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Mysteries Of Gasoline Direct Injection

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MYSTERIES OF GASOLINE DIRECT INJECTION (GDI)

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OVERVIEW

Thirty years ago a Buick Regal was equipped with sequential fuel injection, MAF sensor and a distributorless ignition system. Today, the Buick Regal is equipped with Gasoline Direct Injection (GDI), variable camshaft timing, drive by wire throttle body and multiple computers communicating with each other over a controller area network (CAN). A tremendous amount of technological evolution has happened over the last thirty years. Not just with the Buick Regal, but with all makes and models sold in the marketplace today.

This presentation will be focused directly on the emergence of GDI. We will cover how GDI operates and the benefits to the consumer as well as you the technician.

Gasoline Direct Injection (GDI), also known as Petrol Direct Injection or Direct Petrol Injection or Spark Ignited Direct Injection (SIDI) or Fuel Stratified Injection (FSI), is a variant of fuel injection employed in modern four-stroke gasoline engines. The gasoline is highly pressurized, and injected via a common rail fuel line directly into the combustion chamber of each cylinder, as opposed to conventional multi-point fuel injection that happens in the intake tract, or cylinder port.

In some applications, gasoline direct injection enables a stratified fuel charge (ultra lean burn) combustion for improved fuel efficiency, and reduced emission levels at low load.

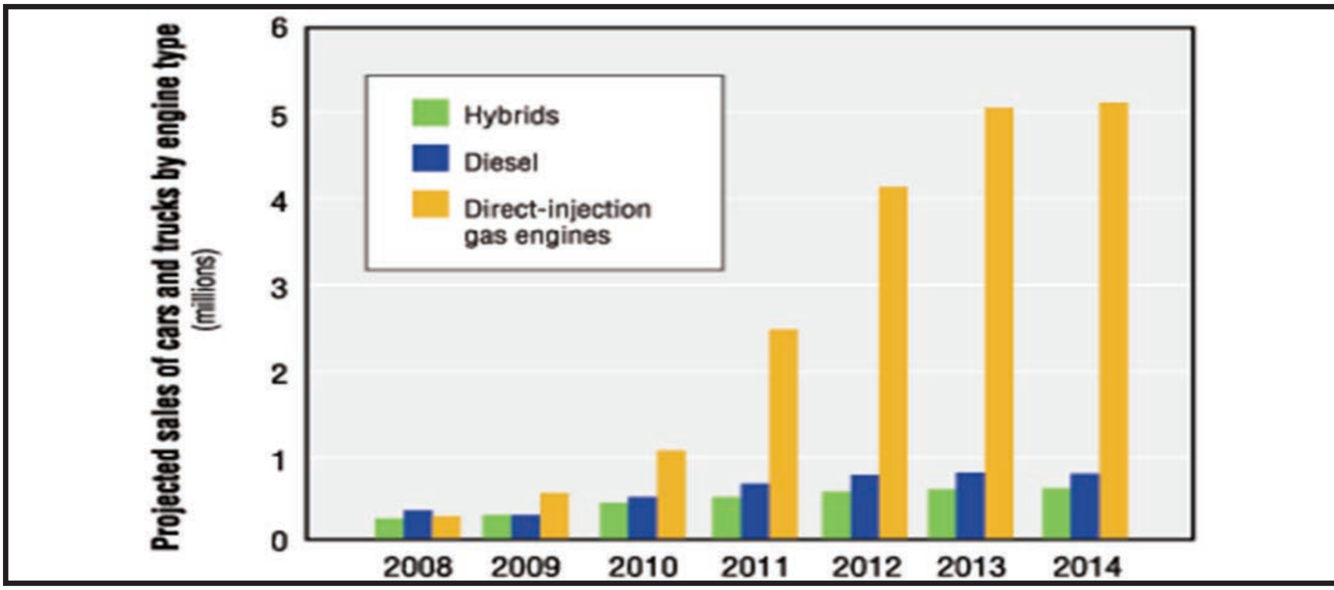
The major advantages of a GDI engine are increased fuel efficiency and high power output. Emissions levels can also be more accurately controlled with the GDI system. The cited gains are achieved by the precise control over the amount of fuel and injection timings that are varied according to engine load. In addition, there are no throttling losses in some GDI engines, when compared to a conventional fuel-injected or carburated engine, which greatly improves efficiency, and reduces 'pumping losses' in engines without a throttle plate.

Engine speed is controlled by the engine control unit/engine management system (EMS), which regulates fuel injection function and ignition timing, instead of having a throttle plate that restricts the incoming air supply. Adding this function to the EMS requires considerable enhancement of its processing and memory, as direct injection plus the engine speed management must have very precise algorithms for good performance and drivability.

PISTON OF A 3.5 L (210 CU IN) FORD ECOBOOST ENGINE WITH A SWIRL CAVITY ON THE TOP

OVERVIEW

CSM Worldwide, a global automotive forecasting and advisory firm, estimates GDI technology will be in 21 percent of new gasoline engines in European-built cars by 2013. CSM also projects sales of vehicles using direct-injection gas engines will jump to 5.1 million by 2014 from 585,000 in 2009.



GDI allows for better control of the fuel trim so the combustion process is more efficient. It also makes more horsepower for a given engine size.

Unlike standard PFI systems, GDI systems offer a 15% - 20% increase in fuel economy, reduce emissions by 40% and give a major increase in the engines volumetric efficiency. With standard PFI systems there were times when the injector on time would reach triple digits causing raw hydrocarbons behind the intake valve, loading the catalytic converter with a high volume of un-burnt hydrocarbons.
In 1993 the EPA required the manufacturers to get the engines in closed loop state within three (3) minutes of start up. Obviously this was back in the PFI days before GDI existed. With GDI, we are able to start the car in closed loop, or the vehicle will go into closed loop within 30 seconds at 32°F.

GDI systems reduce cold start emissions and enter into a closed-loop condition sooner than Port Fuel Injection (PFI) systems. Since the stratified fuel mixture is injected directly into the combustion chamber in precise amounts, raw hydrocarbons are not sprayed onto the back of the intake manifold. This means the engine uses less fuel and less raw fuel enters into the cold catalyst

The engine management system continually chooses among three combustion modes: ultra lean burn, stoichiometric, and full power output. Each mode is characterized by the air-fuel ratio. The stoichiometric air-fuel ratio for gasoline is 14.7:1 by weight (mass), but ultra lean mode can involve ratios as high as 65:1 (or even higher in some engines, for very limited periods). These mixtures are much leaner than in a conventional engine and reduce fuel consumption considerably.

• 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 toroidal or an ovoidal shape, and is placed either in the center (for central injector), or displaced to one side of the piston that is closer to the injector. The cavity creates the swirl effect so that the small amount of 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. Decreased combustion temperature

OVERVIEW

allows for lowest emissions and heat losses and increases air quantity by reducing dilation, which delivers additional power. This technique enables the use of ultra-lean mixtures that would be impossible with carburetors or 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, further cleaned by the catalytic converter.

• 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.

It is also possible to inject more than once during a single cycle. After the first fuel charge has been ignited, it is possible to add fuel as the piston descends. The benefits are more power and economy, but certain octane fuels have been seen to cause exhaust valve erosion.

A vehicle equipped with Port Fuel Injection at idle and in closed loop will have a typical injector pulse width of about 1.5 – 1.7 milliseconds and a fuel pressure reading of about 58 psi. What would be the pulse width if the fuel pressure was ramped up to around 580 psi? The answer is about 0.5 millisecond.

Fuel control on GDI equipped engines is determined or controlled by fuel pressure. The computer will be controlling a fuel volume regulator and a high pressure mechanical pump. The Buick Regal of today uses a fuel system which is an electronic returnless on-demand design. A returnless fuel system reduces the internal temperature of the fuel tank by not returning hot fuel from the engine to the fuel tank. Reducing the internal temperature of the fuel tank results in lower evaporative emissions.

An electric turbine style fuel pump attaches to the fuel tank fuel pump module inside the fuel tank. The fuel pump supplies fuel through the fuel feed pipe to the high pressure fuel pump. The high pressure fuel pump supplies fuel to a variable-pressure fuel rail. Fuel enters the combustion chamber through precision multi-hole fuel injectors. The high pressure fuel pump, fuel rail pressure, fuel injection timing, and injection duration are controlled by the engine control module (ECM).

What are some of the benefits of GDI? Under a high pressure system, the fuel is pressurized at a higher pressure than a normal injection system and when it's finally given room to expand it drops in temperature and provides a cooling effect to the cylinder in which it’s injected. This allows the car manufacturer to run a more aggressive timing profile, for both fuel and injection, resulting in more power. It also, if they so choose, can make a car engine more fuel efficient by running it with less fuel but the same timings as if it was designed without GDI. The end result is that you either could gain power or gain fuel efficiency.

With better fuel efficiency comes better emissions performance. Fuel injected vehicles produce far fewer carbon based emissions than vehicles with carburetors. Vehicles that use direct fuel injection are better equipped to handle alternative fuels, and fuels with additives that are designed to help keep your car engine clean.

