# FUEL TRIM(MING) DIAGNOSTIC TIME

**BY BOB PATTENGALE**

**No matter what the driveability issue happens to be, beginning by checking the PCM's fuel trim decisions can get you pointed in the right direction, and may end up cutting your diagnostic time in half.**

The year is 2006, and for those who may have overlooked it, this is the 10th anniversary of On-Board Diagnostics II (OBD II). I believe it's cause for celebration. Here's an example of how it used to be: I was recently called to help a shop with a 1992 Subaru. In order to retrieve the diagnostic trouble codes (DTCs), I had to remove the driver's kick panel, visit a vehicle repair information source for the instructions on how to jumper the diagnostic connector, then

Photo montage: Harold A. Perry; injector photo: Karl Seyfert; space images: NASA

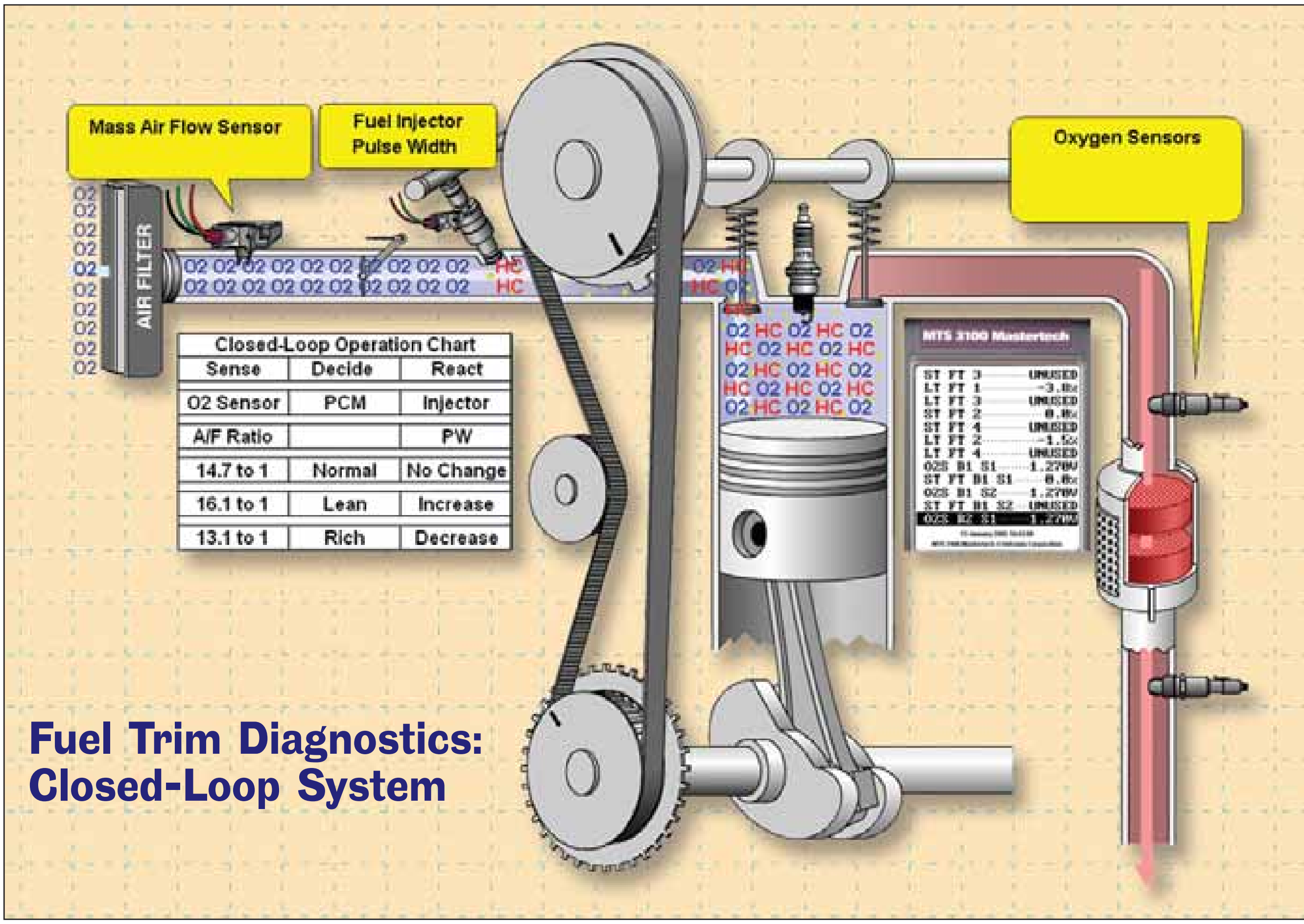



Illustration courtesy Automotive Test Solutions

**Fig. 1:** Most fuel control systems fall into two categories: speed density using rpm and a MAP sensor or mass airflow using rpm and a MAF sensor to determine engine load. This illustration displays the component layout of a typical mass airflow engine control system and its fuel trim decision-making process.

count the flashes of the malfunction indicator light (MIL). The final step was looking up the DTC description. Total time from start to finish was approximately 15 minutes. If this had been an OBD II vehicle, I would have had the information in under 30 seconds. The standardization associated with OBD II, which gives us easy access to fuel trim data, has really simplified the diagnostic process.

