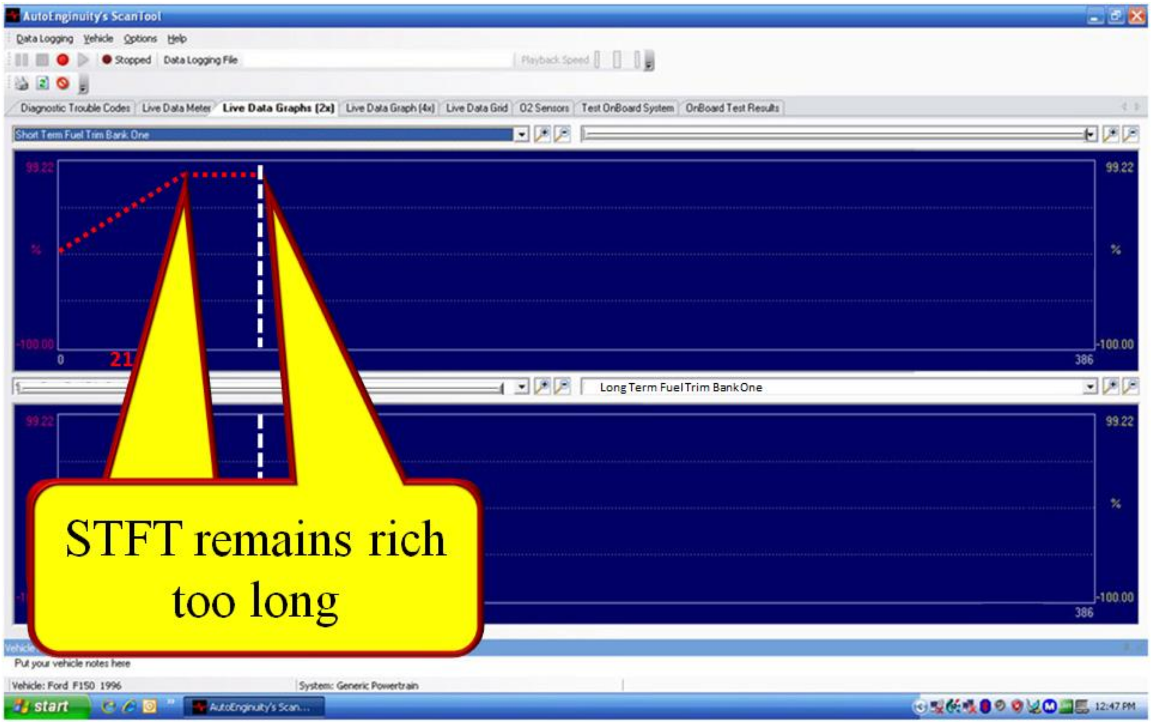
When STFT moves too far or remains too long in any one correction direction it drives Long Term Fuel Trim (LTFT).

We will walk through fuel correction.

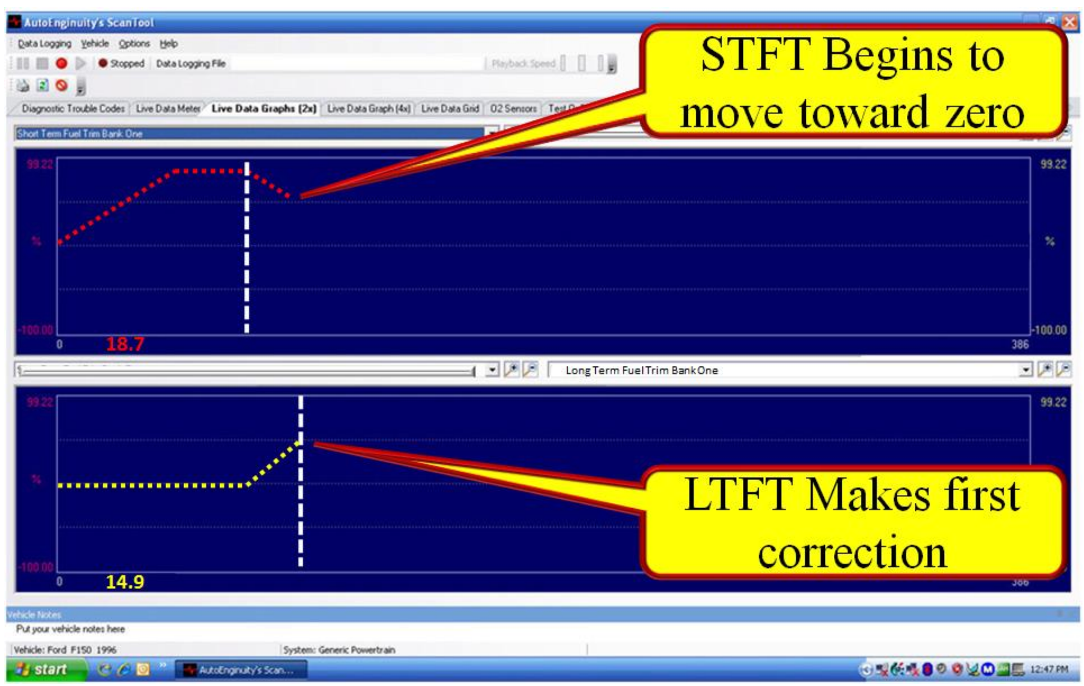
We will start when short term shifts to correct for a lean condition.

The initial reaction of long term fuel trim is to do nothing; long tern stores events that last long enough to clearly be a problem.



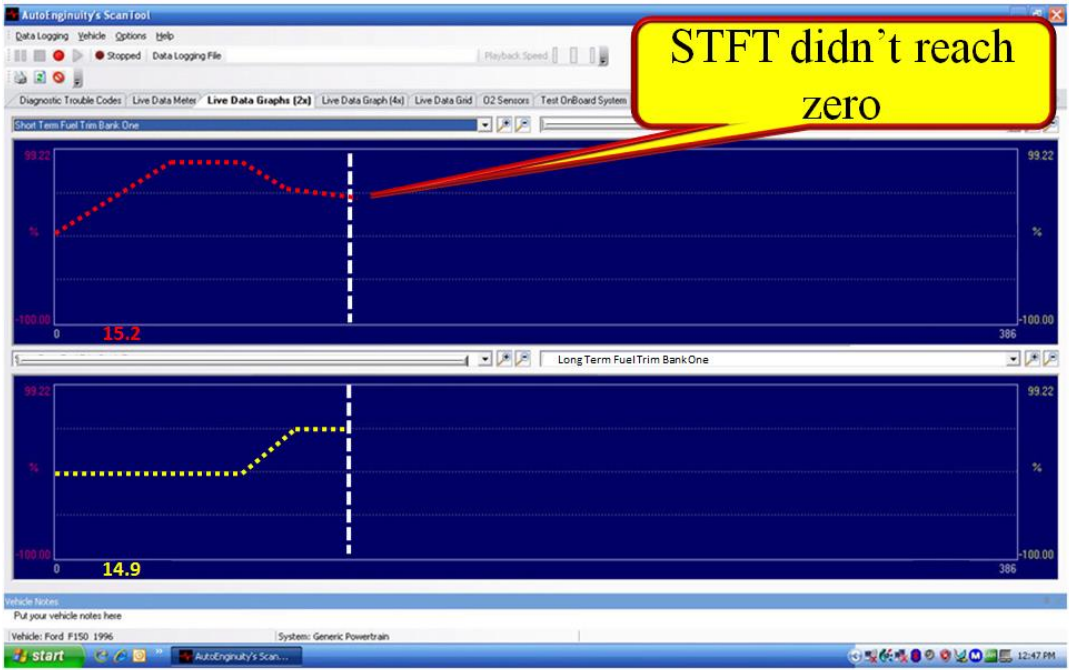


If short term stay richer long enough, long term will slowly start making adjustments.



When long tern starts making adjustment, the added fuel starts being short term back toward normal.