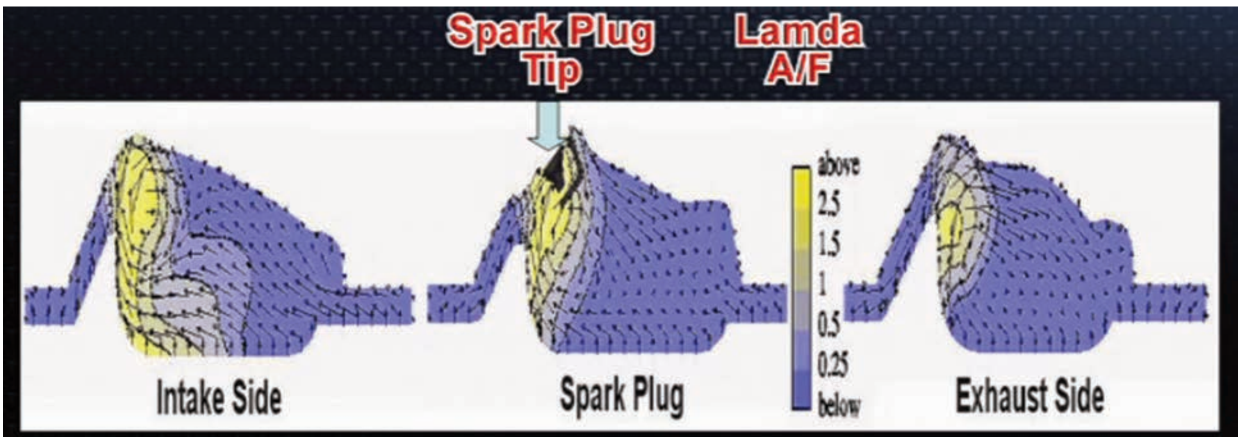
What are some of the drawbacks of GDI? Although Direct Injection provides more power and efficiency, a carbon build-up occurs in the intake valves that over time reduces the airflow to the cylinders, and therefore reduces power. Because the fuel is not longer being sprayed in the intake valves, which contains various detergents and keeps the intakes clean, small amounts of dirt from intake air, even with air filters that prevent most of the dirt from entering the cylinder, cakes on the intake walls.

This build-up can become severe enough that a piece can break off and has been known to burn holes in catalytic converters. It can also cause sporadic ignition failures. These problems have been known for some time and technologies have been improved to reduce or eliminate the carbon build-up.

GDI OPERATIONAL MODES

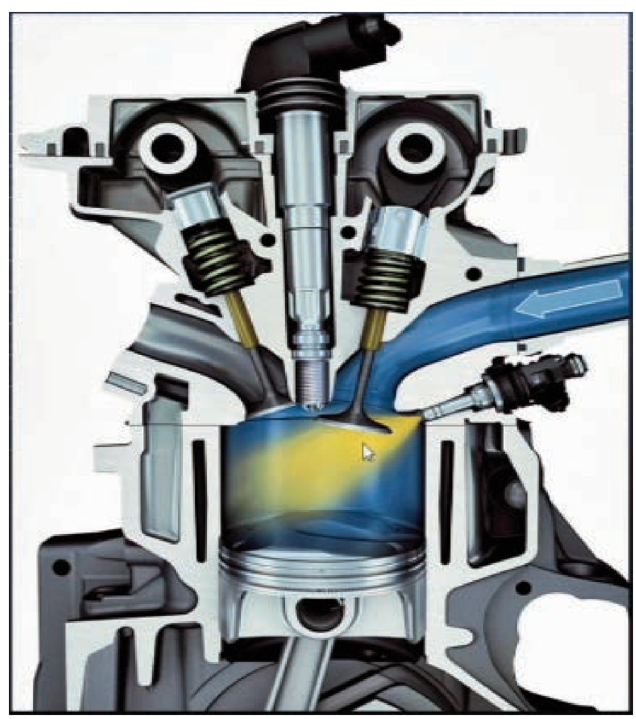
There are two types of GDI operational modes. Homogenous and stratified. The homogeneous mode is to enhance the mixing resulting in a near-stoichiometric uniformly distributed mixture inside the engine cylinder. The parameters primarily used to meet this opposing requirement of mixing intensity at different operating conditions include injection timing, injection duration, injection strategy, injection pressure, boost pressure and cylinder and port geometry.

For the stratified mode of operation, the central single hole of the new proposed injector is made to open by a central single needle, producing a well-concentrated spray, which along with proper air guidance can enable a region of stoichiometric mixture to be present near the spark plug. The injector is fired during the compression stroke. Firing the injector during the compression stroke creates "outer boundary" layers of leaner air/fuel



STRATIFIED EXAMPLE: SPARK PLUG MIXTURE TARGETING AND AIR FLOW SWIRL/TUMBLE

mixtures.
For homogeneous mode operation, the six circumferential holes are made to open by an inner annular needle, producing a well-dispersed spray. Since both of the needles are actuated by separate solenoids, when both needles open they can create a third spray structure which can be useful for high-power conditions. The injector is fired with the intake valve open and the cylinder pressure is decreased because of the open intake valve. However, high injector pressures are still maintained to promote vaporization.



HOMOGENEOUS MODE WITH INTAKE VALVE OPEN

• Central hole injection gives near-stoichiometric charge around the spark plug for stratified mode of operation. The mass percentage of near-stoichiometric charge present within a radius of 2 cm around the spark plug was 12.1% as compared to 2.5% for the six-hole injection. The value of equivalence ratio for the new injector at the same location is about 0.93 as opposed to 0.6 for the six-hole injection.

• Six-hole injection gives a near-stoichiometric charge (80% of the total charge) at the onset of combustion for homogeneous mode of operation.

• 6+1-hole injection delivered a high quantity of near-stoichiometric charge (96% of the total charge) best suited

NEW GDI TECHNOLOGY

The 2014 Chevrolet Silverado and the new Corvette engines are utilizing GDI fuel systems. But what is unique is the use of a Gen V pushrod type engine. In any engine equipped with GDI you are going to see a variety of weird shapes on the top of the piston. These weird shapes are new designs specifically made to help the fuel reach the outer boundaries during stratification. GM spent over one million hours of CAD work to produce these new designs.

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The new Corvette engine produces 460 horsepower with 450 ft. lbs. of torque but for fuel economy, it is also equipped with an active fuel management system. When the vehicle is cruising in the economy mode, the lifters will collapse effectively shutting off half of the engine. The engine will go from a 6.2L engine to a 3.1L engine yielding a fuel economy of approximately 40 mpg.

The advances of GDI go even further because of variables such as injector timing. Where do we want the injector to fire in relation to piston position? How many degrees before top dead center do we want the injector to fire during the compression stroke? The answer to these, and many other questions, is constantly changing as automotive engineers continue to find ways to burn all of the fuel in the combustion chamber. Simply put, if we burn all of the fuel in the combustion chamber, we won’t have any byproducts polluting the air we breathe as well fuel economy and top performance.

Other new GDI technology is the “Start/Stop” feature equipped on the 2013 Chevrolet Malibu. After the engine is started and has reached operating temperature, the auto stop feature may cause the engine to turn off when the brake pedal is applied and the vehicle comes to a complete stop. When the brake pedal is released, or the accelerator pedal is applied, the engine will restart. The engine will continue to run until the next auto stop.

This feature saves fuel by shutting the engine off when the vehicle is stopped. When the engine shuts off automatically, all the accessories will continue to operate normally. In very hot or cold conditions, the engine will only shut off automatically part of the time.

This system uses a high voltage battery, which is cooled with air drawn from the vehicle interior. The cold air intake for the battery is behind the rear seat, on the filler panel.

NEW GDI TECHNOLOGY

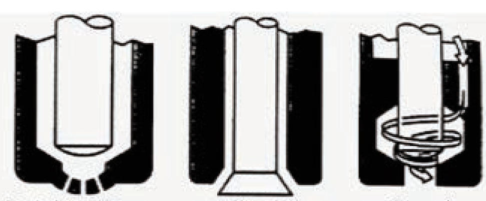
The Engine Will Remain Running When:

- The engine, transmission, or high voltage battery is not warmed up yet.
- The outside temperature is less than −20°C (−4°F).
- The air conditioning or defrost system need the compressor to maintain vehicle comfort. The warmer it is outside, the shorter the time before the engine is restarted to provide cabin cooling. To maximize fuel economy, use the eco air conditioning mode.
- The shift lever is in P (Park), N (Neutral), R (Reverse), or M (Manual Mode).
- The high voltage battery pack charge is low.
- The hood is not fully closed.
- Brake pedal pressure is low.
- The malfunction indicator lamp is on; auto stop may be prevented.
- High humidity is detected.

The Engine Will Restart When:

- The brake pedal is released.
- The accelerator pedal is applied.
- Shifting out of D (Drive) to any other gear.
- The air conditioning or defrost system need the compressor to maintain vehicle comfort. The warmer it is outside, the shorter the time before the engine is restarted to provide cabin cooling. To maximize fuel economy, use the eco air conditioning mode.
- The climate control system is turned from off to normal air conditioning or defrosts.
- The engine is required to run for either heater or climate control performance.
- The high voltage battery pack charge is low and requires recharging.
- Auto stop time is greater than two minutes.
- The hood is opened.

GDI INJECTOR DESIGNS



	Delphi & Denso	Hitachi	Bosch
Criteria	Multi hole concept	Outward opening concept	Inward opening concept
Flexibility of spray pattern	++	+	+
Potential for inclined spray axis	+	–	++
Atomization quality at system pressure = 10 MPa	–	0	++
Robustness against fouling	–	++	+

There are four major manufacturers for injectors designed for use in GDI equipped engines. The manufacturers are Delphi, Denso, Hitachi and Bosch. Delphi and Denso tend toward the multi hole concept, Hitachi uses the outward opening concept and Bosch uses the inward opening concept.

The Delphi & Denso GDI Multi-Hole Fuel Injectors are designed for homogeneous combustion gasoline direct injection engine applications. This family of flexible packaging and performance-optimized injectors features an inwardly opening valve group and a multi-hole spray generator.

GDI INJECTOR DESIGNS

GDI MULTI-HOLE FUEL INJECTOR

The Multec 10 GDIi Injector is capable of high pressure, up to 200 bar nominal system pressure with maximum 230 bar. The Multec 12 GDi Injector is capable of 200 bar nominal pressure with maximum pressure of 260 bar. Additional enhancements are available with the Multec 12.1 GDI Injector, which offers improved high pressure, multi-pulse operation of 250 bar nominal and 320 bar maximum, and reduced minimum fuel capability.

Delphi Multec GDi Multi-Hole Fuel Injectors can be applied to any size gasoline engine, from small displacement turbo-charged engines to large displacement engines, including central mount applications. The small particles in the spray allow optimum charge distribution for reduced emissions on cold start and for future combustion processes such as gasoline homogeneous charge compression ignition (HCCI).

