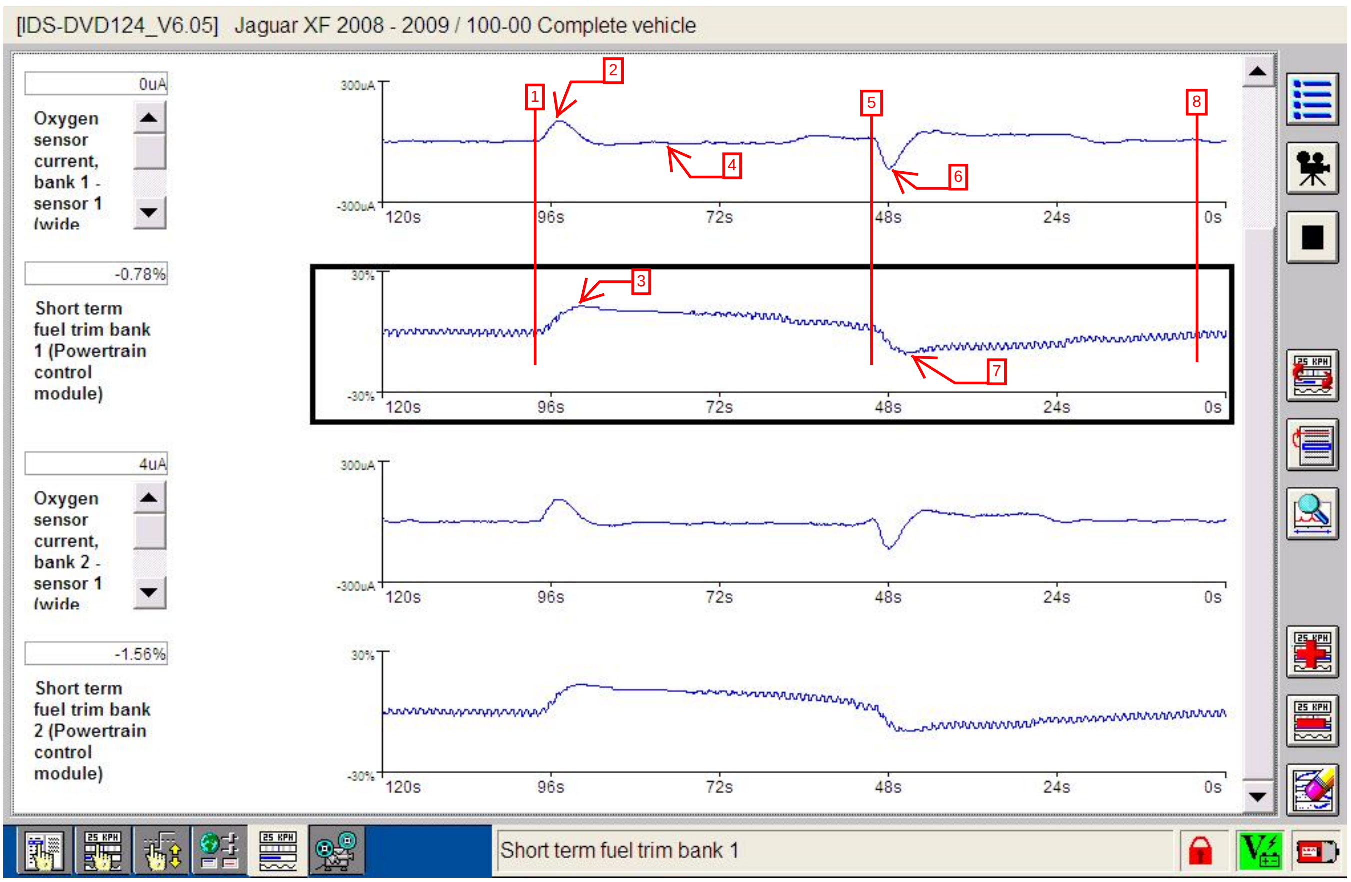
OBDII Primer –Using Fuel Trims for Diagnostics

In the first paper we saw what fuel trims are and how they work, now we'll put them to use and see what they tell us about what's going on in our engine.