What is fuel trim? Fuel trim is a window that allows you to see what the computer is doing to control fuel delivery and determine how the PCM's adaptive strategy is operating.

Why was fuel trim created? In order for vehicle manufacturers to comply with EPA emissions regulations, catalytic converters were added to reduce tailpipe emissions. Catalytic converters need a stoichiometric air/fuel ratio of approximately 14.7:1 to obtain the greatest emissions reductions. Vehicle engineers designed closed-loop engine control systems to maintain that ratio, adjusting injector pulse width based on information from the oxygen sensor and other inputs. Short-term fuel trim (STFT) and long-term fuel trim (LTFT) are expressed as a percentage, and the ideal range should be within ±5%.

Positive fuel trim percentages indicate that the powertrain control module (PCM) is attempting to richen the fuel mixture, to compensate for a perceived lean condition. Negative fuel trim percentages indicate the PCM is attempting to lean out the fuel mixture, to compensate for a perceived rich condition. STFT and LTFT percentages are the adjustments made by the PCM to maintain the 14.7:1 ratio.

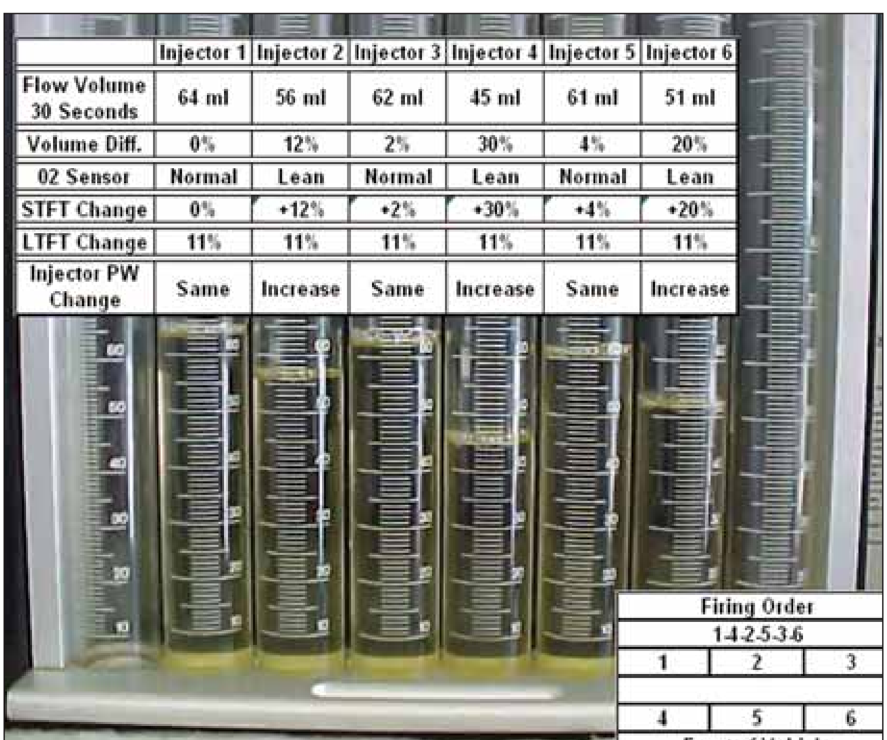
No matter what the driveability issue happens to be, the fuel trim window should be used first to check the STFT and LTFT parameters.