Although the designs are different, all of the GDI injector designs directly target the spark plug. When you test a GDI injector on a flow bench you may think it is spraying the fuel in the wrong direction or in a miss-direction. This is because when the injector is properly installed in the vehicle, the spray pattern is directly targeted at the spark plug.

All three elements – injectors, combustion chamber and piston design are critical to GDI. As stated before, many hours and millions of dollars have been spent by the manufacturers to bring the concept of GDI to the marketplace.

Pictured above is a General Motors Spark Ignited Direct Injection (SIDI), injector from a 2.0L Ecotech engine. As you look at the injector please note the two seals, one at the top and one at the bottom indicated by the "Replace" and the arrow. These seals need to be replaced whenever you are servicing or replacing the injectors

GDI INJECTOR DESIGNS

and a special tool is needed to perform this replacement. However, on GM OE replacement injectors, the injectors will come with all of the necessary parts you need including the seals.

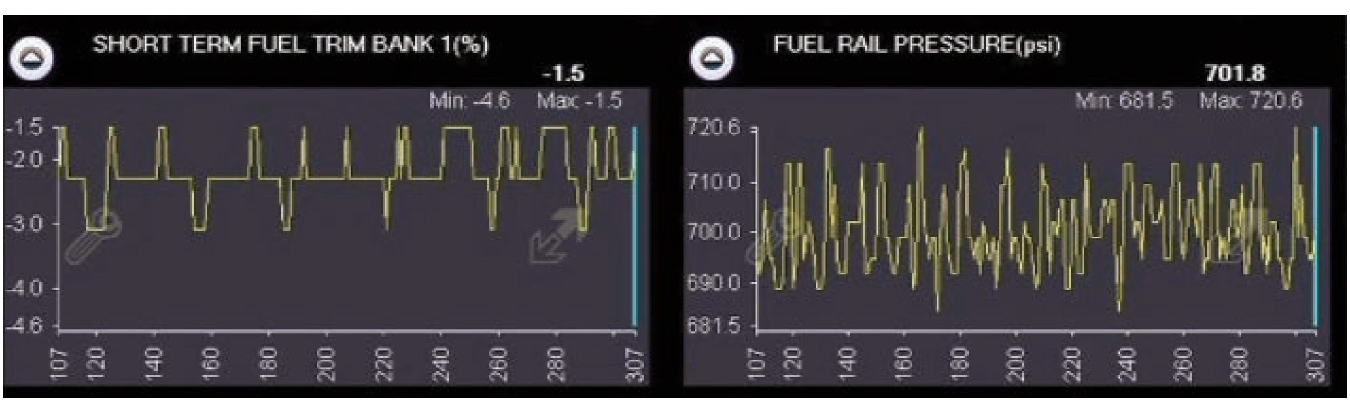
TECH TIP! Whenever you replace a high pressure injector, you must also replace the line connected to that injector. DO NOT REUSE THE INJECTOR LINES!

As you can see in the illustration there is carbon buildup on the injector just above the lower Teflon seal. As this carbon builds up over time it can make it difficult to remove the injector from the cylinder head. There are special tools that can be used to aid in the removal of the injectors when this happens. Pictured below is one of the tools that is manufactured by Kent-Moore that is specifically made to remove GDI injectors.

This tool is used with a slide hammer to remove the SIDI injector from the bore in the cylinder head. Because the tip of the injector is inside the combustion chamber, it can have carbon build up. This build up makes removal difficult, and the injector may only be grasped in specific locations. Failure to use a tool such as this will result in injector damage.

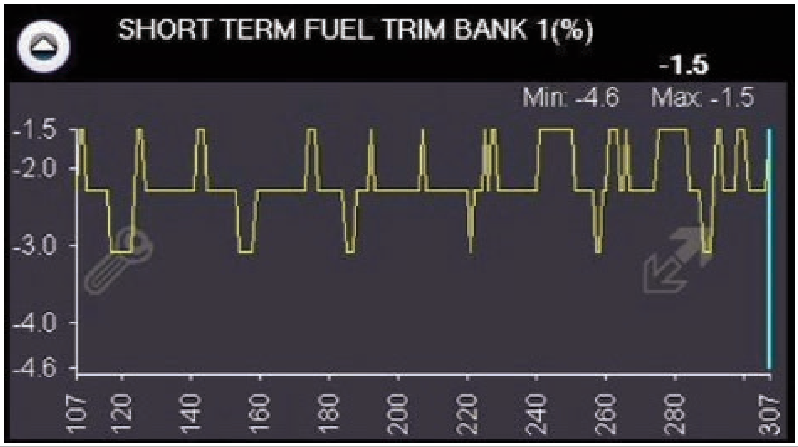
GDI CLOSED LOOP FUEL CONTROL

Closed loop fuel control on GDI equipped engines work quite a bit different than that of Port Fuel injected engines. All of us have monitored oxygen sensors switch from rich to lean on a scan tool in graphing mode. What drives the oxygen sensor to do this? The answer is short term fuel trim. When the oxygen sensor voltage on a narrow band is high, this indicates the fuel mixture is in a rich condition and we will see short term fuel trim dip to a lower value. When we see the oxygen sensor has lower voltage, this means the short term fuel trim goes high. The short term fuel trim is a mirror image of the oxygen sensor giving immediate adjustment to the fuel mixture.



GDI CLOSED LOOP FUEL CONTROL

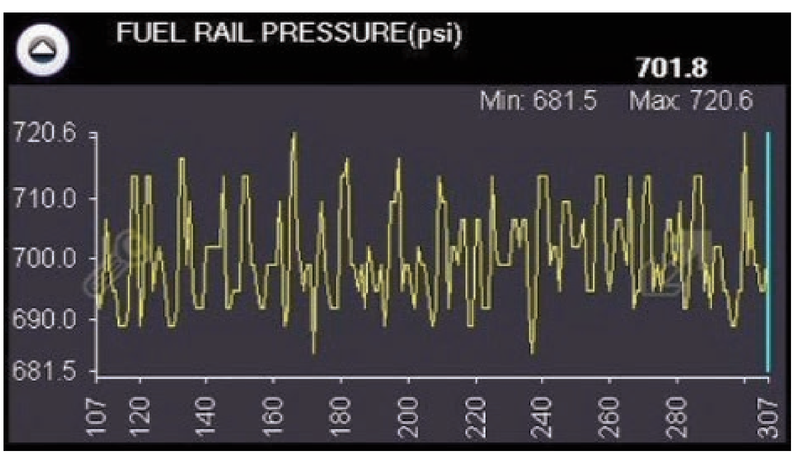
With GDI we still have short term fuel trim as illustrated in the scan tool screen capture. As you can see in the screen capture the short term fuel trim on bank 1 is moving up and down as indicated by the pattern on the scan tool. Although the oxygen sensor pattern is not shown, it mirrors the short term pattern.



Looking at the fuel rail pressure pattern, we see the pressure switches from a low of about 681 psi to a high of about 721 psi. Why the wide variation of fuel pressures? The answer in the case of GDI is that fuel pressure controls short term fuel trim and short term fuel trim controls the oxygen sensor.

In port fuel injection, another term for short term fuel trim might be micro-injector pulse width. This is the time the injector is turned on or off by the ECM. As the time either increases or decreases, this would be like the short term fuel trim going from rich to lean. However, in GDI, changes in short term fuel trim are made with fuel pressure, not injector pulse width. The injector pulse width is held steady by the ECM and the fuel pressure is fluctuated.

If a GDI engine is in closed loop, you will see the fuel pressure change at an approximate 40 – 50 psi range. Again, in GDI, fuel pressure controls the fuel delivery more than the injector on time.



GDI AIRFLOW

While Ford Motor Company has the EcoBoost GDI engine and GM continues upgrading its SIDI system, we have yet to see any GDI system from Chrysler. GM still uses volumetric fuel injection with a Mass Air Flow (MAF) sensor but has modified the MAF by adding high speed air temperature and humidity sensors.

The earlier GM GDI systems used a mechanical fuel pressure regulator that was integrated into the fuel pump module inside of the fuel tank. These types of systems did not use a low pressure fuel sensor that you could monitor using a scan tool. In 2009, GM began to use an electronic returnless fuel system that employed a low pressure fuel sensor that could be monitored by a scan tool.

The volumetric efficiency of a GDI system is much better than that of a PFI system. The drive by wire system on a PFI equipped engine would normally have throttle openings at idle around 6%. When these engines had very little throttle opening either at an idle condition or under a light load, there was a severe pressure drop across the throttle plates. This condition will not happen on vehicles equipped with GDI systems.

The ECM controls the air/fuel metering system in order to provide the best possible combination of driveability, fuel economy, and emission control. The ECM monitors the heated oxygen sensor (HO2S) signal voltage while in Closed Loop and regulates the fuel delivery by adjusting the pulse width of the injectors based on this signal. The ideal fuel trim values are around 0 percent for both short and long term fuel trim.

A positive fuel trim value indicates the ECM is adding fuel in order to compensate for a lean condition by increasing the pulse width. A negative fuel trim value indicates that the ECM is reducing the amount of fuel in order to compensate for a rich condition by decreasing the pulse width. A change made to the fuel delivery changes the long and short term fuel trim values. The short term fuel trim values change rapidly in response to the HO2S signal voltage.