One more bit of ground work before we get started. I touched on the oxygen sensors before, but I think a further illustration of their interaction with trims may be helpful. Some folks are just more visual than others. Figure 1 shows the O2 sensor responding to the air leak I created by unseating the dipstick, and the fuel trim action in response. [These are the "wideband" oxygen sensors, and the parameter is a current measurement rather than voltage as with 1st generation sensors; the action or reaction of the Engine Management System is the same, however]



1. Air leak introduced.
2. O2 sensors detect added air and current rises.
3. Fuel Trim goes positive in response, adding fuel to compensate for the leak.
4. O2 sensor goes back to neutral as a result.
5. Air leak removed.
6. O2 measures the air loss and current falls.
7. Fuel Trim flips to negative to reduce fuel accordingly, again compensating for the change in detected air.
8. O2 sensor and trims all settle back to normal.

That completes the circle so to speak; hence the term "closed loop fueling". We watch the exhaust, record a drift one direction and make a balancing change to compensate. Essentially it's a sense, decide, react type of sequence. That is the constant back and forth the Engine Management mounts to keep things in line, stoichiometry. In contrast, open loop fueling is when the system is not ready for closed loop operation, as when cold; not wanted, like at full throttle; or when there is a component failure that renders closed loop impossible. Such would be the case if an oxygen sensor failed so the exhaust could not be monitored.

Back to fuel trims.......

Next we'll take a look at how the fuel trims are implemented in the Engine Management system. In the first installment I mentioned the engineers "doing their thing" and that was determining how much fuel the engine needed at a given RPM and load range. [from here on out, I'll just use the term "load range"] From that they created and programmed the ECM with a FUELLING MAP. That basically amounts to a look-up table for the ECM to use to know how much fuel to inject for a given set of conditions.
Let's backup slightly and explain "load range" a little better. The load range is actually an OBDII parameter that the ECM calculates, that provides an indication of the percentage of engine capacity that is being used (with wide open throttle being 100%). It is called the Calculated Load Value or CLV; and for our purposes CLV = Load Range. So the ECM has a look up table, or fuelling map that tells it to inject a given amount of fuel at X RPM and X Load Range. It can be represented in a grid, or MAP like this one:

Diagnostics | Performance | Dashboards | Tools | Settings | Console | **FT Analysis** | FT Data | O2 Raster | MAF Balance | MAF Test | Torque Converter

SAE.LONGFT1 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 1 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		-0.6	-0.3	-0.7	-0.8	-0.9	-1.1	-1.6	-1.6	
20		0.7	0.0	-0.9	-1.0	-1.0	-1.1	-0.5		
30		0.3	-0.4	-0.9	-1.0	-0.0	0.3	-0.8		0.8
40		1.6	-1.0	-0.7	-0.4	0.2	0.4	-0.4	0.8	
50		0.0	-0.8	-0.6	0.6	0.4	0.8	0.8		
60		-0.8		-0.4	0.3	0.0	0.8			
70				0.4	0.8					
80					0.8					
90					0.4					

SAE.LONGFT2 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 2 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		-0.8	-0.4	-0.8	-0.9	-0.7	-1.2	-2.3	-2.3	
20		0.1	0.0	-0.8	-1.0	-0.8	-1.1	-1.1		
30		-0.4	-0.9	-0.8	-1.2	-0.6	-0.3	-0.8		0.0
40		0.8	-1.0	-0.7	-0.8	-0.2	-0.2	-1.6	-0.5	
50		-0.8	-1.0	-0.4	-0.3	0.0	0.0	0.0		
60		-0.8		-0.6	-0.1	-0.8	0.0			
70				-0.2	-0.4					
80					0.0					
90					0.0					

These are two maps I created in a PC Scantool that I use, one map for each bank. They can be represented differently in other tools, but the idea is always the same. The left vertical scale is the Load Range in percent. The top scale is the RPM in thousands and the cells themselves show the Long Term Fuel Trim in percent. This example is a 22 minute drive at several speeds, accelerations and gear ranges to fill a wide range of cells. [You would be surprised how much time the engine spends in a very narrow load range band during "normal driving"!] This example is your basic perfectly running car, everything is bouncing right around 0%. That is exactly what we want, and tells us all is on program.

Remember:

RPM

0

LOAD

SAE.LONGFT1 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 1 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		-0.6	-0.3	-0.7	-0.8	-0.9	-1.1	-1.6	-1.6	
20		0.7	0.0	-0.9	-1.0	-1.0	-1.1	-0.5		
30		0.3	-0.4	-0.9	-1.0	-0.0	0.3	-0.8		0.8
40		1.6	-1.0	-0.7	-0.4	0.2	0.4	-0.4	0.8	
50		0.0	-0.8	-0.6	0.6	0.4	0.8	0.8		
60		-0.8		-0.4	0.3	0.0	0.8			
70				0.4	0.8					
80					0.8					
90					0.4					

Now we'll look at a problem car. I'll not say just yet what the problem is. We'll look at it the same way it presents to us in the field. Someone has a Check Engine Light, they bring it to us, and we start collecting facts. I read the codes, of course, and that may appear pertinent, it may not. So, I know the fault code, but I'm keeping that to myself for now.

