Pegasus Fuel Injection

Closed Loop Operation with PFI

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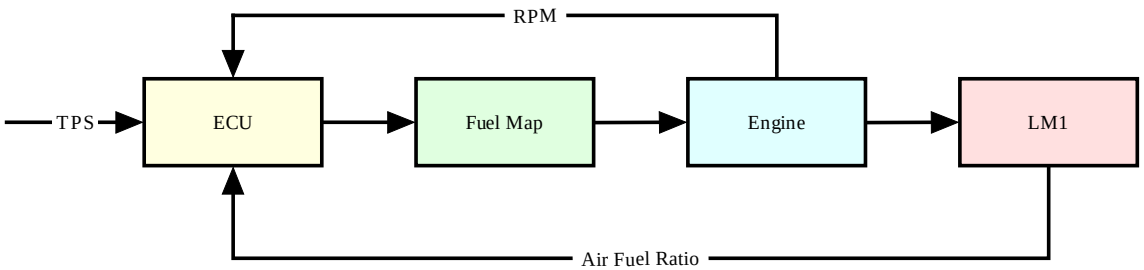


Introduction

The Pegasus fuel injection (PFI) system is designed to operate in an "open loop" mode, meaning it doesn't use an oxygen sensor in the exhaust stream to measure the engine's air fuel ratio. We do this because PFI is a *Performance* product, designed to run lean and mean, with a minimum of wires and sensors, and certainly no giant oxygen sensor hanging out of your custom exhaust system!

This document assumes you have already:

- Installed PFI mechanical on your motorcycle and read the hardware installation guide
- Verified the system functions properly, and checked all wiring twice
- Checked the fuel system for leaks and bled it properly
- Started the motorcycle
- Installed Pegasus60 on your computer
- Established serial communications between PFI and your computer

If you haven't performed all of the above, you are not ready to attempt closed loop operation using PFI, and you should become familiar with PFI first. If you consider yourself a PFI expert, read on!

Air Fuel Ratio Background

Closed loop control using the air fuel ratio sensor can enhance your engine's performance, so we have added a "closed loop mode" to help you create fuel maps…tune your engine closed loop and create perfect fuel maps, then run it open loop over the road!

PFI is designed to interface with InnovateMotorSports® LM1 Digital Air Fuel ratio meter.
(http://www.innovatemotorsports.com/) The LM1 is a complete kit containing everything you will need to measure air fuel ratio and interface with PFI. According to Innovate:

The LM-1 is a hand-held instrument used to measure the Air/Fuel Ratio (AFR) or Lambda for an engine. For gasoline-driven engines, the theoretically optimal air fuel ratio is 14.7 pounds of air for every pound of fuel. At this ratio, theoretically, all available oxygen in the air combines with all available fuel. This ratio is called the stoichiometric ratio.

The measurement Lambda is the actual air fuel ratio over the stoichiometric ratio. A Lambda measurement of "1" equates to the air fuel ratio of 14.7 (for gasoline engines).

When Lambda is less than 1 the engine runs "rich", i.e., unburned fuel exists in the exhaust stream. If lambda is greater than 1 the engine runs lean, i.e., free oxygen (02) is present in the exhaust. Depending on the engine, maximum power is typically delivered when the engine runs slightly rich (for example at lambda values of 0.8 to 0.9 for most engines). This instrument provides a means to measure the actual air fuel ratio or lambda in the engine in operation directly from the exhaust. For this a special wide-band oxygen sensor is used to measure the lambda value derived from the oxygen content (or lack thereof) of the exhaust gases.

In other words, the LM1 will allow you to read the actual air fuel ratio in your exhaust system with a wide-band exhaust gas sensor (WEGO). When used in conjunction with PFI, you can close the loop around the WEGO, forcing your engine to a desired air fuel ratio. This is a fantastic way to create custom fuel maps!