There are two basic fuel control systems used on most vehicles: *speed density systems*, which use rpm, manifold absolute pressure (MAP) and barometric pressure (BARO) to calculate engine load, and *mass airflow systems*, which use the mass airflow sensor (MAF) and rpm to calculate engine load. In both cases, the PCM begins with a standard injector pulse width calculation, based on various inputs and internal fuel cell tables.

The equation used by early Chrysler speed density OBD II vehicles to establish initial pulse width is: Injector Pulse Width = (RPM × MAP/BARO) ×

Photos and screen captures: Bob Pattengale

**Fig. 2:** These fuel injectors from a 2000 Honda Odyssey are being tested by Linder Technical Services on an injector test bench. The injectors have been identified as the likely cause of idle speed and fuel trim issues. Starting from left to right, injectors 4 and 6 exhibit very irregular spray patterns.



| | Injector 1 | Injector 2 | Injector 3 | Injector 4 | Injector 5 | Injector 6 |
|---|---|---|---|---|---|---|
| Flow Volume 30 Seconds | 64 ml | 56 ml | 62 ml | 45 ml | 61 ml | 51 ml |
| Volume Diff. | 0% | 12% | 2% | 30% | 4% | 20% |
| 02 Sensor | Normal | Lean | Normal | Lean | Normal | Lean |
| STFT Change | 0% | +12% | +2% | +30% | +4% | +20% |
| LTFT Change | 11% | 11% | 11% | 11% | 11% | 11% |
| Injector PW Change | Same | Increase | Same | Increase | Same | Increase |



**Fig. 3:** The injectors are checked for flow and volume next. At the conclusion of the test, it was determined that there was a 30% variation from the highest to the lowest flow rate. This imbalance will make the PCM work extra hard as it attempts to maintain the proper air/fuel ratio.

TPS × ECT × IAT × Battery Volts × $O_2$ (Short Term x Long Term). Once the vehicle is running and the engine control system enters closed-loop, the PCM relies primarily on feedback from the oxygen sensor to determine if the stoichiometric air/fuel ratio is being maintained.

Think of closed-loop operation as a Sense-Decide-React sequence. The Closed Loop System Operation sequence in Fig. 1 on page 66 provides an explanation of the Sense-Decide-React process. The PCM determines the base injector pulse width as described above. Once the system enters closed-loop, the Sense phase begins, and is handled by the oxygen sensor. In the Decide phase, the PCM uses the oxygen sensor data to determine if the proper 14.7:1 air/fuel ratio is being maintained. If the ratio is correct, the PCM decides that no change should be made to the injector pulse width. In this scenario, the React phase maintains the same injector pulse width. However, if the air/fuel ratio is 16.1:1 (lean) during the Sense phase, the PCM makes the decision to increase the injector pulse width to correct the lean air/fuel ratio condition. In the React phase, the PCM commands the fuel injector to stay open longer. The Sense-Decide-React sequence continues throughout closed-loop operation, maintaining the proper air/fuel ratio.

During closed-loop operation, the PCM reports changes in fuel trim calculations via the OBD II generic data parameters short-term and long-term fuel trim. STFT for most vehicles will normally sweep rapidly in response to the oxygen sensor. In many cases, if you graph Bank 1 STFT and B1S1 $O_2$ sensor, you'll see the oxygen sensor go rich and STFT go lean to adjust the air/fuel ratio. The oxygen sensor will then go lean and STFT will go rich.

LTFT for most vehicles will remain more stable, adjusting over a longer period of time. On some vehicles, if STFT has reached the specified limit, LTFT will change in a few seconds. On other vehicles it may take 15 to 20 seconds before a change occurs. The LTFT calculation is normally kept in memory, so the PCM is ready to use the last known injector pulse width following a restart. STFT will normally begin at 0% and adjust to the current conditions. Both STFT and LTFT will normally reset when all trouble codes are cleared.