Long Term Fuel Trim (LTFT)

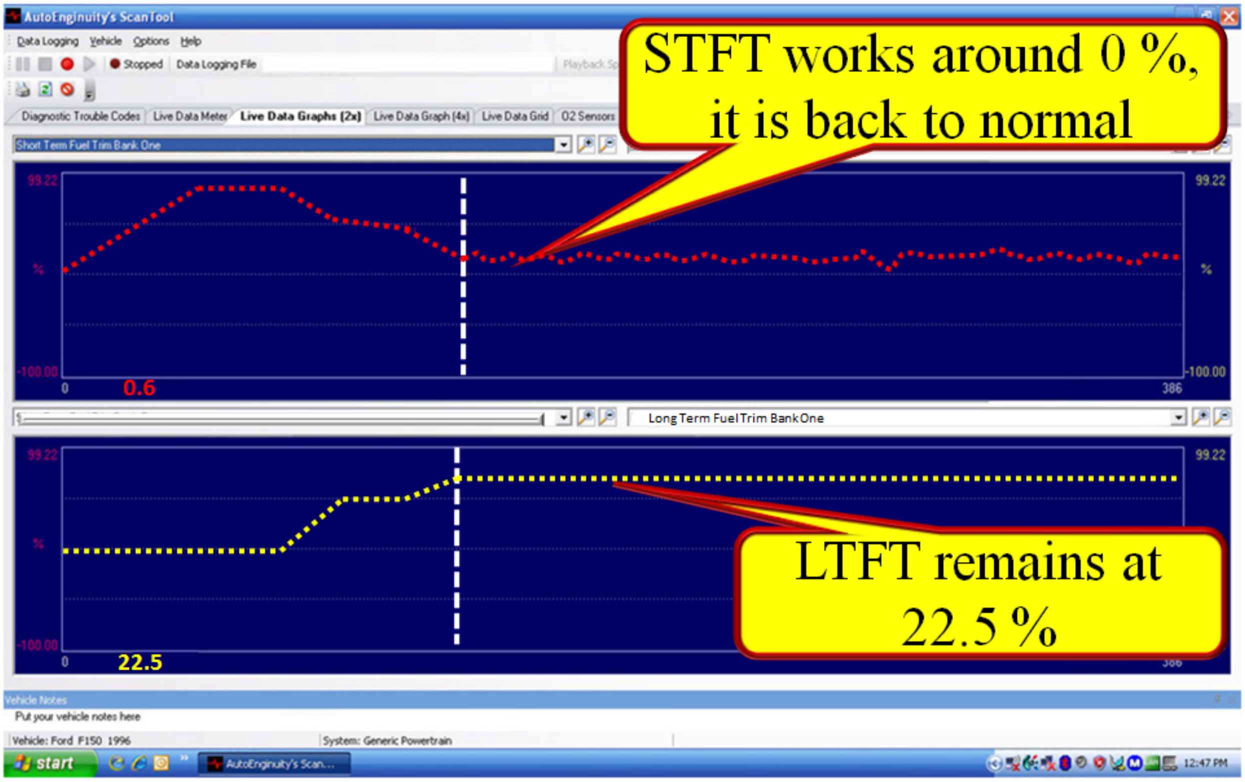


Long Term Fuel Trims are adjustments for conditions that are present over a longer period, have moved to an extreme side of correction.
LTFT corrections are stored in memory that uses keep alive memory power to retain data after the ignition is switched off.

The first LTFT adjustment did not return STFT back to normal, so additional changes are necessary.

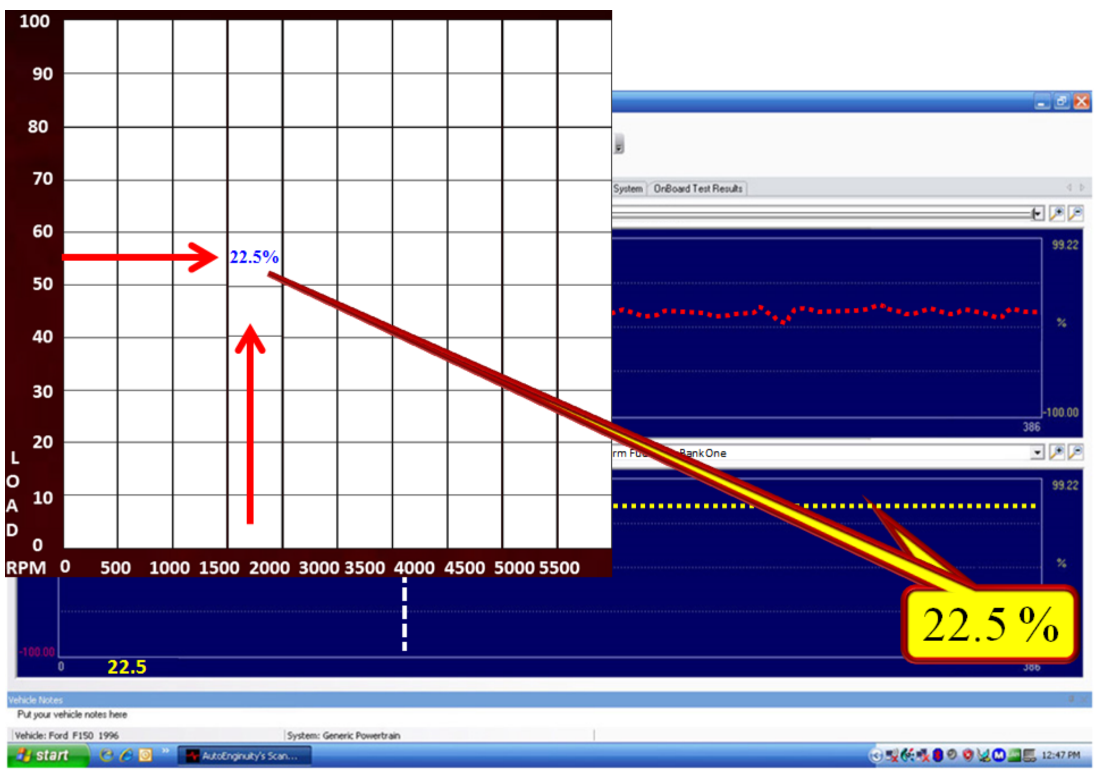
After the second adjustment, STFT is not back to normal but it is closer.

LTFT needs to make adational adjustments to bring STFT back to normal.



STFT is moving slightly above and below 0%, it is normal.

TFFT is up at 22.5% and this is the value that will be stored for this set of operating conditions. There are long term fuel trim memory cells for a number of operating conditions.



This set of condition was engine speed about 1750 RPM with engine load at about 55%. The next time the vehicle is in this set of conditions, the PCM will add 22.5% more fuel than the value calculated for "normal" conditions.

The different operating conditions will have a stored LTFT for each set of conditions.

Long Term Fuel Trim Cells

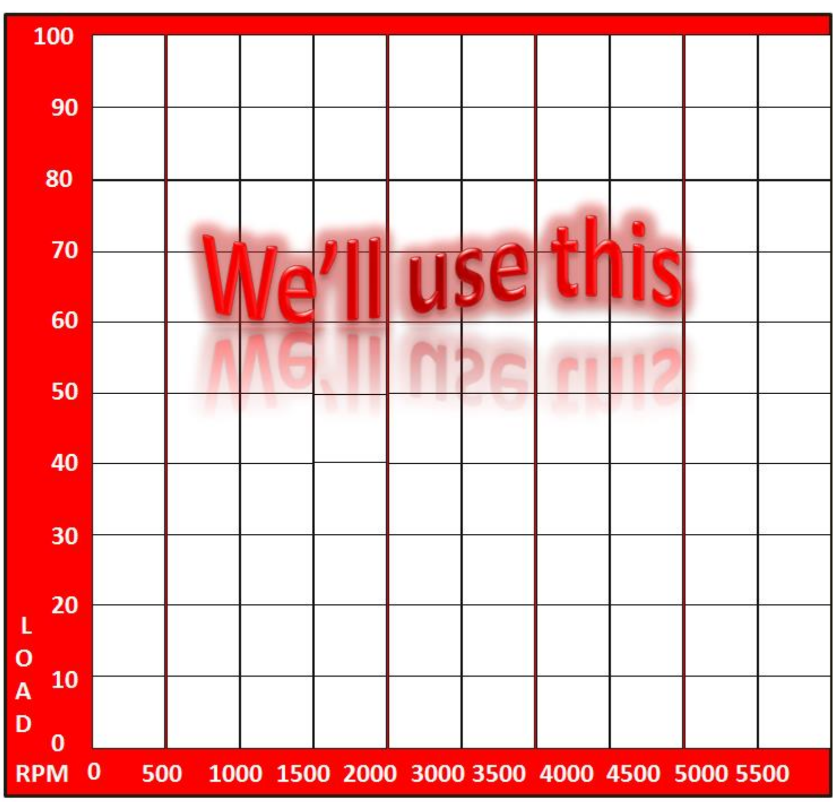
Fuel trim refers to adjustments being made dynamically to the base fuel table to get the proper ratio of fuel to air. Short term fuel trim refers to adjustments being made in response to temporary conditions. Long Term Fuel Trims are adjustments for conditions that are present over a longer period.