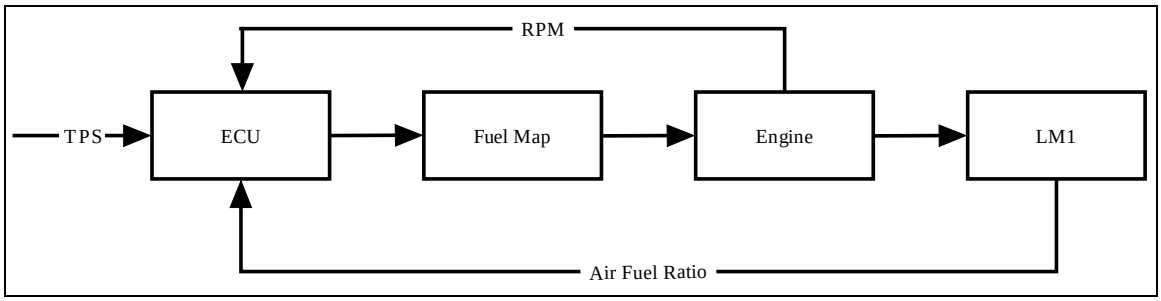


Figure 1. PFI can use the LM1 to close the loop around air fuel ratio.

Things to know

What is an EGO sensor? This acronym stands for an EXHAUST GAS OXYGEN sensor. Also known as a narrow band sensor, it only can tell if the mixture is rich or lean.

What is a WEGO sensor? This acronym stands for: WIDE-BAND EXHAUST GAS OXYGEN sensor. This sensor outputs a voltage that is proportional to air fuel ratio, thus it tells us more information than an EGO sensor does.

What is a UEGO sensor? Wide-band sensors used to be called UNIVERSAL EXHAUST GAS OXYGEN sensors. They are effectively the same and you will see WEGO and UEGO used interchangeably thoughout this document.

What does OPEN LOOP MEAN? An open loop system doesn't use any feedback information for correction.

What does CLOSED LOOP MEAN? A closed loop system uses feedback information from sensors to correct the system and reduce error. A closed loop system is also called a SERVOMECHANISM, and when we close the loop we call this SERVO-ING. In this document, "servo on" means closing the air fuel ratio loop.

What is the EQUIVALENCE RATIO? Think of the equivalence ratio as the percent rich or lean relative to the stoichiometric air fuel ratio. An equivalence ratio of 1.2 means 20% rich. In PFI terms, we use an equivalence ratio of 100 to represent stoic, 120 to represent 20% rich, while 90 means 10% lean. It is also the inverse of lambda.

Setting up the LM1

The LM1 kit must be adjusted to interface with PFI. After reading the LM1 installation manual and setting up the instrument, the analog output calibration must be changed.

Figure 2. LM1 kit.

With the LM1 instrument on and the software installed on your computer and open, select the analog output 1 screen:

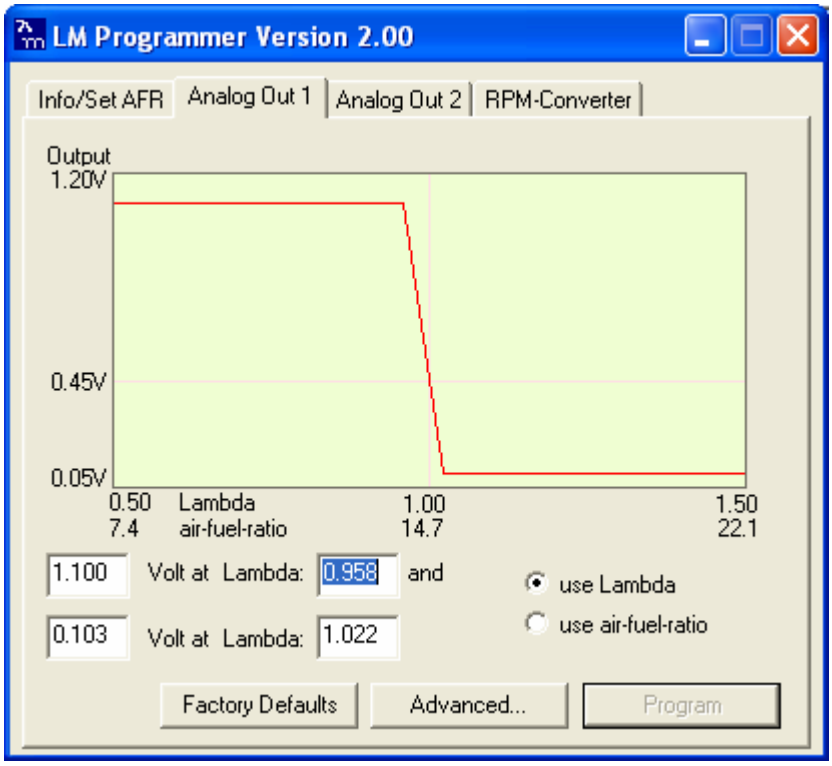


Figure 3. LM1 analog output 1 screen.