I always stress, the Fuel Trims are the FIRST thing to at least look at [in my opinion] if you are investigating a drivability issue; virtually anything that adversely affects an engine, impacts Fuel Trims.

Here is an image of the Fuel Trims from a 20 minute drive while monitoring the engine for our Check Engine Light diagnosis.

Diagnostics | Performance | Dashboards | Tools | Settings | Console | **FT Analysis** | FT Data | O2 Raster | MAF Balance | MAF Test | Torque Converter

SAE.LONGFT1 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 1 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		3.9	-1.0	-2.9	-2.1	-2.0	-1.6	-1.2		
20		5.9	0.6	-0.6	-0.3	0.0	0.0	2.0		
30		5.4	-1.7	-0.4	-0.1	0.9	2.7	3.1		
40		4.1	-1.6	0.6	1.6	3.1	3.1	3.1		
50			-0.6	0.5	3.1	3.1	2.2			
60			0.0	3.3	2.5	3.1				
70		7.0	0.0	2.8	3.1					
80				3.1	3.1		3.1			
90										

SAE.LONGFT2 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 2 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		1.8	-0.1	-2.2	-1.2	-0.3	-0.8	-0.4		
20		4.2	-0.1	-0.7	0.5	1.0	0.8	2.0		
30		3.7	-1.4	0.4	0.7	1.2	2.0	3.1		
40		3.1	-0.6	1.1	2.0	2.2	3.1	3.1		
50			0.2	1.6	3.1	2.2	2.0			
60			0.8	2.0	2.8	3.1				
70		3.9	0.8	3.1	3.1					
80				2.3	3.1		2.0			
90										

At first glance the usual response is, "What the………". Well, let's see what we do know.

1. Very low RPM, regardless of load the ECM is ADDING fuel.
2. Very low load, higher RPM the ECM is SUBTRACTING fuel.
3. High RPM, high load the ECM is ADDING a little fuel.

Now that we have some data, let's check the Fault Code description and see if it seems plausible. The code is P0441 - Purge Valve Range/Performance. That indicates a PERFORMANCE fault, as opposed to a CIRCUIT fault. A circuit fault would be an open solenoid winding, a shorted coil winding or a wire broken or disconnected. A performance fault means the system says the circuit tests OK, but the ECM does not see the correct PERFORMANCE of the system. You see the ECM tests the system when it performs an action; it looks for the change when it opens the Purge Valve in this case. It should see a change in both the Induction Manifold Pressure AND usually the Oxygen Sensor. If it doesn't see the expected changes, it assumes the valve isn't PERFORMING, and records a fault. So in this case, the Purge Valve has failed such that it is always open, meaning it is always trying to purge the carbon canister and tank of fuel vapor.

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Let me add a side note here:

I said that it records a fault, instead of sets a Check Engine Light, purposely. The first time the ECM sees this failure, it records a pending fault. The Check Engine Light will not be turned on until this failure is seen twice, on CONSECUTIVE drive cycles. For instance, if for some reason this failure occurred only every other drive cycle, the Check Engine Light will never be turned on. The fault has to be recorded on two consecutive drives cycles before the light is ever illuminated.

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Let's go back to the things we determined we DO know listed above.

1. At very low RPM regardless of load, the ECM is adding fuel.
   Here is where you have to wrap your head around the big picture. At low RPM the engine is "gulping" air at its lowest volume. So the open Purge Valve is a rather large vacuum leak, with a little fuel vapor thrown in. That also means the vacuum leak is at its largest, as compared to the air going thru the engine. So, the ECM has to ADD fuel to go with that air.