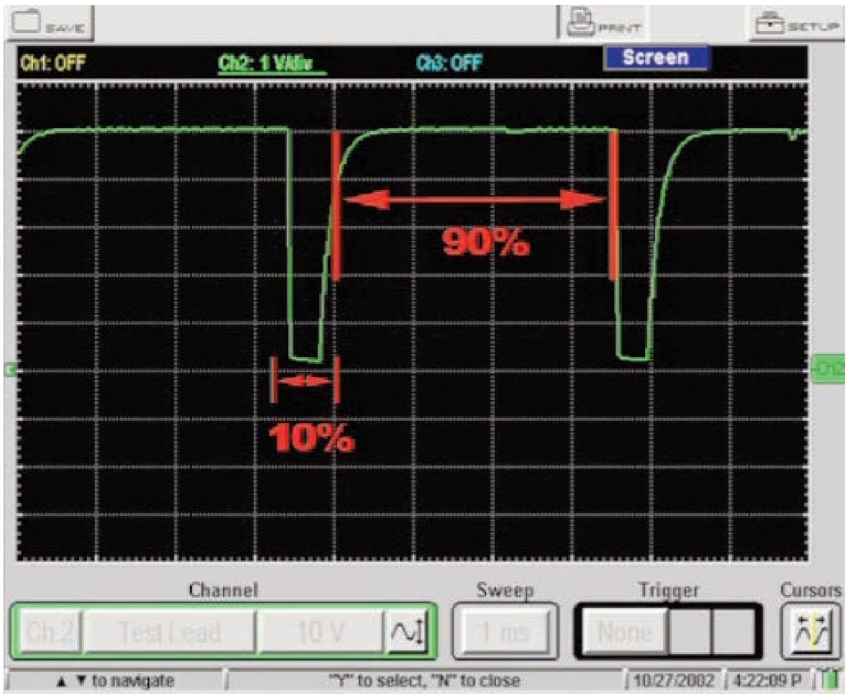
These changes fine tune the engine fueling. The long term fuel trim makes coarse adjustments to fueling in order to re-center and restore control to short term fuel trim. A scan tool can be used to monitor the short and long term fuel trim values. The long term fuel trim diagnostic is based on an average of several of the long term speed load learn cells. The ECM selects the cells based on the engine speed and engine load. If the ECM detects an excessively lean or rich condition, the ECM will set a fuel trim diagnostic trouble code (DTC).

Ford however has switched back to speed density but uses an improved and enhanced version. This enhanced version uses two intake manifold pressure sensors. These sensors monitor the pressure in front of the throttle body and the back of the throttle body. There are also three intake air temperature sensors: ambient air, charge air cooler and the manifold pressure sensor before the throttle body which is actually a dual function sensor. This dual function sensor will not only provide the pressure data in front of the throttle body, it will also relay air temperature to the ECM as well.

Pictured right is an illustration of the new GM SIDI eight wire Mass Air Flow (MAF) sensor. This sensor can be quickly identified by the eight wire connector. It is being utilized on some PFI engines along with GDI engines. When GM first started using MAF sensors they were only three wire sensors. There was a voltage supply wire, a ground wire and a wire that reported the variance in frequency which was controlled by air flow. Next, GM moved to a five wire MAF sensor because the air charge temp sensor was moved into the MAF sensor housing. The air charge temp sensor was nothing more than a thermistor. As the temperature rose, the resistance goes down.

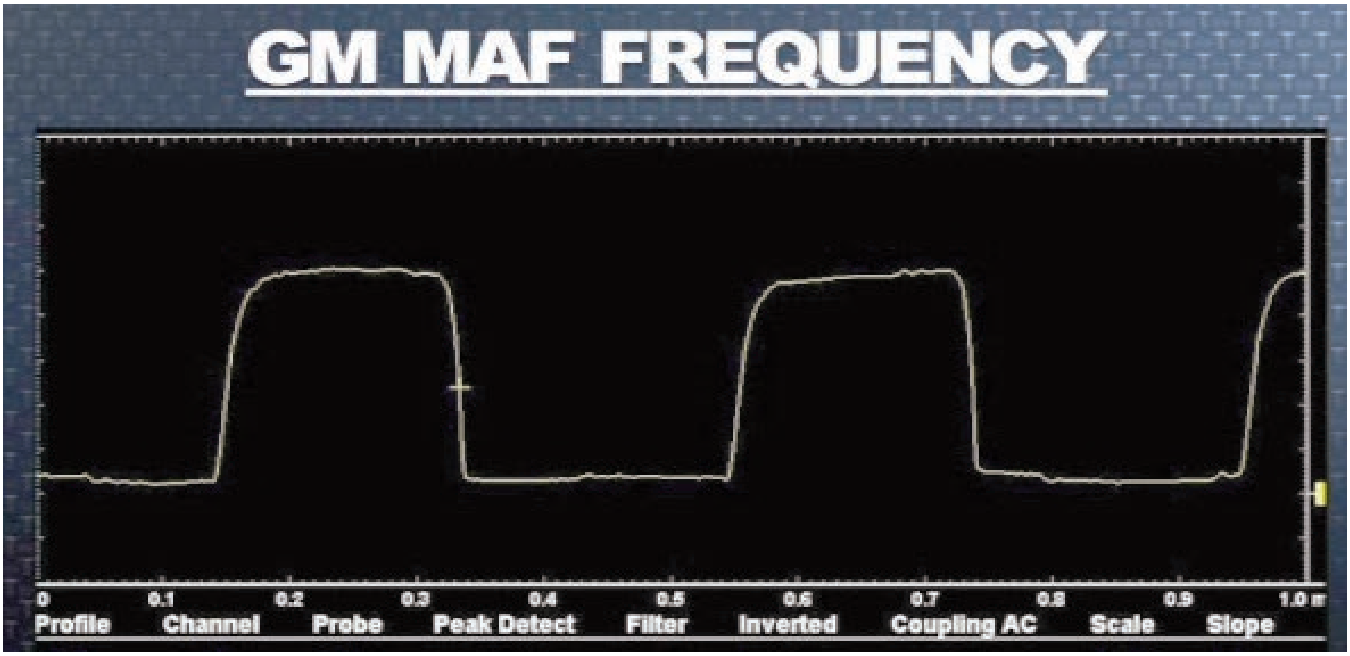
GDI AIRFLOW

In this case, we now have high speed air temperature and we also have humidity. The SIDI system now has data on very small and rapid temperature changes along with data regarding humidity. This additional data can now be seen via two new scan tool PIDs.

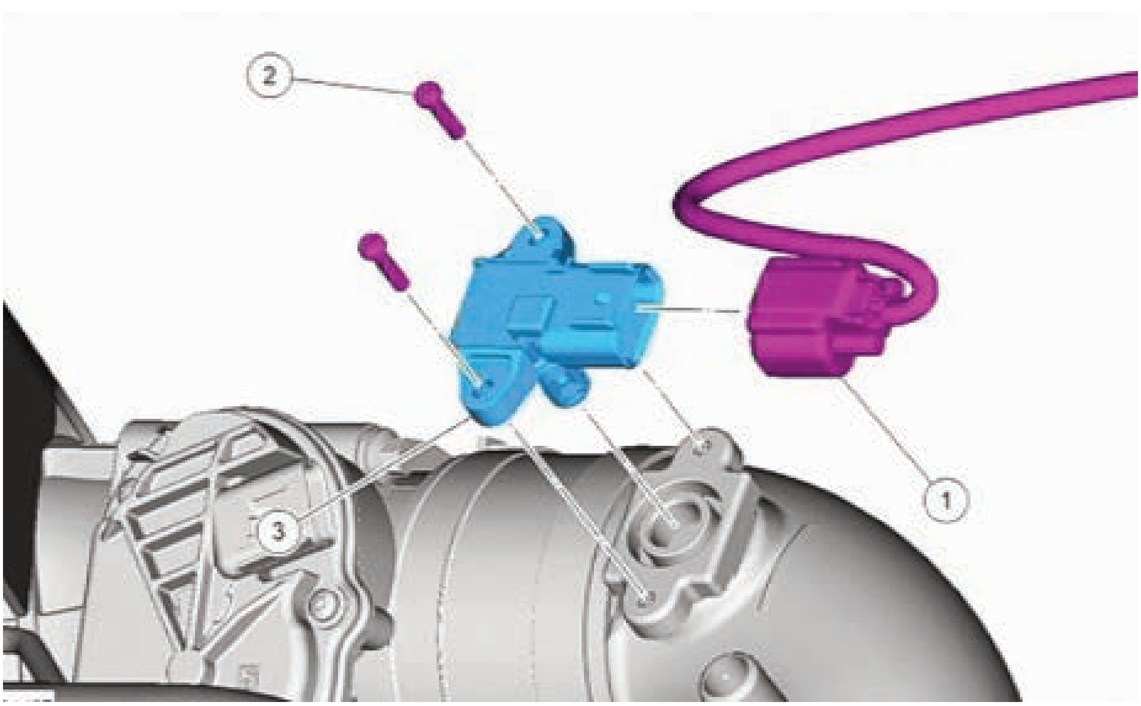


Pictured above is a waveform of the signal that provides humidity and high speed air temperature information to the ECM. As you can see, the high side duty cycle is roughly 90% while the low side is roughly 10%. This duty cycle will be referenced by the ECM and compared to a chart representing the percentage of humidity in the air. The ECM will make a calculation based on this comparison and adjust the system accordingly.