Fuel trims are expressed in percentages; positive values indicate lean (add fuel) and negative values indicate rich (subtract fuel).

Fuel trim banks refer to the cylinder banks in a V style engine. Cylinder #1 is always in bank 1. Short and Long term fuel trim generally should not exceed +-5%. As a rule if an engine has excessive mileage (70,000 miles) or appears as if it wasn't maintained correctly, we allow a value of +- 10%. Any value over or under zero percent indicates a problem. Values under or over +-5% would be small and very difficult to find. +- 10% problems are also small and require strong diagnostic procedures to find. But they can be found with proper procedures.

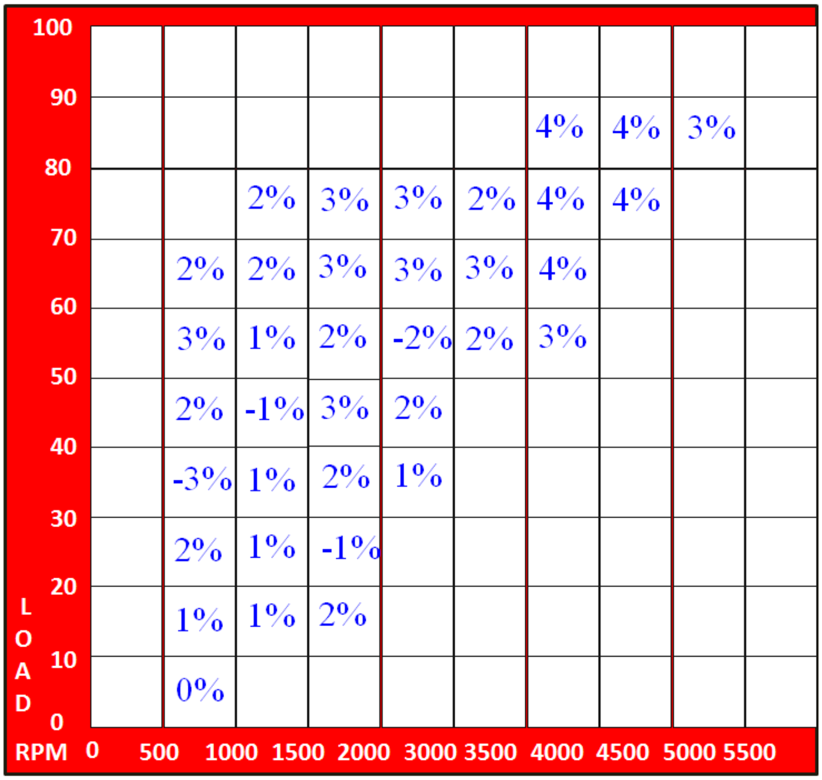
Long Term Fuel Trim (LTFT) is a matrix of cells arranged by Engine RPM and Load;

- Each cell of the long term fuel trim is stored in a register (memory)
- As the engine RPM/load changes, the PCM will switch from cell to cell to determine what the LTFT factor is and use in the base pulse width equation



It is impossible to show what memory cells look like because they are in the PCMs memory.

We will use a chart that has blocks for engine speed VS throttle opening.



We can look at the data is the memory cells with scan data on a few vehicles. This example is created by the Escan scan tool and we find it useful.

These are the stored values of LTFT needed to bring STFT back to normal for the different operating conditionds.

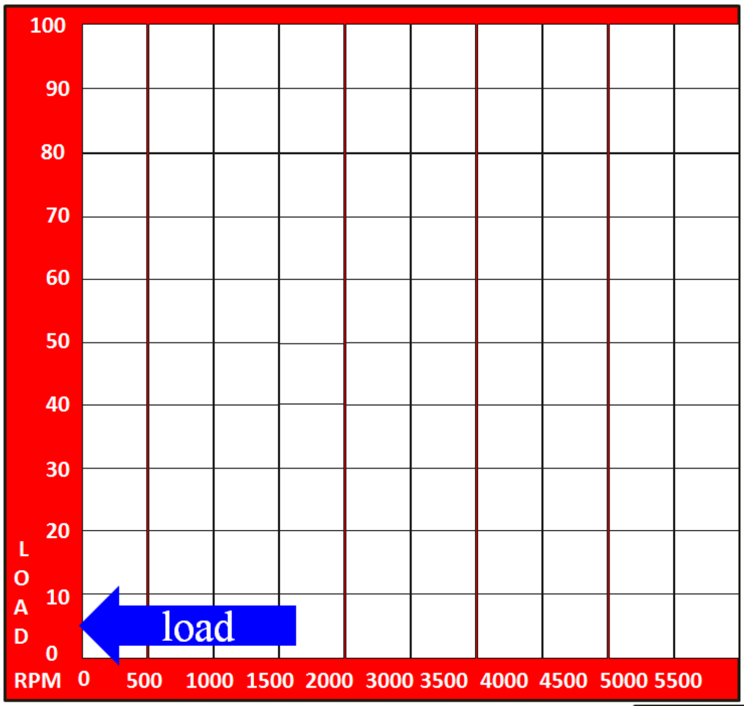
Long Term Fuel Trim Description

While in any given cell, the PCM also monitors the short term fuel trim
If the short term fuel trim has moved far enough from 0%, the PCM will change the Long Term Fuel Trim value in that specific cell
As the LTFT value changes, it should force the STFT back toward 0%
Normal Fuel Trim Values;

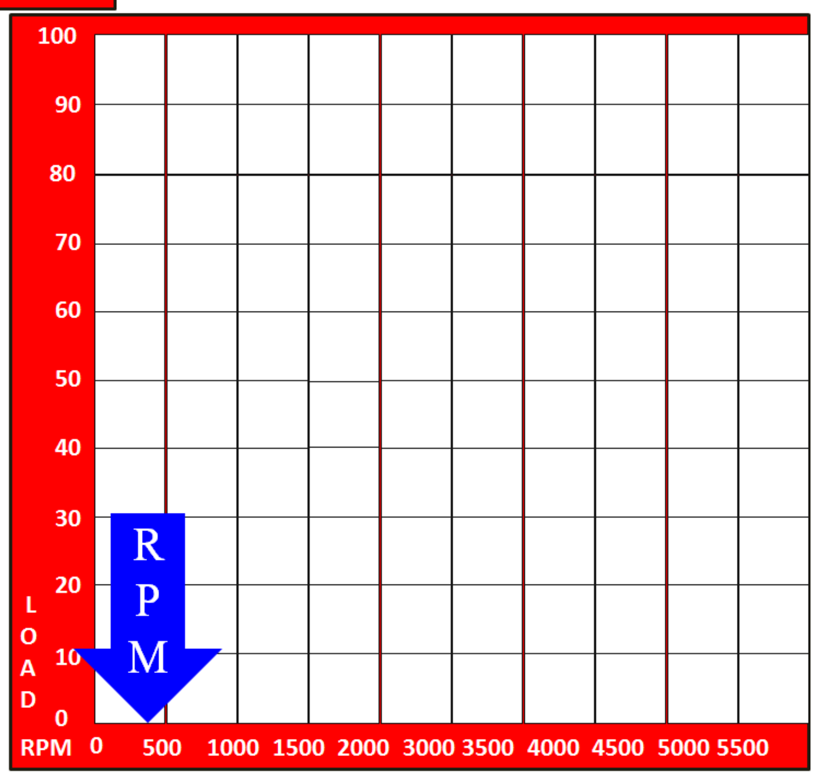
- Plus (adding fuel) or Minus (Subtracting fuel) 5% is normal
- Vehicles that have excessive miles on them or haven't been maintained correctly Plus or Minus 10% is acceptable
- Total Fuel Trim (STFT+LTFT) + or – 10% are acceptable