SAE.LONGFT1 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 1 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		3.9	-1.0	-2.9	-2.1	-2.0	-1.6	-1.2		
20		5.9	0.6	-0.6	-0.3	0.0	0.0	2.0		
30		5.4	-1.7	-0.4	-0.1	0.9	2.7	3.1		
40		4.1	-1.6	0.6	1.6	3.1	3.1	3.1		
50			-0.6	0.5	3.1	3.1	2.2			
60			0.0	3.3	2.5	3.1				
70		7.0	0.0	2.8	3.1					
80				3.1	3.1		3.1			
90										

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2. At very low load, but higher RPM, the ECM is SUBTRACTING fuel.
   Hmmm. Why is that, you ask? Remember the BIG picture? What's going on under those conditions?? Well, if you have high RPM at a very low load, that tells me you are DECELLERATING. That means, closed throttle, very little air coming in, HIGH MANIFOLD VACUUM [remember that], and the engine speed trying to suck a lot of air in. If the throttle is closed, then it must be sucking pretty hard through that open Purge Valve. That means unmetered air AND fuel vapor. Here's where it gets interesting, under these conditions the ECM does what they call 'over-run fuel cut off'. Closed throttle coasting causes fuel cut off, little or no injection. So now we find the ECM, through the Oxygen Sensors, sees this fuel vapor being sucked into the engine when the fuel is basically cut off. So it SUBTRACTS fuel from the program; and that's what we see here, negative fuel trims. Ain't science grand!!

SAE.LONGFT1 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 1 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		3.9	-1.0	-2.9	-2.1	-2.0	-1.6	-1.2		
20		5.9	0.6	-0.6	-0.3	0.0	0.0	2.0		
30		5.4	-1.7	-0.4	-0.1	0.9	2.7	3.1		
40		4.1	-1.6	0.6	1.6	3.1	3.1	3.1		
50			-0.6	0.5	3.1	3.1	2.2			
60			0.0	3.3	2.5	3.1				
70		7.0	0.0	2.8	3.1					
80				3.1	3.1		3.1			
90										

And finally.......

3. At high RPM, high load, the ECM is adding fuel to the program, at a little less than half the rate it added at low RPM. Under these conditions though, the ECM is pouring on the fuel, and the little bit of vapor coming through the purge valve doesn't mean much. It is still a vacuum leak of consequence though, so the ECM has to add a little fuel to go with it to make the Oxygen Sensors happy.

SAE.LONGFT1 x SAE.RPM x SAE.LOAD_PCT [Long Term Fuel Trim - Bank 1 x Engine ...

	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0										
10		3.9	-1.0	-2.9	-2.1	-2.0	-1.6	-1.2		
20		5.9	0.6	-0.6	-0.3	0.0	0.0	2.0		
30		5.4	-1.7	-0.4	-0.1	0.9	2.7	3.1		
40		4.1	-1.6	0.6	1.6	3.1	3.1	3.1		
50			-0.6	0.5	3.1	3.1	2.2			
60			0.0	3.3	2.5	3.1				
70		7.0	0.0	2.8	3.1					
80				3.1	3.1		3.1			
90										

Now you see that Fuel Trims are not a singular value. There's a bunch of 'em. I'm not actually clear on exactly how many 'Load Cells' there are in the ECM's fuelling map, but that number is really immaterial. As long as you can see most of the picture, you can diagnose and lead to the cause, or possible causes of wandering Trims. But like I said, you have to grasp the big picture to be effective.

I'll add now that the images on page 2 were collected during a retest of the same car AFTER the Purge Valve was replaced. All the Trim values are right where we want them, at or near zero for the most part. A complete repair always includes confirmation that the repair actually corrected the fault you were attacking in the first place. A good tech doesn't do guesswork!