GDI AIRFLOW

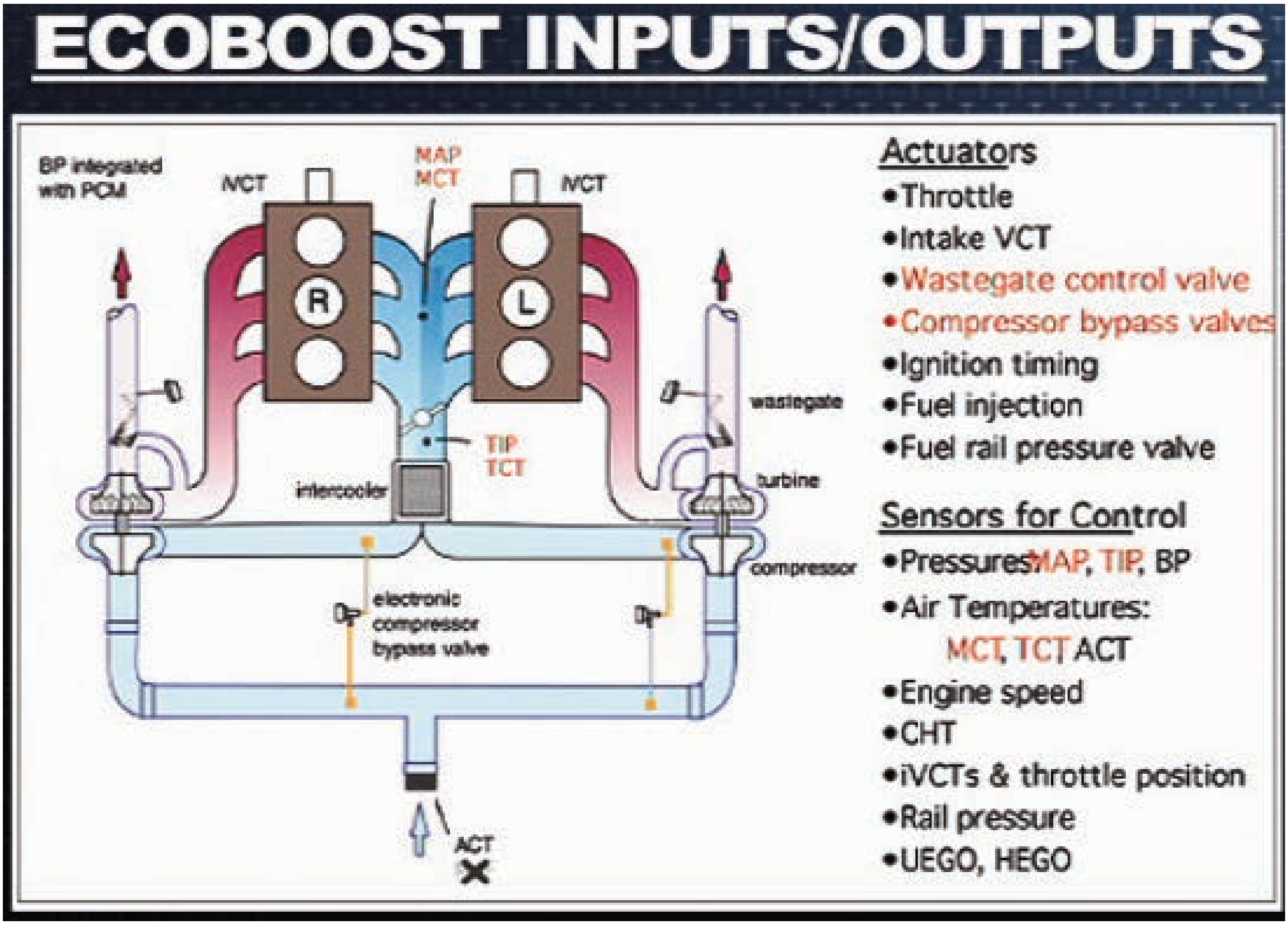


Pictured above is a typical waveform illustrating the MAF frequency coming from the MAF and going to the ECM. You will typically see pulses in the 2,000 Hz per second range at idle all the way up to 15,000 pulses per second at peak torque.



Pictured above is an illustration of a Ford combination sensor that reads both pressure and air temperature. Remember, this system reads air temperature before and after the throttle body and reports the data to the ECM.

GDI AIRFLOW



Illustrated above is a diagram of the 3.5L Ford EcoBoost system listing the inputs and outputs. Could you possibly believe a full size F150 would ever be equipped with a V6 engine? You might think this application would be grossly underpowered but with twin turbochargers and direct injection and variable camshaft timing, power and torque are not a problem. Technology has come a long way in the last few years.

Looking at the sensors used for control you can see we have three sensors for pressure and three sensors monitoring the air temperature. All of the data from these sensors help the ECM enormously in making corrections to the system to deliver the most power and torque when needed as well as fuel economy.

GDI IGNITION

Both GM and Ford GDI systems use a Coil On Plug (COP) ignition system. Typically we are now calling these systems “Smart Coils”. These coils can be identified by three or more wires going into the coil. These smart coils have switching transistors built into them and you will not be able to see a traditional primary waveform on a scan tool but you will be able to see amperage draw and transistor switching data.

When trying to determine the cause of a misfire on these systems we typically ask ourselves if the misfire is related to the lack of fuel or a lack of spark. A quick tip to help you determine which condition is causing the fault is to remember there is 21% oxygen in the air we breathe. How is this bit of knowledge valuable?

If we know there is 21% oxygen in the air, and if we have a good combustion process within the combustion chamber, how much of the 21% of oxygen is utilized? The answer is almost all of it. You can’t use all of it or the oxidation in the catalyst would not occur and the oxygen sensors would not operate. The reality is if we have a good combustion event, approximately 1% oxygen would be left over. If you think you have a misfire, monitor the rear O2 sensor. In either case of lack of spark or lack of fuel, the rear O2 sensor will give you the answer.

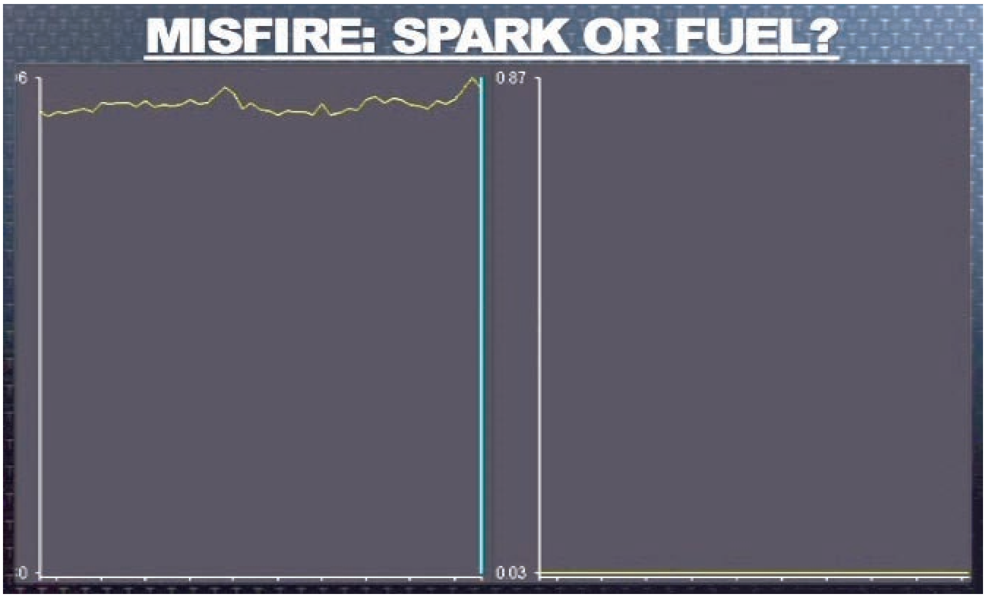
If the misfire is caused by a lack of spark, 21% of the oxygen would not have been burned. This means 21% oxygen is presented to the CAT along with raw fuel. Think of the CAT as a miniature oven. Combustion does occur within the converter so what do you think the rear O2 sensor will see? When presented with an abundance of raw fuel, a narrow band O2 sensor voltage will go high. Look to the rear O2 sensor during a misfire event and see if the voltage goes high, if it does, you will know the fault is due to lack of spark. Conversely, if the voltage goes low, you will know the misfire was due to a lack of fuel.

When diagnosing this way, you have to be quick. As soon as the ECM sees this event, it will turn the suspect cylinder off by shutting down the injector.

Pictured above is a waveform for misfire on the left, and a rear O2 sensor on the right.. This sensor is on a Ford EcoBoost and is called a universal heated exhaust gas oxygen sensor. This is what Ford uses as a wide band air/fuel ratio sensor. This means the PID is showing us amperage on the wide band. Amperage will go up as oxygen is presented to the exhaust system compared to the atmosphere. If the fuel mixture is lean, the amperage goes high. If the mixture is rich, the amperage goes low.

Looking at this waveform, can you tell if the misfire is due to lack of spar or lack of fuel? As the misfire occurs, you can see the amperage of the sensor goes high.

GDI IGNITION



After a very short period of time after the misfire occurred, the waveform on the left still tells us we have an abundance of oxygen in the exhaust, but the right waveform has flat lined low. This means there is no fuel. These waveforms tell us there was originally a high rate of misfire due to lack of spark, the ECM saw this and shut down the fuel injector to the suspect cylinder. With no fuel going to the suspect cylinder, the rear O2 sensor fell all the way down to 0.03 V.

You can utilize the rear O2 sensor to pinpoint whether or not the misfire is due to a lack of spark or a lack of fuel. From that point, you can tailor your diagnostic approach to determine the root cause of the misfire.

NOTES

GDI DESIGNS AND COMPONENTS

Pictured above is the 2.0L SIDI engine used in the 2012 and beyond Buick Regal. This engine provides 270 HP which equates to 135 HP per liter. Never before has GM had an engine produce this much horsepower per liter. This engine is GDI with variable timing, drive by wire and turbocharged.

The fuel system is an electronic returnless on-demand design. A returnless fuel system reduces the internal temperature of the fuel tank by not returning hot fuel from the engine to the fuel tank. Reducing the internal temperature of the fuel tank results in lower evaporative emissions.

An electric turbine style fuel pump attaches to the fuel pump module inside the fuel tank. The fuel pump supplies fuel through the fuel feed pipe to the high pressure fuel pump. The high pressure fuel pump supplies fuel to a variable-pressure fuel rail. Fuel enters the combustion chamber through precision multi-hole fuel injectors. The high pressure fuel pump, fuel rail pressure, fuel injection timing, and injection duration are controlled by the engine control module (ECM).