To better understand how fuel trim is used to maintain the proper air/fuel ratio, look at the set of fuel injectors in Fig. 2, which are being tested prior to cleaning/rebuilding. The injectors were removed from a 2000 Honda Odyssey that had idle quality and fuel trim problems, with related DTCs. You can see some differences in the spray patterns and volume. Injectors 1, 3 and 5 look very similar in spray and volume. Injector 2 seems to spray a little less volume. Injectors 4 and 6 have even less volume, and the spray patterns are not good.

Fig. 3 shows the total volume the injectors flowed in 30 seconds at 40 psi. The actual injector volume seems related to the spray patterns from Fig. 2, but knowing exactly how much flow occurred provides a better picture. Let's take a closer look at how injector volume and fuel trim relate to one another.

Injectors 1, 3 and 5 are very close in flow volume—approximately 61 to 64mL. For discussion purposes, we'll use 64mL as a baseline for 100% correct injector volume, or a 14.7:1 stoichiometric air/fuel ratio. One thing I noticed right away—and this turned out to be just a coincidence—was that the even-numbered injectors all had flow issues. On this vehicle, the affected injectors are actually on different banks (see the Firing Order table in Fig. 3). If all the even-numbered injectors were on one bank, it might indicate possible contamination or fuel flow restrictions in the fuel rail. Also, we do not have bank-to-bank fuel control for this particular vehicle, so the LTFT will be an average of all injectors.

**Fig. 4:** The fuel injectors are tested for leaks when closed by applying fuel pressure without energizing the solenoids. As you can see, the injector in the center is leaking fuel under pressure. This was causing a rich condition at idle and setting a DTC P0172 (Fuel System Too Rich).

If we compare the best injector (No. 1) to the worst (No. 4), the difference indicates that approximately 30% less fuel is being delivered to cylinder 4. If we look at the closed-loop process for cylinder 4, the oxygen sensor would have reported to the PCM that the air/fuel ratio was excessively lean. The PCM would have commanded an increase in injector pulse width the next time the injector supplied fuel to cylinder 4. The ultimate goal of the PCM is to return cylinder 4 to a 14.7:1 air/fuel ratio. The STFT parameter in the OBD II generic scan tool would have reported STFT at approximately +30%. To complete the cycle, the oxygen sensor reports the results of the pulse width increase back to the PCM. If the air/fuel ratio is now correct, no further adjustments are required. Over the next few cycles, STFT and injector pulse width will stabilize. The next step is for the PCM to make a permanent LTFT correction, if required.

If this were a one-cylinder engine, LTFT would eventually report +30% and STFT would return to 0%. In some cases, the PCM might limit LTFT to a specific maximum or minimum value. For example, if the maximum LTFT adjustment is +25% and the total fuel trim adjustment is +30%, then LTFT will report +25% and STFT will report +5%, for a total fuel trim value of +30%. The LTFT calculation is kept in memory on most vehicles, so the PCM does not need to relearn the fuel trim calculation the next time the vehicle is started.

The firing order for this engine is 1-4-2-5-3-6. Let's look at how the injector flow issues will affect the balance of the engine. Cylinder 1 is normal, cylinder 4 is lean, cylinder 2 is lean, cylinder 5 is normal, cylinder 3 is normal and cylinder 6 is lean. As you can see, the fuel injector issue might create a rough idle condition. If only one injector was failing, the PCM should be able to stabilize fuel trim and control idle speed within an acceptable range. However, with three cylinders causing problems, it would be very difficult to maintain a good balance.

How will the PCM average out LTFT? If this engine had bank-to-bank fuel control, we might expect Bank 1 LTFT to be close to 0%, and if we averaged Bank 2 LTFT the adjustment might be approximately +20%. However, this particular Honda does not have bank-to-bank fuel control, so the average LTFT will most likely be approximately +11% and STFT will be constantly changing from 0% to +20%. Various vehicle manufacturers employ different methods to make these adjustments; the important thing is to observe the differences among cylinders when diagnosing fuel trim issues.