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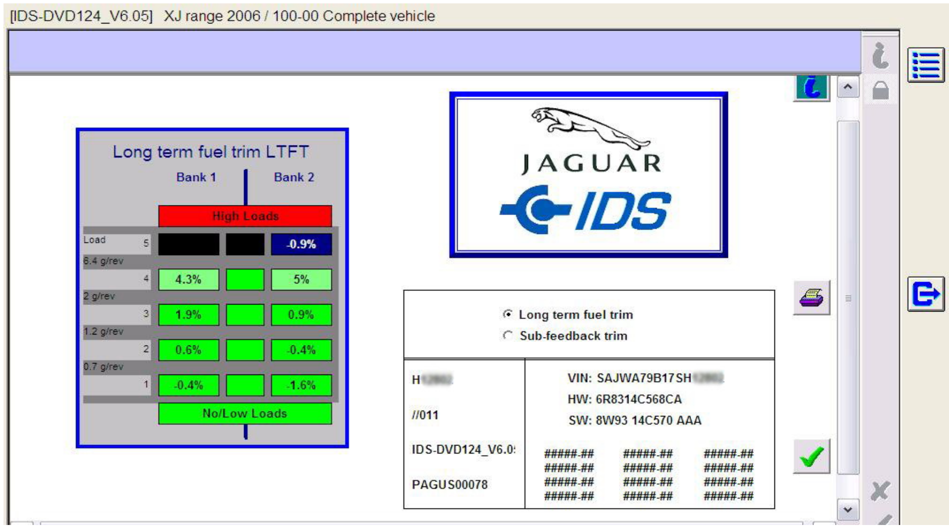
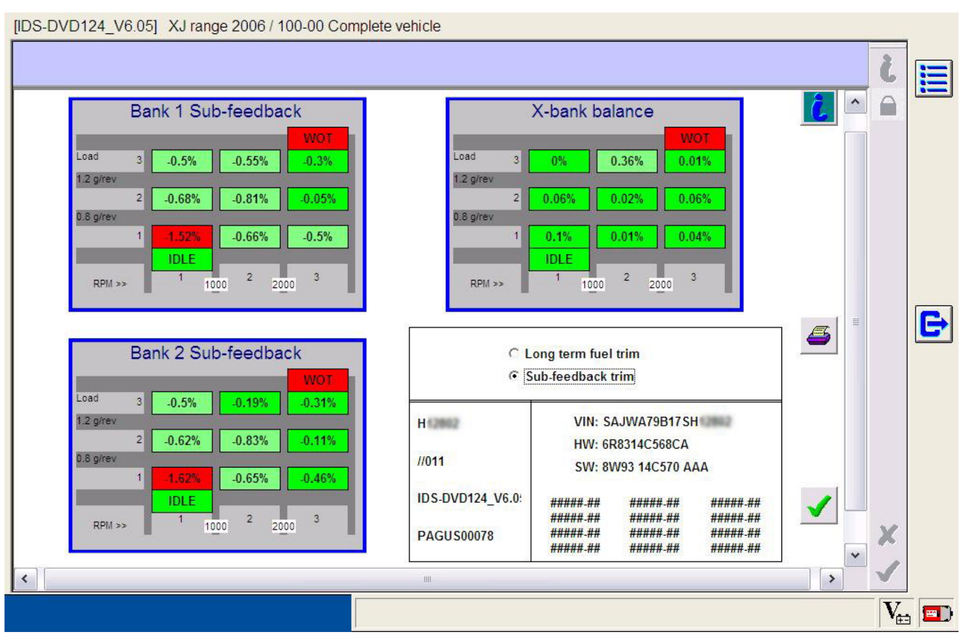
Just for good measure, on the next page I'll give you a taste of another 'version', if you will, of a Fuel Trim diagnostic tool. It is one provided by Jaguar as a part of the IDS/SDD diagnostic tool. I mentioned earlier that there are various forms of displaying and interpreting Fuel Trim data, but the overall idea is the same; this is my proof!

Jaguar calls this the Adaptive Fuel Trim Display application. This one is designed to collect and track fuel trim data over a long period of time. As you can see, it shows a more limited grid with just five load ranges per engine bank. There is still enough there to grasp what's going on, but much more limited in scope.



However, there is something else incorporated in that trim display application that is not available anywhere else; but by the same token, is of very limited value for drivability diagnostics. It is called Sub-Feedback Trim. We'll not get into it here other than for illustration purposes; but it sort of indicates just how deep into fueling control they have gone in today's cars. Sub-feedback is actually using the downstream O2 Sensors to even more finely tune fueling after it's been done the first time, as described earlier in this paper. The downstream sensors are there to monitor the catalysts to make sure they are working. Well, they have figured out that signal can also be used to minutely alter [trim] fueling to even further clean up the exhaust leaving the catalyst. I have said many, many times before; most people just have no idea the sum total of what's going on in their late model car!



You will notice the Sub-Feedback trim figures are extremely small, that gives you an idea what I mean when I say, finely trim fueling. I'll just leave it by saying; the engineers sure know their stuff, yes??

Finally, there is an X-Bank Balance display that just calculates and displays the difference between bank 1 and bank 2. Obviously you could do that for yourself, but sometimes it's helpful to pay attention to that difference.

There you have it…………

I don't know whether it was H20boy [Matt] or Translator [Richard] that I told several months ago that I would have a follow-up to the Primer I did in early 2011. Kind of been at it piece-meal since. Sparkenzap [Ross] posed a question last week and made me figger I better polish it off.

It will be too much information for some; but I know there are some nerds out there that may find it helpful.

Cheers!

JaguarForums.com – Ain't it great!!

Steve Petry
Indianapolis, IN
Rev. 1