If the LTFT PID changes while you are watching it, compare it to the throttle changes.
If the throttle is moving the LTFT will move (Change values) because the fuel control system is moving through the fuel cells. This is normal activity as viewed in Scan-Data. There is an exception to this. If LTFT has been cleared each cell would report 0% making it appear as if fuel control wasn't moving through the fuel cells.
If the throttle isn't moving (held steady) and the LTFT PID is moving (changing values) it indicates that LTFT is in the process of learning. As an example if the technician created a vacuum leak at idle, he would see the LTFT values change as the PCM leans the vacuum leak and makes adjustment. The vacuum leak wouldn't change the LTFT quickly because the fuel control algorithm would first use STFT in an attempt to correct for

the extra air (lean air fuel mixture). When STFT couldn't make the correction, LTFT would makes its attempt to correct and that is when the LTFT PID values would be seen changing.
This information may be used for diagnostics. If the throttle is steady and LTFT PID values are moving the technician knows the problem is present. This can help with finding an intermittent problem that isn't always present.

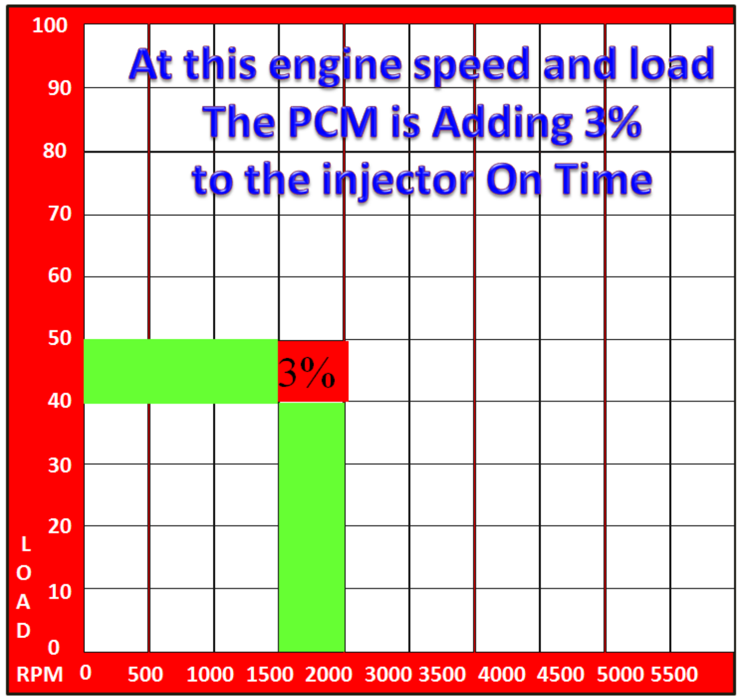


The load values are shown on the left vertical scale,



Engine speed is shown on the bottom horizontal scale.

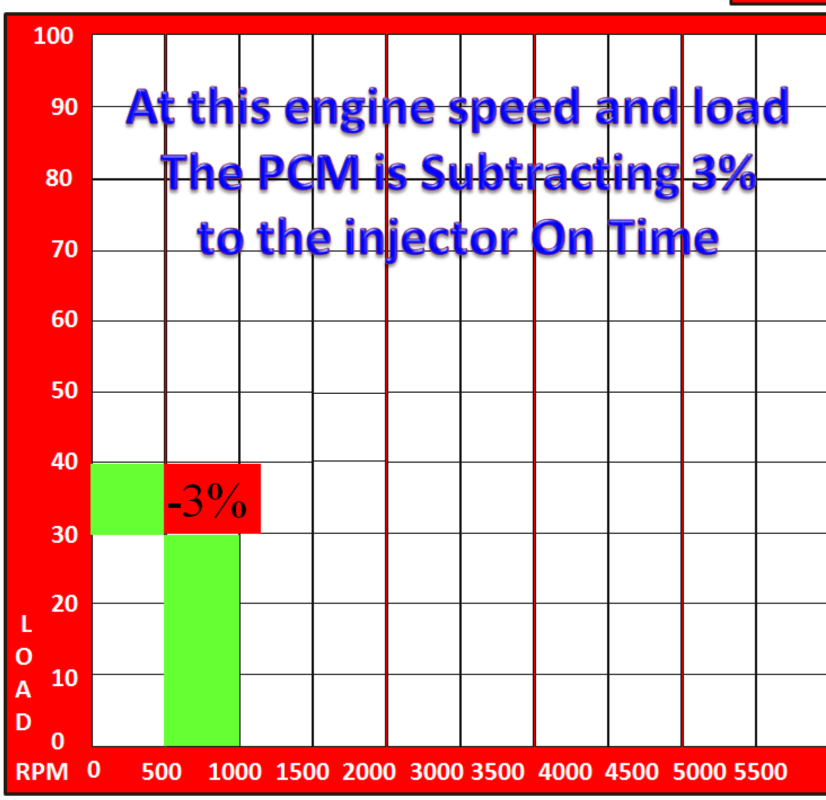
Next we will go through the process the PCM uses to add data to the cells.



We will select 45% load and 1750 RPM.

The PCM has determined than 3% extra fuel is required in this cell to keep short term in the normal range.

Just remember, each cell can have different requirements.



We will look at 35% load and 860 RPM next.

The PCM is reducing fuel by -3% in this cell.

Remember, we don't get concerned until the numbers get to 5% and we find the problem at 10%.
We also want to look for diagnostic patterns that help diagnose problems that accrued at highway speeds.

This example is the results we found after taking the vehicle for a test drive that included heavy acceleration to enter a freeway.

These values indicate that only moderate changes in fuel delivery were required to bring fuel mixture to the ideal point.

LOAD \ RPM	0–500	500–1000	1000–1500	1500–2000	2000–3000	3000–3500	3500–4000	4000–4500	4500–5000	5000–5500
90–100										
80–90							4%	4%	3%	
70–80			2%	3%	3%	2%	4%	4%		
60–70		2%	2%	3%	3%	3%	4%			
50–60		3%	1%	2%	-2%	2%	3%			
40–50		2%	-1%	3%	2%					
30–40		-3%	1%	2%	1%					
20–30		2%	1%	-1%						
10–20		1%	1%	2%						
0–10		0%								

Now it is time to look at a test drive that had fuel delivery problems.

LOAD \ RPM	0–500	500–1000	1000–1500	1500–2000	2000–3000	3000–3500	3500–4000	4000–4500	4500–5000	5000–5500
90–100										
80–90							12%	15%	12%	
70–80			2%	3%	3%	8%	8%	5%		
60–70		2%	2%	7%	6%	6%	7%			
50–60		5%	4%	6%	6%	7%	5%			
40–50		2%	1%	3%	2%					
30–40		3%	1%	2%	1%					
20–30		2%	1%	1%						
10–20		1%	1%	2%						
0–10		0%								

Over + or – 10% Never Normal

We see fuel adjustments are major at high loads and high engine speed.

This indicates we are not receiving adequate fuel when fuel demands are high.

Dirty injectors would show up at all loads.

Restricted fuel filter or low volume fuel pumps can’t supply high fuel flow and result in patterns that look like this.