Based on the data from the fuel injectors, what DTC do you think should


**Fig. 5:** This is a screen capture from a 2000 Saturn using the ATS EScan Sharpshooter. If the fuel injector connectors are accessible, you can perform an injector balance test using STFT and/or LTFT. The LONGFT1 graph clearly shows a cylinder-to-cylinder difference in injector performance.

be present? I would have assumed a P0171 (Fuel System Too Lean). Actually, the codes present were P1491 (EGR Valve Lift Insufficient) and P0172 (Fuel System Too Rich). The EGR DTC is listed as a possible cause for a P0172 and should be corrected first. The EGR system was checked and cleaned, but the P0172 returned. What should the next step be?

The next step is to determine whether the condition exists over more than one operating range. Fuel trim should be checked at idle, 1500 rpm and 2500 rpm. In this case, STFT at idle was approximately −23% and LTFT was −4%, for a total fuel trim calculation of −27%. No matter how long the vehicle idled, LTFT never went above −4%. In this case, STFT carried a greater weight than LTFT. STFT and LTFT at 1500 rpm and 2500 rpm each were approximately 3%, which is within normal operating range. Our diagnosis will need to focus on a condition that occurs only at idle.

After checking all the items that might cause a rich air/fuel ratio condi-

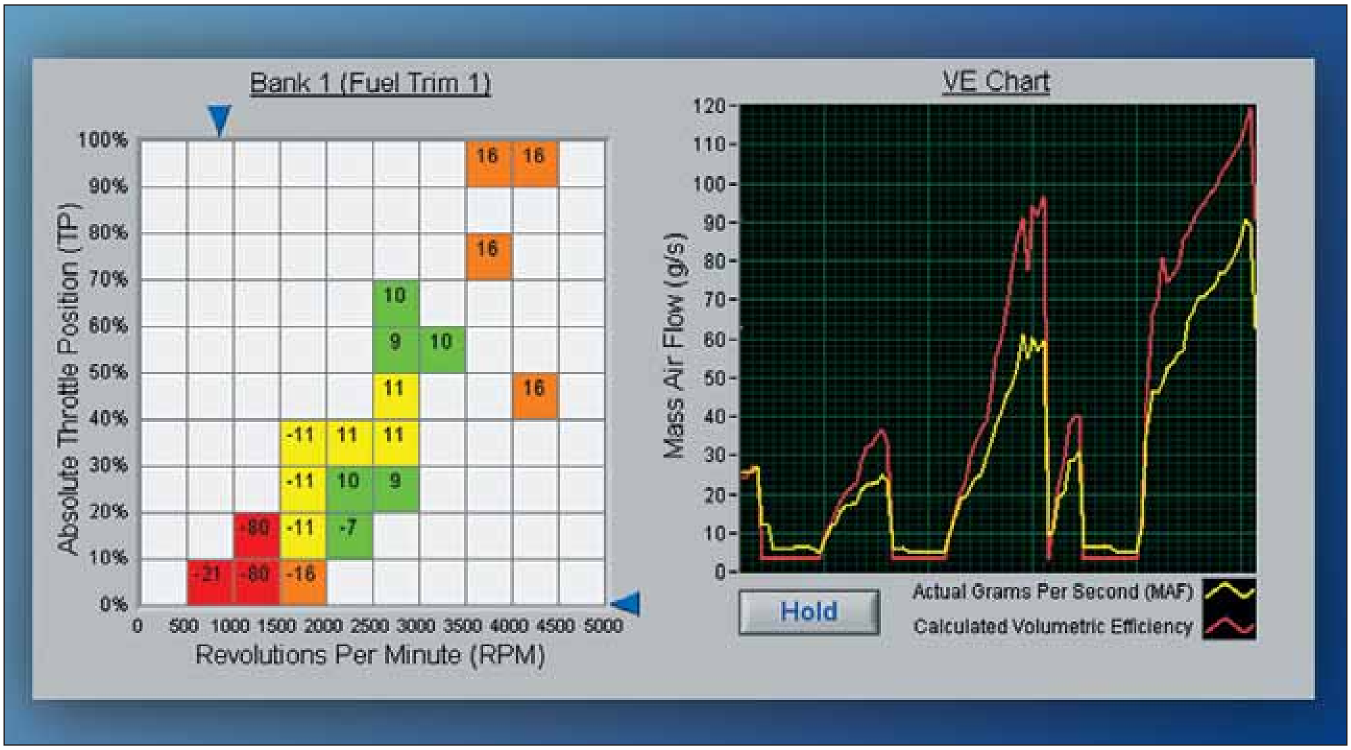



**Fig. 6:** Diagnosing dirty MAF sensors is a snap with the ATS EScan. This fuel trim map from a 2000 Pontiac GrandAm shows negative fuel trims at idle and positive fuel trims at cruising speed. This is typically how a dirty MAF sensor responds. The MAF overestimates airflow at idle and underestimates it at cruising speeds. The VE chart on the right confirms the diagnosis.