Electronic Returnless Fuel System
The electronic returnless fuel system is a microprocessor controlled fuel delivery system which transports fuel from the tank to the fuel rail. It functions as an electronic replacement for a traditional, mechanical fuel pressure regulator. A pressure relief regulator valve within the fuel tank provides an added measure of over pressure protection. Desired fuel pressure is commanded by the engine control module (ECM), and transmitted to the fuel pump flow control module via a GMLAN serial data message. A liquid fuel pressure sensor provides the feedback the fuel pump flow control module requires for Closed Loop fuel pressure control.

Fuel Pump Flow Control Module
The fuel pump flow control module is a serviceable GMLAN module. The fuel pump flow control module receives the desired fuel pressure message from the engine control module (ECM) and controls the fuel pump located within the fuel tank to achieve the desired fuel pressure. The fuel pump flow control module sends a 25 kHz PWM signal to the fuel pump, and pump speed is changed by varying the duty cycle of this signal. Maximum current supplied to the fuel pump is 15 A. A liquid fuel pressure sensor provides fuel pressure feedback to the fuel pump flow control module.

GDI DESIGNS AND COMPONENTS

Fuel Pressure Sensor
The fuel pressure sensor is a serviceable 5 V, 3-pin device. It is located on the fuel feed line forward of the fuel tank, and receives power and ground from the fuel pump flow control module through a vehicle wiring harness. The sensor provides a fuel pressure signal to the fuel pump flow control module, which is used to provide Closed Loop fuel pressure control.

Flex Fuel Sensor
The flex fuel sensor measures the ethanol-gasoline ratio of the fuel being used in a flexible fuel vehicle. Flexible fuel vehicles can be operated with a blend of ethanol and gasoline, up to 85 percent ethanol. In order to adjust the ignition timing and the fuel quantity to be injected, the engine management system requires information about the percentage of ethanol in the fuel.

The flex fuel sensor uses quick-connect style fuel connections, an incoming fuel connection, and an outgoing fuel connection. All fuel passes through the flex fuel sensor before continuing on to the fuel rail. The flex fuel sensor measures the fuel alcohol content, and sends an electrical signal to the engine control module (ECM) to indicate ethanol percentage.

The flex fuel sensor has a three-wire electrical harness connector. The three wires provide a ground circuit, a power source, and a signal output to the ECM. The power source is battery positive voltage and the ground circuit connects to an engine ground. The signal circuit carries the ethanol percentage via a frequency signal.

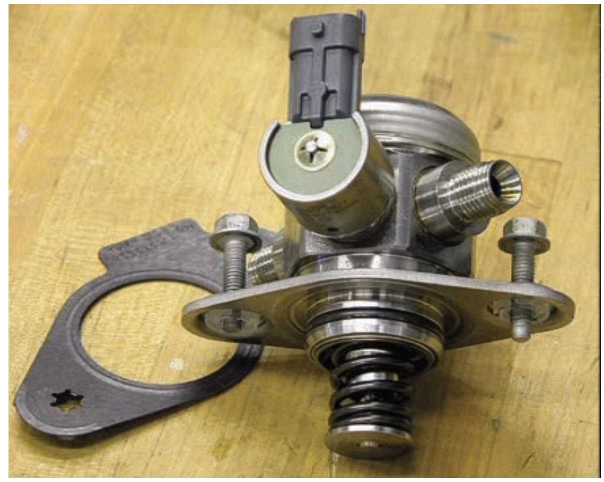
The flex fuel sensor uses a microprocessor inside the sensor to measure the ethanol percentage and changes the output signal accordingly. The ECM provides an internal pull-up to 5 V on the signal circuit, and the flex fuel sensor pulls the 5 V to ground in pulses. The normal range of operating frequency is between 50 and 150 Hz, with 50 Hz representing 0 percent ethanol, and 150 Hz representing 100 percent ethanol.

The microprocessor inside the sensor is capable of a certain amount of self-diagnosis. An output frequency between 180 Hz and 190 Hz indicates that the fuel is contaminated. Certain substances dissolved in the fuel can cause the fuel to be contaminated, raising the output frequency higher than the actual ethanol percentage should indicate. Examples of these substances include water, sodium chloride (salt), and methanol.

It should be noted that it is likely that the flex fuel sensor will indicate a slightly lower ethanol percentage than what is advertised at the fueling station. This is not a fault of the sensor. The reason has to do with government requirements for alcohol-based motor fuels. Government regulations require that alcohol intended for use as motor fuel be denatured. This means that 100 percent pure ethanol is first denatured with approximately 4½ percent gasoline, before being mixed with anything else. When an ethanol gasoline mixture is advertised as E85, the 85 percent ethanol was denatured before being blended with gasoline, meaning an advertised E85 fuel contains only about 81 percent ethanol. The flex fuel sensor measures the actual percentage of ethanol in the fuel.

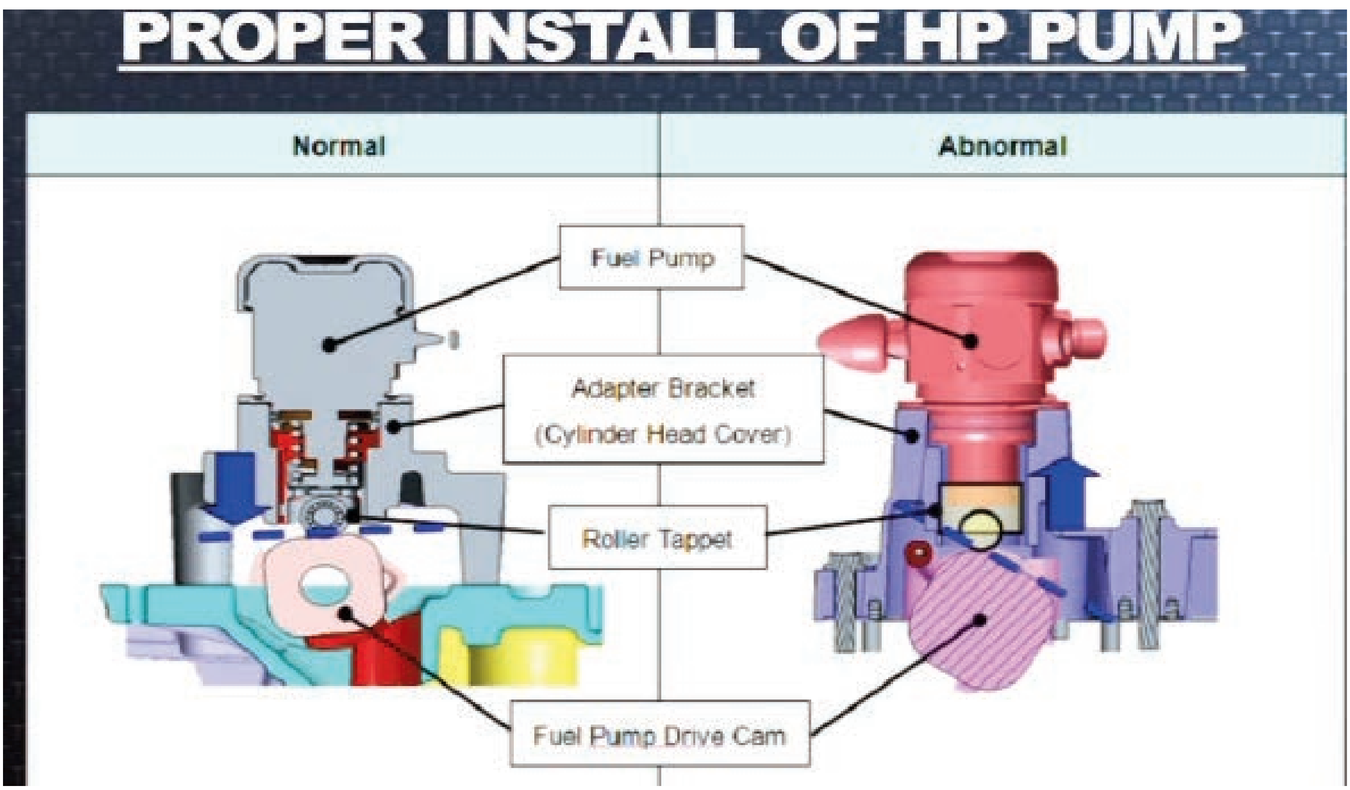
GDI DESIGNS AND COMPONENTS

High Pressure Fuel Pump



The high fuel pressure necessary for direct injection is supplied by the high pressure fuel pump. The pump is mounted on the rear of the engine and is driven by a three-lobe cam on the camshaft. This pump also regulates the fuel pressure using an actuator in the form of an internal solenoid-controlled valve. In order to keep the engine running efficiently under all operating conditions, the engine control module (ECM) requests pressure ranging from 2 to 15 MPa (290 to 2176 psi), depending on engine speed and load.

Output drivers in the ECM provide the pump control circuit with a 12 V pulse-width modulated (PWM) signal, which regulates fuel pressure by closing and opening the control valve at specific times during pump strokes. This effectively regulates the portion of each pump stroke that is delivered to the fuel rail. When the control solenoid is NOT powered, the pump operates at maximum flow rate. In the event of pump control failure, the high pressure system is protected by a relief valve in the pump.



When these pumps fail, they will pump fuel into the crankcase diluting the engine oil. The obvious outcome of this is the breakdown of lubrication in the crankcase and possible engine damage or even failure. To verify if this has happened, the dipstick is a great test both by sight and by smell. If this is verified, do not run the engine. Tow the vehicle to the shop for further repair.

GDI DESIGNS AND COMPONENTS

Fuel Rail Assembly
The fuel rail assembly attaches to the cylinder head. The fuel rail distributes high pressure fuel to the fuel injectors. The fuel rail assembly consists of the following components:

The direct fuel injectors
The fuel rail pressure sensor

Fuel Injectors
The fuel injection system is a high pressure, direct injection, returnless on-demand design. The fuel injectors are mounted in the cylinder head beneath the intake ports and spray fuel directly into the combustion chamber. Direct injection requires high fuel pressure due to the fuel injector's location in the combustion chamber. Fuel pressure must be higher than compression pressure requiring a high pressure fuel pump. The fuel injectors also require more electrical power due to the high fuel pressure.