We have some older vehicles that displayed fuel cells in scan data, this is an example;

Sensor Name	Value	Units	Minim...	Maxim
Actual Delivered Spark Advance	15.5	Deg	-64.0	63.5
Adaptive Fuel Factor #1 (Truck/Jeep Vehicles) - Slow Speed	6.6	%	-50.0	50.0
Bank 1 Normal Adaptive Memory Fuel Cell #00	2.5	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #01	3.3	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #02	2.0	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #03	4.5	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #04	3.3	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #05	6.0	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #06	6.4	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #07	4.9	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #08	5.3	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #09	4.1	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #10	5.1	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #11	6.0	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #12	5.3	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #13	4.1	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #14	3.1	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #15	6.0	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #16	4.5	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #17	3.9	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #18	1.0	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #19	0.8	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #20	1.0	%	-100.0	100.0
Bank 1 Normal Adaptive Memory Fuel Cell #21	3.3	%	-100.0	100.0
Battery Voltage - Sl			0.00	16.00
Battery Voltage Re			0.00	15.75
Cam-Crank Diagno			0	1
Cam-Crank Diagno			0	1
Current IAC Steps			0	127
Desired Idle Speed			0	9000
EGR Position Sens			0.00	5.00
Engine Vacuum			0.0	31.0
Engine Speed			0	9000
O2 Sensor 1/1 - Slo			0.00	5.00
Throttle Position -			0.00	5.00

21 Cells
Numbered 00 to 21

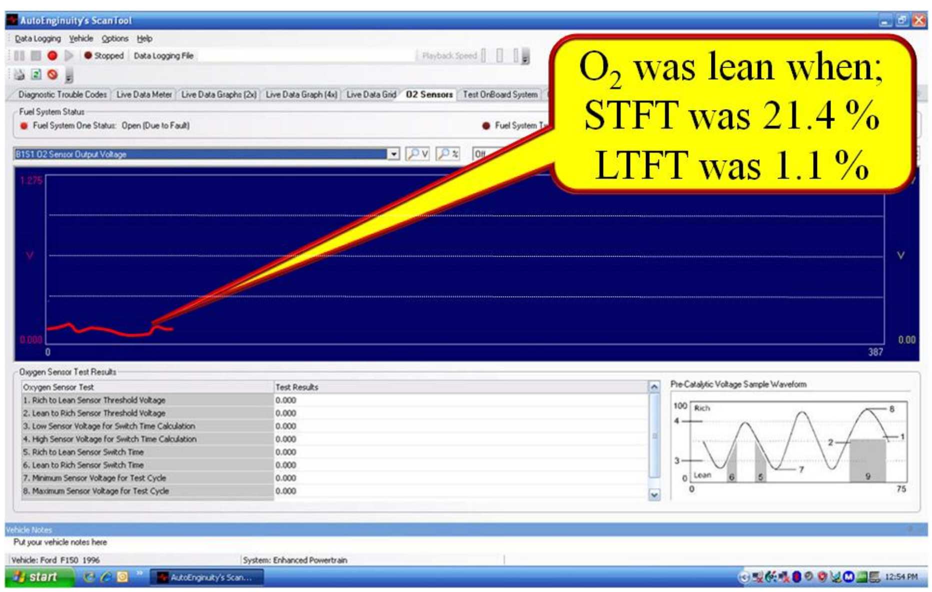
Cell 00 is wide open throttle at maximum engine speed and 21 is warm idle. Memory cells and LTFT don't update until engine temperature is over 160-170^{o} F. We have a few cells in the middle over 5%, but the high loads cell of 00 is 2.5%.

When the engine is shut off these values will be stored in memory for the next start up.

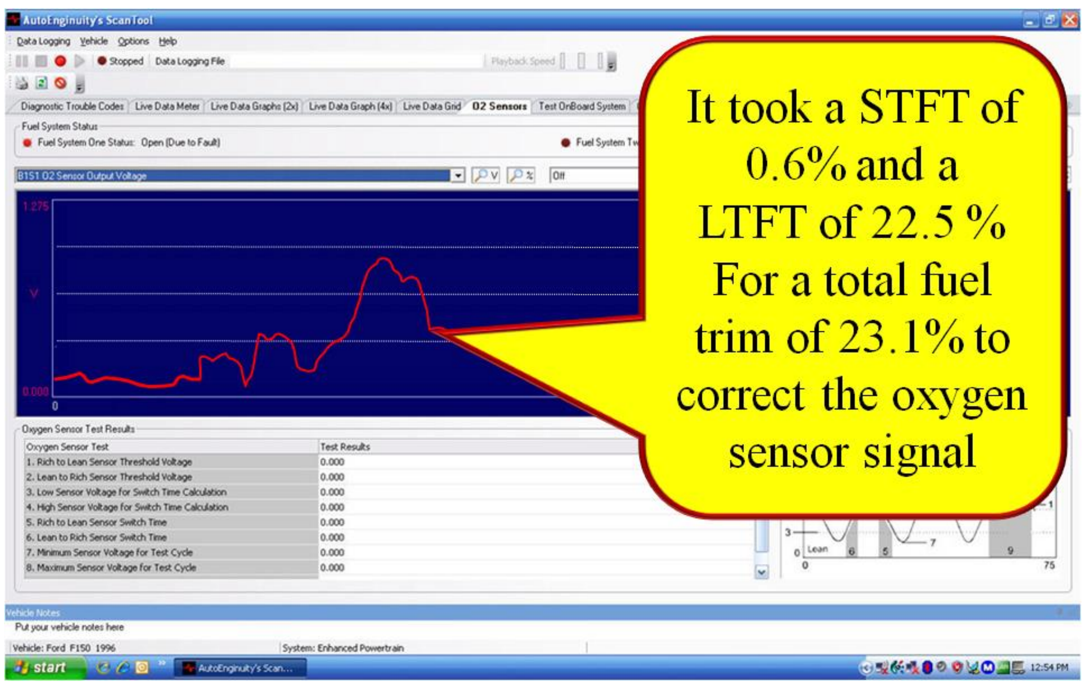
Next we need to watch the oxygen sensors while these corrections are taking place. Remember, short term fuel trim responded to changes reported by the oxygen sensor.

O_2 Sensor response to fuel trim

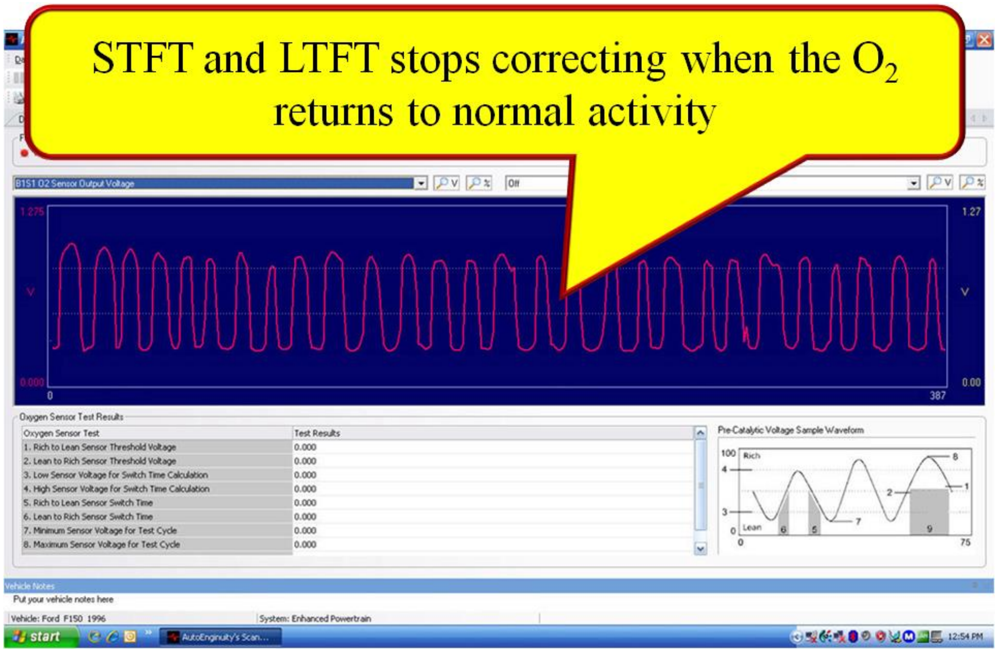
The oxygen sensor signal was very lean when short term fuel trim started making adjustments.



The oxygen sensor signal starts to improve as the fuel trim starts adding more fuel.