tion, the only remaining possibility had to be the fuel injectors. I performed an injector balance test (described below) using fuel trim data from a graphing OBD II generic scan tool to confirm the injector issue. Fig. 4 on page 70 shows a close-up of injector No. 4 leaking fuel under normal fuel pressure while sitting in the test stand. Remember, an injector tip is subject to intake manifold vacuum and a leaking injector might be worse under vacuum conditions. A new set of injectors fixed the idle quality and fuel trim DTC.

If you suspect a problem with the fuel injectors, use STFT or LTFT to check proper operation. Fig. 5 is a graph of LTFT from a 2000 Saturn with a cylinder misfire. The baseline is −10% LTFT. So the PCM is decreasing injector pulse width to compensate for a slightly rich condition.

Performing an injector balance test is simple, as long as you can gain access to the fuel injector connectors. Unplug one injector at a time and wait until the maximum LTFT change is reached. On some vehicles you'll use STFT for this test, or a combination of both STFT and LTFT. With one fuel injector unplugged, the oxygen sensor will see a lean condition and the PCM will compensate by increasing the pulse width of the functioning injectors to reach stoichiometry. The results of this particular test, with injector No. 1 unplugged the LTFT change is approximately +14%, injector 2 +10%, injector 3 +17% and injector 4 +16%. Injectors 3 and 4 contribute a greater volume of fuel than injectors 1 and 2. We know this because the amount of fuel trim increase is greater with these injectors unplugged. Injector 2 is the cause for concern; with injector 2 unplugged, the remaining injectors need to supply only +10% total. This injector may have a slight leak that's causing the negative fuel trims. A new set of injectors fixed this vehicle. Unfortunately, I was unable to test the old injectors.


**Fig. 7:** Volkswagens and Audis have different fuel trim strategies from other manufacturers. Additive Mixture Correction is equivalent to STFT in OBD II generic and changes only at idle speed. Multiplicative Mixture Correction is LTFT in OBD II generic and changes only at cruising speeds. Injection duration changes first for a period of time, then additive and multiplicative will change. It may take as long as 30 seconds before you see any change.

One of the more difficult DTCs to diagnosis is P0171 (Fuel System Too Lean). The first item to get replaced is often the oxygen sensor, but most of the time this will not fix the problem. A dirty MAF sensor can cause this issue, but that diagnosis can be tricky. Fig. 6 shows fuel trim and volumetric efficiency charts related to the MAF sensor. This data was captured from a 2000 Pontiac GrandAm. The fuel trim chart on the left shows negative fuel trims at idle and positive fuel trims at cruising speeds. This is typical of a dirty MAF sensor. The MAF sensor overestimates airflow at idle, which causes the negative fuel trim values. It then underestimates airflow at cruising speeds, which accounts for the positive fuel trim values.

The volumetric efficiency was checked to confirm the diagnosis. The red graph represents calculated VE based on engine size and engine speed. The yellow graph represents the actual grams per second recorded during the test. As you can see, the MAF sensor is overestimating at idle and underestimating at cruising speed. A new MAF sensor will correct this fuel trim issue.

VW and Audi use a slightly different fuel trim strategy from other manufacturers. Fig. 7 is a screen capture from the Vetronix/Bosch KTS-650. Additive Mixture Correction 1 is STFT in OBD II generic and will change only during idle operation. Multiplicative Mixture Correction 1 is LTFT in OBD II generic and will change only during cruising speeds.

No matter what the driveability issue happens to be, begin with STFT and LTFT. The PCM will usually point you in the right direction. Once you know what the PCM is thinking, in many cases you can cut your diagnostic time in half. Finally, don't forget to check for specific fuel trim diagnostic suggestions provided by the vehicle manufacturer. M

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