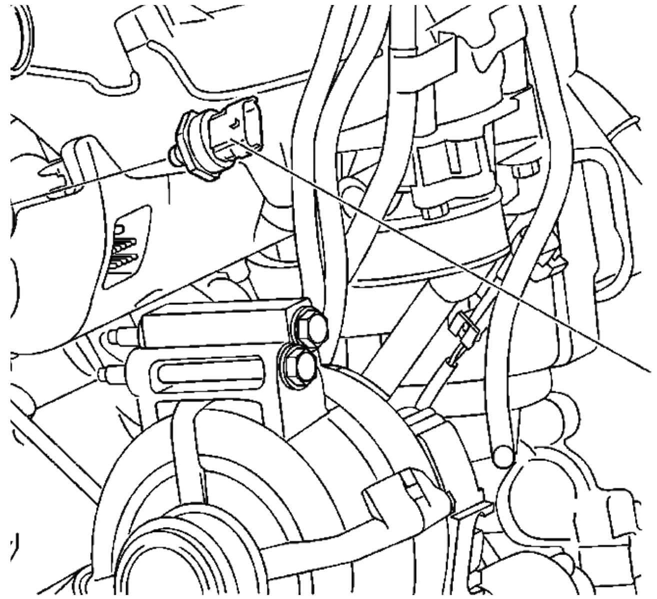
The ECM supplies a separate high voltage supply circuit and a high voltage control circuit for each fuel injector. The injector high voltage supply circuit and the high voltage control circuit are both controlled by the ECM. The ECM energizes each fuel injector by grounding the control circuit. The ECM controls each fuel injector with 65 V. This is controlled by a boost capacitor in the ECM. During the 65 V boost phase, the capacitor is discharged through an injector, allowing for initial injector opening. The injector is then held open with 12 V.

The fuel injector assembly is an inside opening electrical magnetic injector. The injector has six precision machined holes that generate a cone shaped oval spray pattern. The fuel injector has a slim extended tip in order to allow a sufficient cooling jacket in the cylinder head.

NOTES

GDI DESIGNS AND COMPONENTS

Fuel Injection Fuel Rail Fuel Pressure Sensor
The fuel rail pressure sensor detects fuel pressure within the fuel rail. The engine control module (ECM) provides a 5 V reference voltage on the 5 V reference circuit and ground on the reference ground circuit. The ECM receives a varying signal voltage on the signal circuit. The ECM monitors the voltage on the fuel rail pressure sensor circuits. When the fuel pressure is high, the signal voltage is high. When the fuel pressure is low, the signal voltage is low.



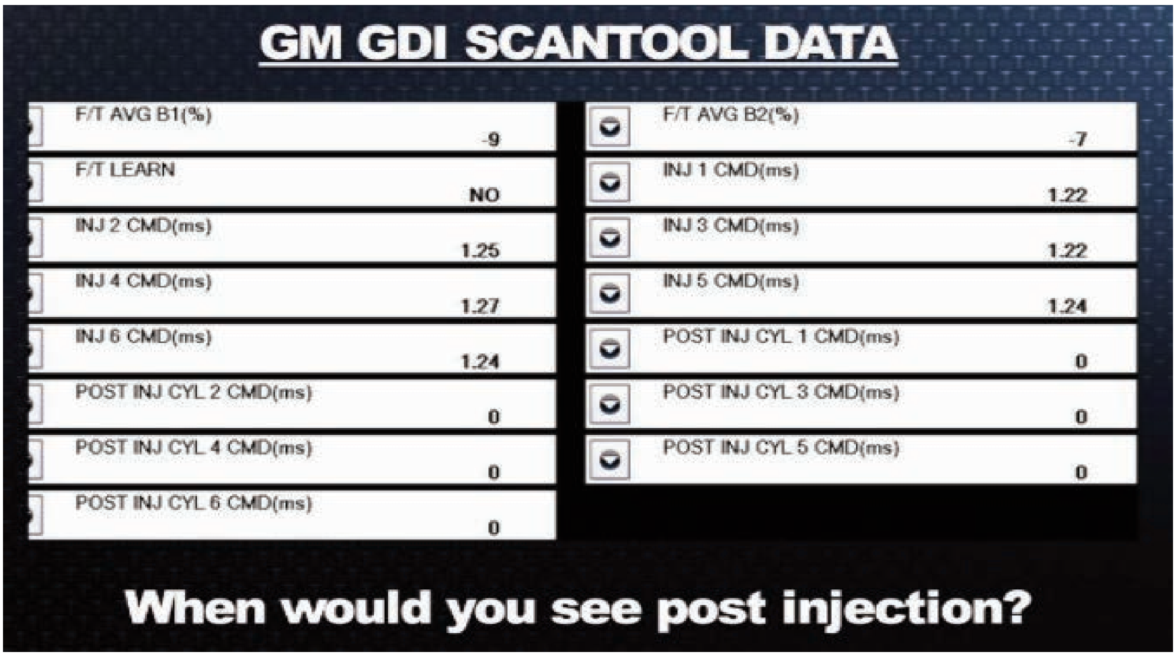
Fuel Trim
The control module controls the air/fuel metering system in order to provide the best possible combination of driveability, fuel economy, and emission control. The control module monitors the heated oxygen sensor (HO2S) signal voltage while in Closed Loop and regulates the fuel delivery by adjusting the pulse width of the injectors based on this signal.

The ideal fuel trim values are around 0 percent for both short and long term fuel trim. A positive fuel trim value indicates the control module is adding fuel in order to compensate for a lean condition by increasing the pulse width. A negative fuel trim value indicates that the control module is reducing the amount of fuel in order to compensate for a rich condition by decreasing the pulse width. A change made to the fuel delivery changes the long and short term fuel trim values. The short term fuel trim values change rapidly in response to the HO2S signal voltage. These changes fine tune the engine fueling.

The long term fuel trim makes coarse adjustments to fueling in order to re-center and restore control to short term fuel trim. A scan tool can be used to monitor the short and long term fuel trim values. The long term fuel trim diagnostic value is based on an average of several of the long term speed load learn cells. The control module selects the cells based on the engine speed and engine load. If the control module detects an excessively lean or rich condition, the control module will set a fuel trim diagnostic trouble code (DTC).

GDI SCAN TOOL DIAGNOSTICS

With all of the new technology surrounding GDI, technicians may be asking what is all of this going to cost in regards to purchasing new tools for diagnostics and repair. The short answer is not a lot. You probably already own a professional level scan tool and all of the information we need for diagnostics is readily available. This information includes low and high side pressures as well as bi-directional control over outputs.



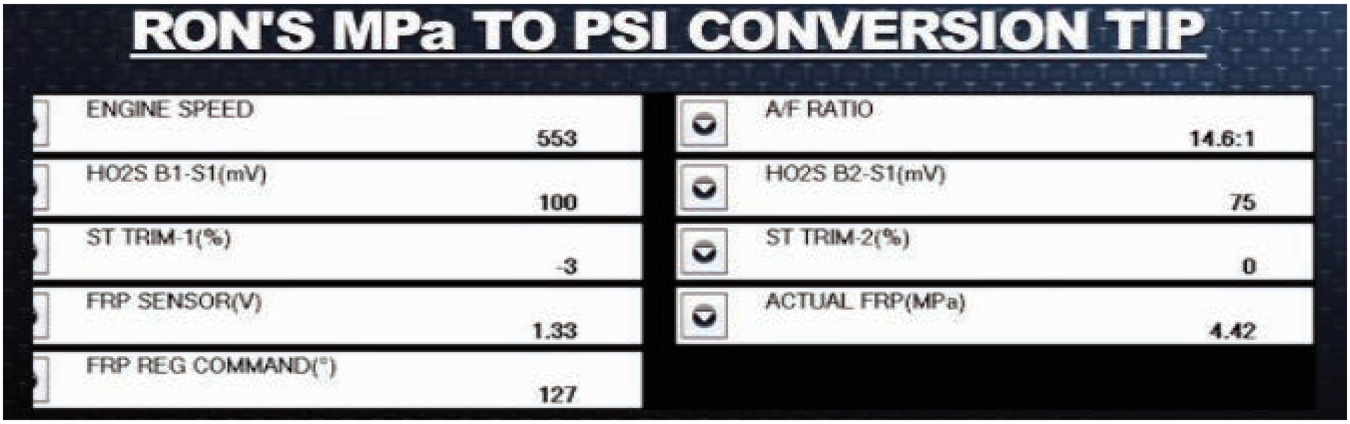
Pictured above is a screen capture of several PIDs from a GM GDI vehicle. The scan tool data shows we have post injection data for all six cylinders. The question presented in the screen capture is “when would you see post injection?” Well, you would need the injector to fire again with the exhaust valve slightly open to quickly heat up the CAT. This means you may see a post injection event during cold engine operation. You may also see a post injection event on full power or anytime the engine needs additional fuel delivery.

When diagnosing a fuel delivery problem with a GDI system, the first area you want to look at is the low pressure side of the system. The low pressure system will have a fuel pump control module. Both the power and the ground going to the fuel pump are controlled by this fuel pump control module. You will also have a low side pressure transducer and you will be able to control this system with your scan tool using the bi-directional tests and controls. This will allow you to confirm the pressure readings are accurate on the low side using a gauge and the test port. Also, you may need to access the fuel pump control module directly to get all of the data you need for your diagnosis.