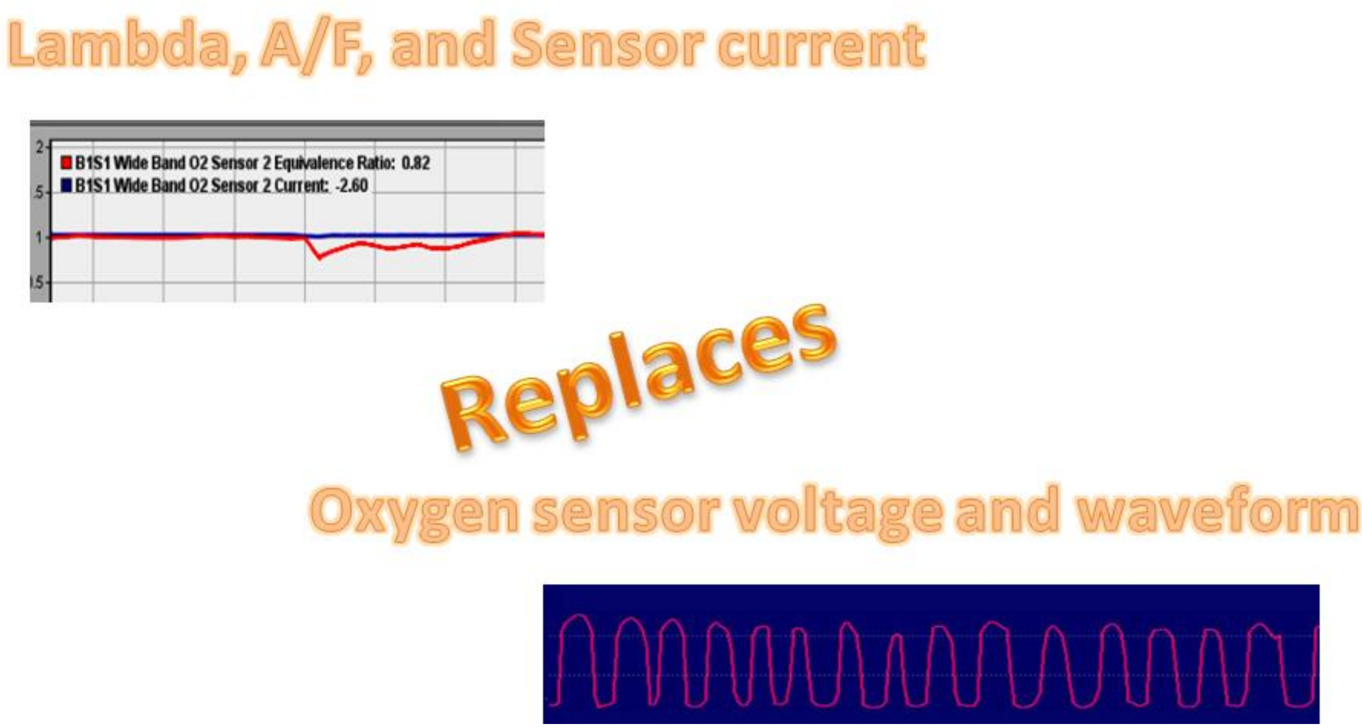


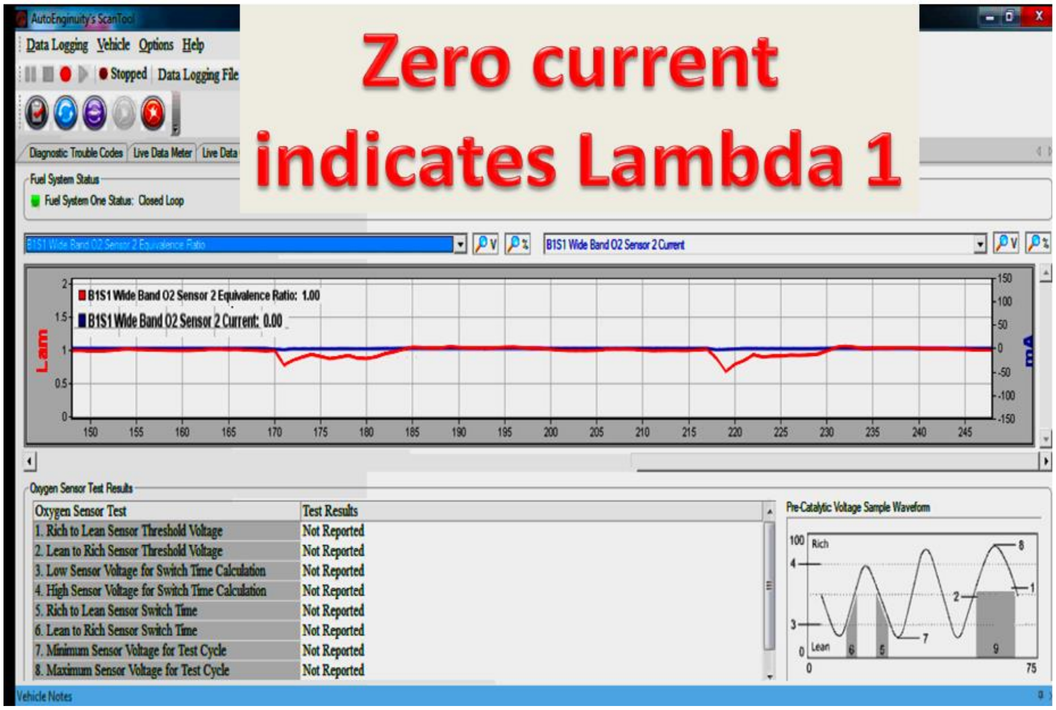
The oxygen sensor signal is normal when the total correction is complete and the value to correct it is stored in long term fuel trim.



The oxygen sensor signal is normal after the complete correction is done.