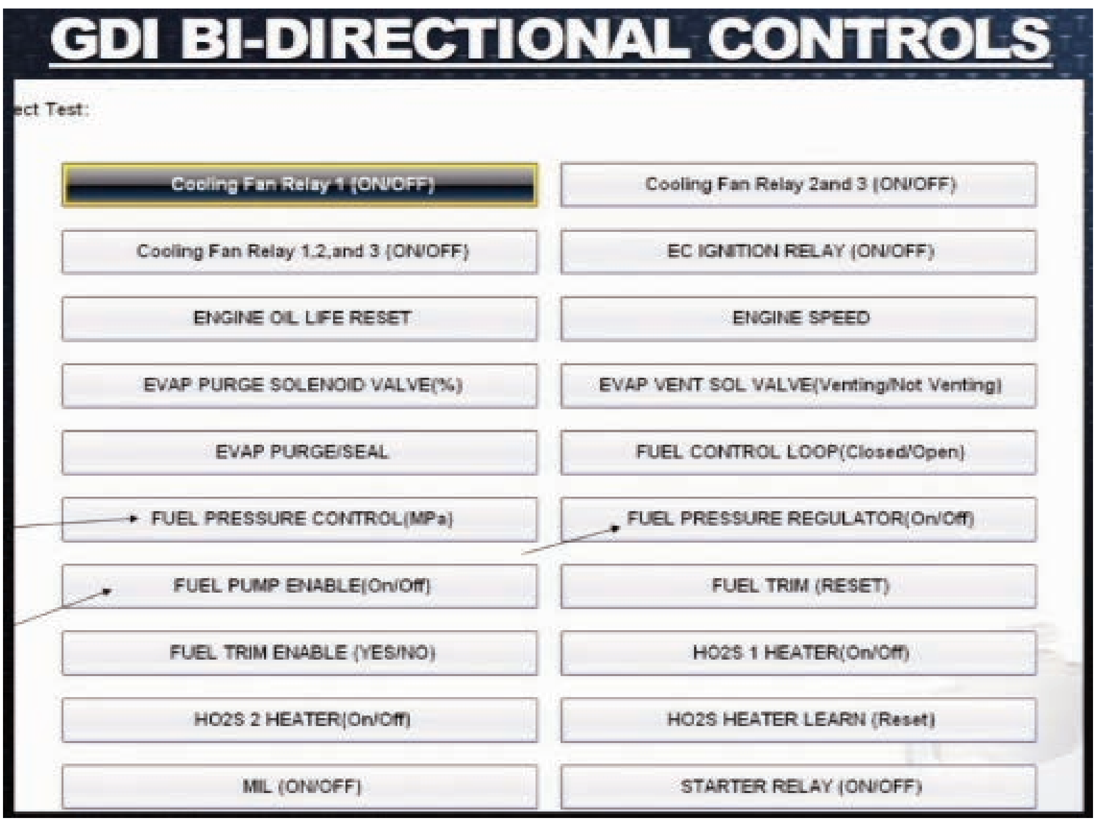
Once you have confirmed the low side of the system is working correctly and is able to feed the high pressure mechanical pump, then you can move on to diagnosing the high pressure side of the using the information stored on the ECM. The ECM has control of the injectors and the fuel volume regulator.

What controls the fuel pressure from going extremely high on the GM SIDI system? The fact of the matter is that the entire fuel delivery system comes into play in controlling pressure through the interplay of feeding and releasing the fuel. This is a balancing act between the on time of the injectors and the duty cycle control of the fuel volume regulator opening the door for the low pressure pump to feed the high pressure pump.

GDI SCAN TOOL DIAGNOSTICS



As you can see in the screen capture above, the high pressure PID is usually presented in MPa (megapascals). A quick tip on converting MPa to PSI is to multiply the MPa value by 145 and you will be very close to the PSI reading. For example: 4.42 MPa X 145 = 640.9 PSI



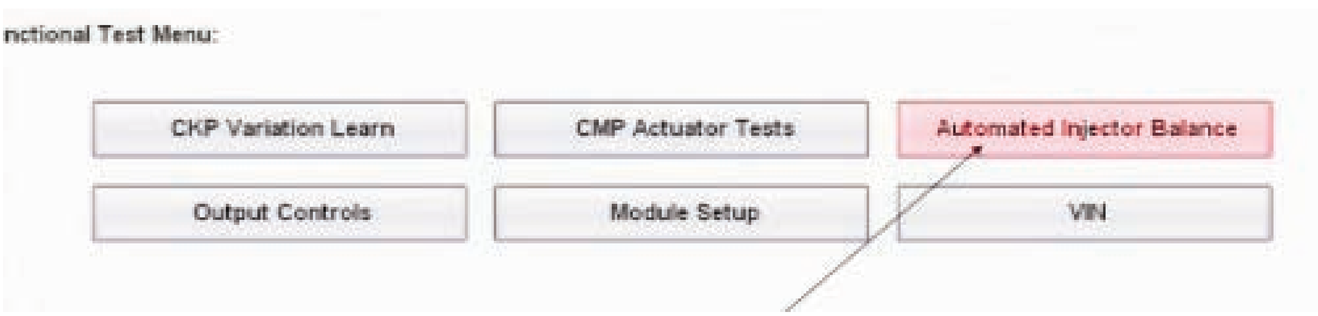
Pictured above is a screen capture from a scan tool showing some of the bi-directional controls that may be available to you during your diagnostic strategy.

The first one we need to discuss is the fuel pump enable (on/off). You will be using this control a lot with the engine running. This is how you would reduce the high pressure if you have to access the high pressure system. The system is under pressure so you would want to turn off the pump with the engine running, wait a few minutes until the engine stops running and verify the pressure has bled completely.

GDI SCAN TOOL DIAGNOSTICS

Some fuel volume regulators are shut with the ignition key in the OFF position and some are open. If the system is open with the key off, what happens to the residual fuel pressure after a long cold soak? As the vehicle sits for a long period of time, overnight, the pressure bleeds off from the intake fuel pump module to the mechanical pump. A unique feature on Ford GDI vehicles to eliminate long cranking times after this type of cold soak is as soon as the door is opened, the dome light circuit sends a message to the BCM, and the BCM turns on the fuel pump. By the time the driver engages the starter, the pressure to the mechanical fuel pump has been increased to the proper specification.

Another test you will use is the Fuel Pressure Control test. With this test, you input the pressure and the fuel pressure regulator reacts to your input. Keep in mind, the formula for fuel delivery also includes RPM. If you are running this test and command the system to 2,000 PSI, you need to raise the RPM to give the mechanical pump a chance to work with you. You can use this test to verify the pump can produce enough pressure to run the engine at idle and higher RPMs.



You will also have an Automated Injector Balance test available to you. With older GM vehicles this test did not work very well due to the fact we were using old technology on old technology vehicles. The first automated injector balance test available used a method of cycling the injectors and observing pressure changes during KOEO. GM has now changed this so we can perform the test with the engine running. Be careful when performing this. On port fuel injected vehicles we would connect a pressure gauge, cycle the injector from a preset pressure and time and observe the pressure drop. Again, on GDI systems, the injector balance test is performed with the engine running. You are actually comparing the rise in pressure in the fuel rail as you turn off each injector. The performance of each injector is based on the pressure differences between the other injectors.

NOTES

SIDI OUTPUT TEST AND SERVICE REVIEW

To review the scan tool output test you can perform the following:
- Cylinder power balance
- Fuel injector balance
- Fuel pressure control
- Fuel pump on/off
- Fuel system high pressure reduction

When removing the injectors, the following must be discarded and replaced:
- Fuel injector hold down clamps
- O-rings
- Plastic spacers
- Fuel injector seal
- The Teflon seal on the tip of the fuel injector must be installed using EN-48266. Refer to the appropriate service information for details.

When removing the high pressure fuel pump, the following must be discarded and replaced:
- Fuel pump bolts
- Fuel pump gasket and O-ring
- High pressure fuel pipe
- When installing the high pressure fuel pump, be sure the roller lifter is oriented properly, the camshaft is at base circle, and the number 1 piston at top dead center (TDC) on the exhaust stroke.

RON'S PERFORMANCE AND PROFIT RECOMMENDATION

From the instructors experience of owning and driving a GDI vehicle, he would notice that within 10,000 – 12,000 miles the vehicle would begin to experience a light throttle hesitation that would progressively get worse over time.

With port fuel injection the injector is directly targeted at the intake valve. With the engine running the intake valve is rotating. Therefore, any deposits on the back of the valve, were quickly cleaned by detergent properties within the fuel. Here is the question. Who or what is going to clean the back of the valves on a GDI engine? The answer is YOU!

Ron recommends an upper intake cleaning every 10,000 – 12,000 miles. This cleaning will allow the chemicals to move through the intake and clean the light residue on the back of the valve. If this is done every 10,000 – 12,000 miles, you will not have carbon buildup on the back of the valves causing driveability problems for the customer. Where does this residue buildup come from? All of the manufacturers are doing whatever they can to reduce internal engine friction. To do this they are adjusting piston ring tension, bearing clearances and oil viscosity levels. The combination of all of this is excessive residue buildup on the intake valves.

As vapors build up within the crankcase the first thing they are going to come into contact with is the drive by wire throttle body. Carbon can and will build up on the throttle body causing the ECM to read excessive amperage and control the vehicle to a limp in mode when what is really needed is to clean the throttle body.

After the throttle body, the vapors migrate into the intake manifold. As the vapors migrate into the intake manifold, it begins to disrupt the designed swirl and tumble and begins to buildup on the back of the intake valve upsetting the airflow into the combustion chamber. What is the number one cause of spark knock? It is not poor fuel quality; it is oil migrating into the combustion chamber.

As you can see, there are a number of problems that can be remedied by selling your customer an upper induction cleaning at the time of service.

CONCLUSION

The first experience you will have with a customer that owns a GDI vehicle will be with routine maintenance. As you begin to see more and more GDI vehicles enter your shop you will probably hear your customers say how much they like the performance and fuel economy the vehicles are giving them. Make sure you let them know you have the knowledge and the tools to service and repair GDI vehicles. In fact, you probably already have the tools available, one of them being a professional level scan tool.

Not only do you have the tools, now you have some training to be successful in your shop when working on Gasoline Direct Injection (GDI) vehicles.

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