New O_2 technology Replaces old technology

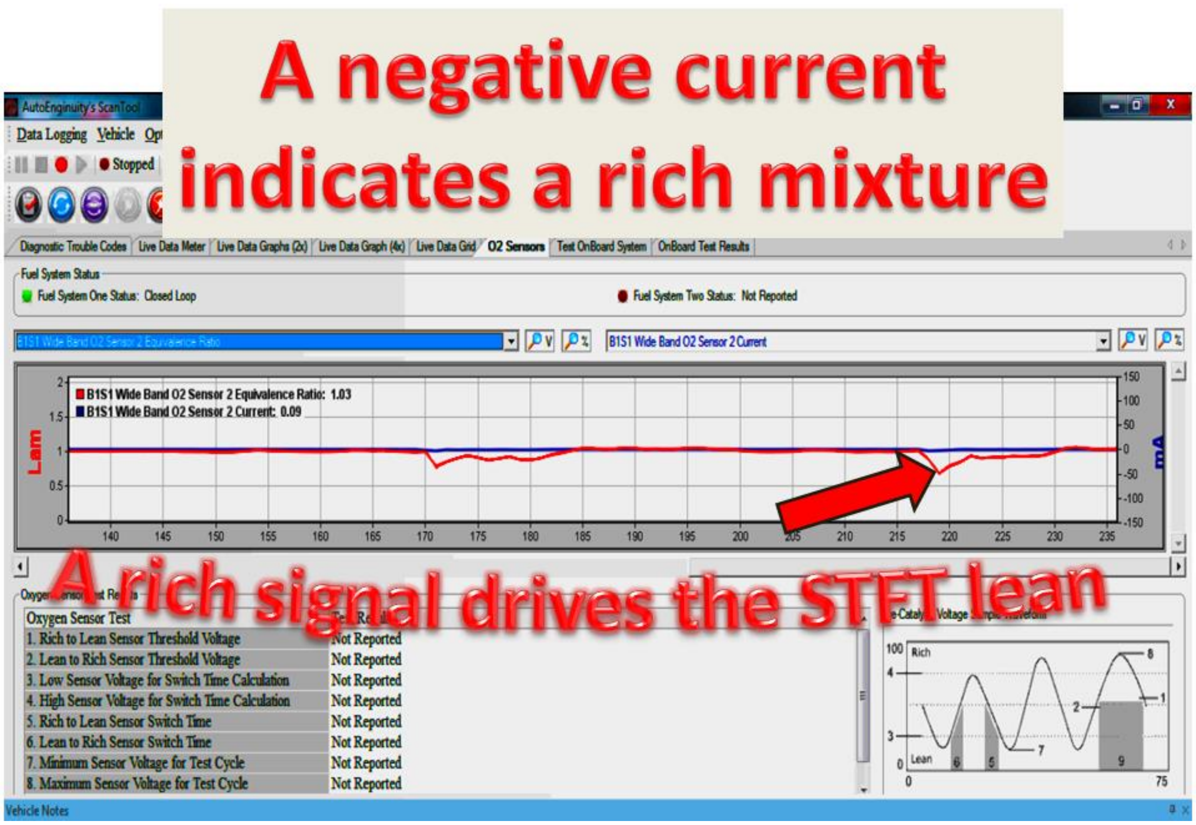


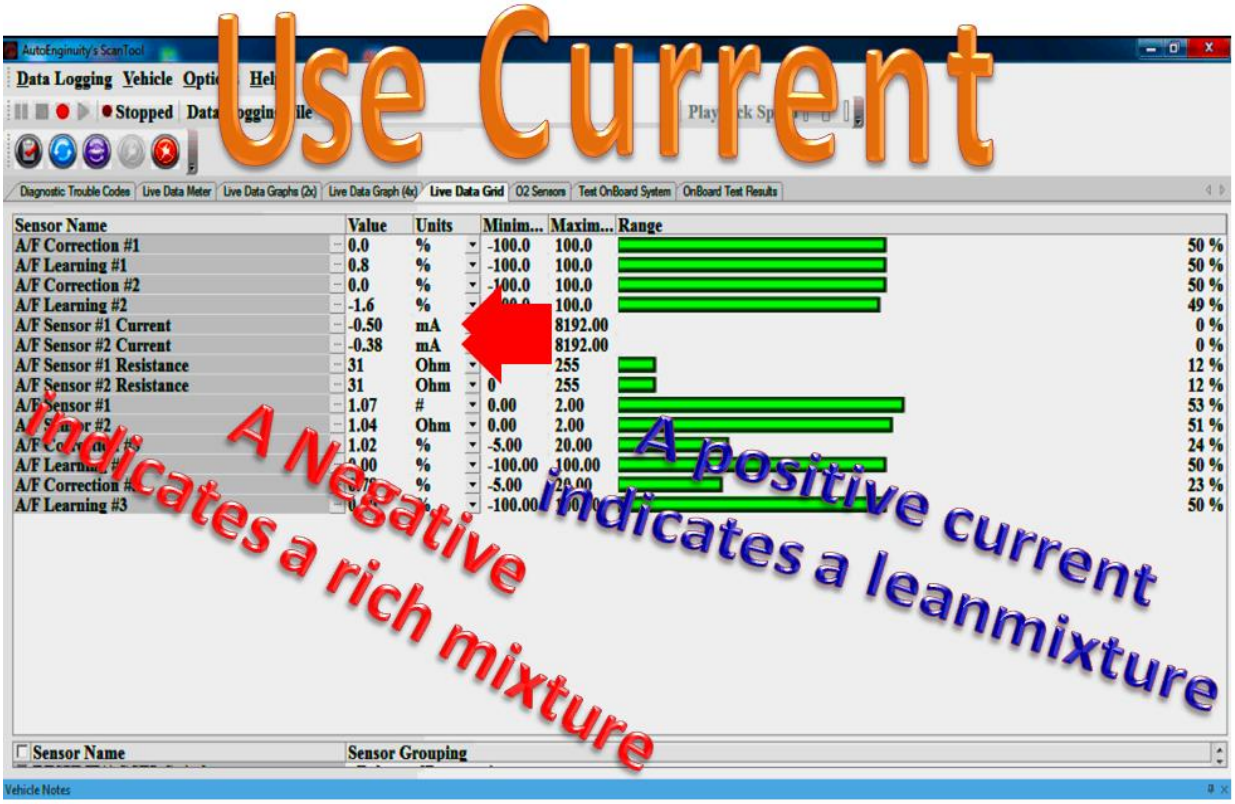


Lambda of 1 is ideal fuel mixture.

Remember, the rules are the same; the mixture must stay rich for fuel trim will make adjustments.

This example was a brief acceleration, which does not require adjustment.





Another PID that will help with oxygen sensor testing is the sensor's current value. As stated the current changes with the air fuel mixture. During the drive we should see the current report positive and negative. In most Scan Tools when the current is negative there will be a symbol for negative in front of the value. When the value is positive there won't be any symbol in front of it.

There aren't any specifications for what the current value should be at any giving moment. You use this PID this way. The current should show a value when the throttle is opened. The value shouldn't remain at 0 all the time that would indicate that the sensor has an open circuit. The value shouldn't go above 3 mA or that would indicate that the sensor is shorted. For any indication of an open or a shorted sensor, ensure it isn't the circuit itself between the sensor and the PCM that has the problem before replacing the sensor.

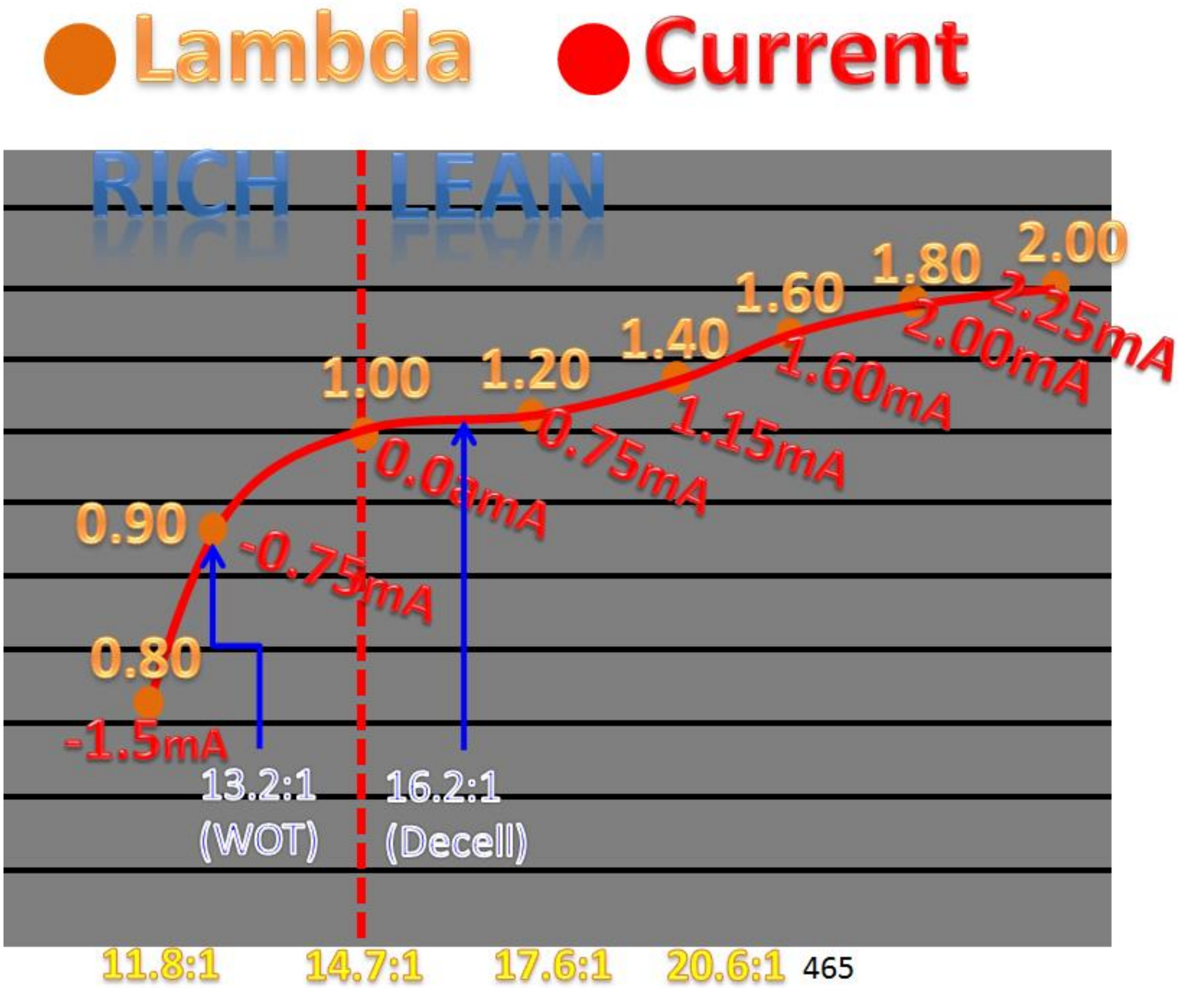
Fuel control / delivery test drive

This test is for No-Code problems with drivability. Perform this test to check for proper fuel control and delivery. Check for any codes or OBD-II failures first. Diagnose any codes first.

Begin with a fully warmed up engine. Connect a Scan-Tool and select the Lambda and A/F PIDS.

1. Allow the engine to idle and stabilize.
2. At idle the engine should be 14.7: A/F ratio.
3. The lambda value should be 1.0 λ.
4. Perform a hard acceleration (not wide open throttle).
5. Under hard acceleration the mixture should be 13.2:1 A/F ratio.
6. The lambda value should be 0.9 λ.
7. Allow the engine and vehicle speed to stabilize.
8. Close the throttle to decelerate.
9. The mixture should be 16.2:1 A/F.
10. Lambda value should be 1.1 λ.

If the A/F ratio doesn't make it to the 16.2:1 point it, indicates that fuel is being burned when the system should be in fuel cut-off. Look for leaking injectors.
If the A/F ratio doesn't make it to the 13.2:1 point it indicates not enough fuel for maximum acceleration. Test the delivery system.



If the A/F ratio or lambda value doesn't reach its normal value;
If the test drive indicates a problem make an attempt to determine which side of the fuel system isn't performing normally. These procedures should divide the fuel control and delivery problems.
Check for diagnostic trouble codes. Also check OBD-II diagnostic test mode-6 for any oxygen sensor problems. Look carefully to see if the test values are close to the maximum or minimum. If there is any indication that the O_2 sensor has a problem, replace it.
If there isn't any O_2 problems look at the LTFT values.
Look for any shift from normal values. If the PCM is compensating for a rich or lean condition, it is doing its job, test the fuel delivery system. If LTFT values don't show a correction, test the inputs.

If there isn't a clear answer test both the fuel control and delivery sides of the fuel system.

- Look for any diagnostic trouble codes
- Look for OBD-II test mode-6 for any O_2 problems
- If there are no O_2 problems
- Look at the long term fuel trim PID(s)
- If there is a LTFT shift the PCM (computer) is doing its job, test the fuel delivery system
- If there isn't a LTFT shift, test the inputs
- If there is a vacuum leak, LTFT will increase in positive values
- If an injector(s) leak, LTFT will increase in negative values

Vacuum Leak At Idle

When there is a vacuum leak;

- Additional air enters the engine that was not metered
- Leaning the Air/Fuel mixture
- The PCM will add fuel for compensation
- The PCM will also correct for the additional air by adjusting the Idle Air Control (IAC)

Compare the Data;

LTFT Plus or minus 5%	IAC 10-24 Counts or %

- If LTFT is not normal and IAC is normal look for a fuel problem
- If LTFT is not normal and IAC is not normal check for a vacuum leak first

New Idle Air Control PIDs

IAC Keep Alive Trim;

- IAC Trim is a stored value for adjustment for electronic throttle settings (ECT PID next)
- Typical values are 0±2 counts (Minus 2 to plus 2)
- This is an air trim learned value that compensates for too much or too little air at idle
- Vacuum leaks drive the values into the positive
- Leaking injectors drive the values into the negative

Example of Throttle Trim PID

Electronic Controlled Throttle Trim PID

The value represents the difference between where the throttle is normally and any adjustment that came from the IAC trim

ETC Trim

Engine off	0-0.3 %
Idle	0.1-0.4 %
30 MPH	0.1-0.4 %
55 MPH	0.2-0.5 %

HYDRAULIC ACTUATED VALVES

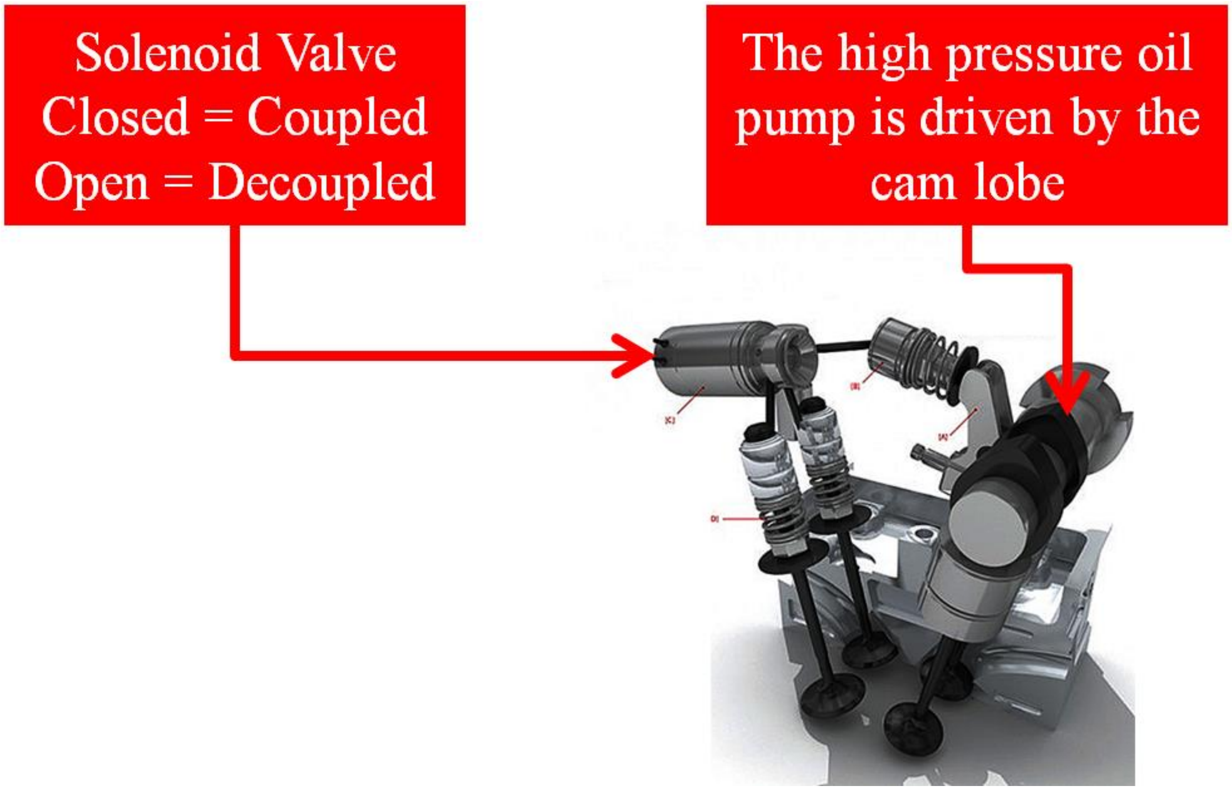
Hydraulic valve lift can control timing and valve lift. Variable valve lift can be used to eliminate the throttle plate. The throttle plate restricts air intake to control idle speed, this creates a vacuum. Manifold vacuum must be overcome by the intake stroke and results in what are called pumping losses.
Pumping loss is the resistance to air movement when the pistons pumps intake and exhaust gases through the cylinder.
Pumping losses are particularly high during intake with the throttle closed at idle.
During light throttle RPM is around 2500 to 3500
The throttle is slightly closed
The pistons are trying to draw air from the intake manifold through an almost closed throttle
The throttle will resist the drawing action of pistons
This wasted energy is called "Pumping Loss"
Use hydraulic laws to open the intake valves
Used to:

1. Small valve opening around 2 mm is used to control idle speed without a throttle plate.
2. Throttle-less operation (using variable valve lift rather than a throttle to limit the air flow into the combustion chamber)
3. Increase valve lift to as high as 13 mm for maximum power like a full race cam.

New technology;

- Changing power output by changing intake valve lift is more efficient and reduces camshaft torque
- Maximum valve lift is maximum power output
- Minimum valve lift is for idle control
- Most hydraulic activate valve are for Intake only
- Exhaust valves seldom use variable valve lift.

The cam drives a high pressure pump to create the hydraulic pressure for valve operation and the PCM controls the oil pressure.



For maximum lift the
Solenoid is closed which causes the valves follow the cam profile.
For less power for throttle control the solenoid open time is varied to bleed off part of the hydraulic pressure under PCM control.