- Begin by changing the output to air fuel ratio, not lambda. Then change the airfuel-voltage calibration to:

    1. 2 volts------->air fuel ratio = 10.5
    2. 3.5 volts----->air fuel ratio =16

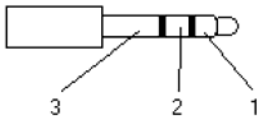
- Now, select the program button to program the LM1 with this information. Analog output calibration is now complete.

Mounting the WEGO in the exhaust pipe

The WEGO itself requires a threaded fitting to be welded onto the exhaust pipe. We recommend placing the sensor in the FRONT exhaust pipe, approximately 1 foot from the exhaust valve. It is possible to run WEGOs in both exhaust pipes as well, but only one can be used to close the loop. Although it is possible to place WEGOs in drag pipes, it is not recommended. BETTER RESULTS WILL BE OBTAINED BY USING A 2-INTO-1 EXHAUST SYSTEM.

Connecting the LM1 to PFI

The LM1 comes with an analog output cable as shown below, which is a 3.5 mm stereo jack connector (available at Radio Shack® or other electronics stores).



The analog 1 connector pinout is as follows:

- Pin 1: Analog output #1
- Pin 3: Analog ground

The PFI closed loop kit comes with a special serial communications cable containing an extra output cable outlet, as shown below. This cable will allow you to communicate with PFI from your computer while at the same time interfacing with the LM1 (the stereo jack is already attached to the cable).

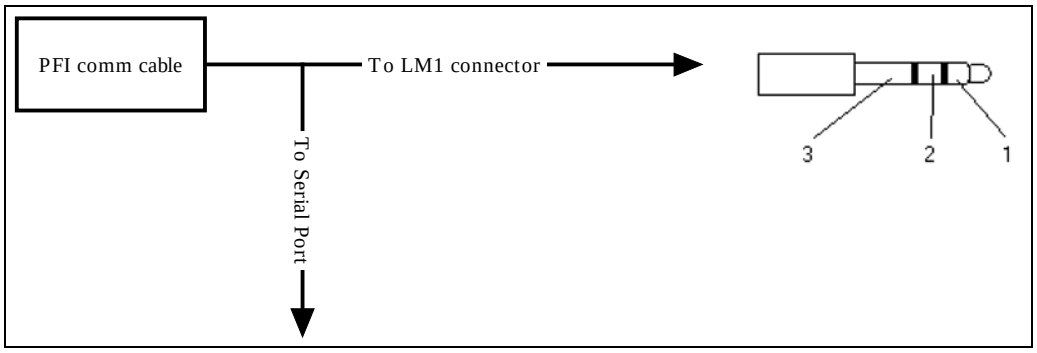


Figure 4. PFI communication cable. Connect s PFI ECU to both the LM1 and the computer.

- Connect the PFI comm. cable to the ECU via the RJ45 connector.
- Connect the PFI comm. cable to the computer via the DB9 connector.
- Connect the PFI comm. cable to the LM1 via the stereo jack.

Electrical connection between PFI and the LM1 is now complete. Make sure the switch that turns on the PFI ECU is the same switch that turns on the LM1. NEVER APPLY POWER TO THE LM1 WITHOUT POWERING THE ECU WITH THE ANALOG OUTPUT CONNECTED.

Establishing communications between PFI, your computer, and the LM1

This section assumes you have already established communications between PFI and your computer via the serial port previously.

- Begin by opening PFIcomm-A (advanced version). Get the map file from the ECU.
- Go to the parameters form, and select the "UEGO" tab to view the parameters.
- The values of K_p, K_i, and K_d don't have to be changed.

- The Uego TC parameter is used to average out the air fuel ratio signal from the LM1. This is necessary because of engine exhaust pulsing. A value of 100 is equal to .1 seconds, which is adequate for most applications.
- The Equivalence Ratio parameter is related to the air fuel ratio, although the correlation is not exact. A value of 100 corresponds to an air fuel ratio of 13.5.
- You don't have to change any parameters, just press "send" to send them to the ECU.

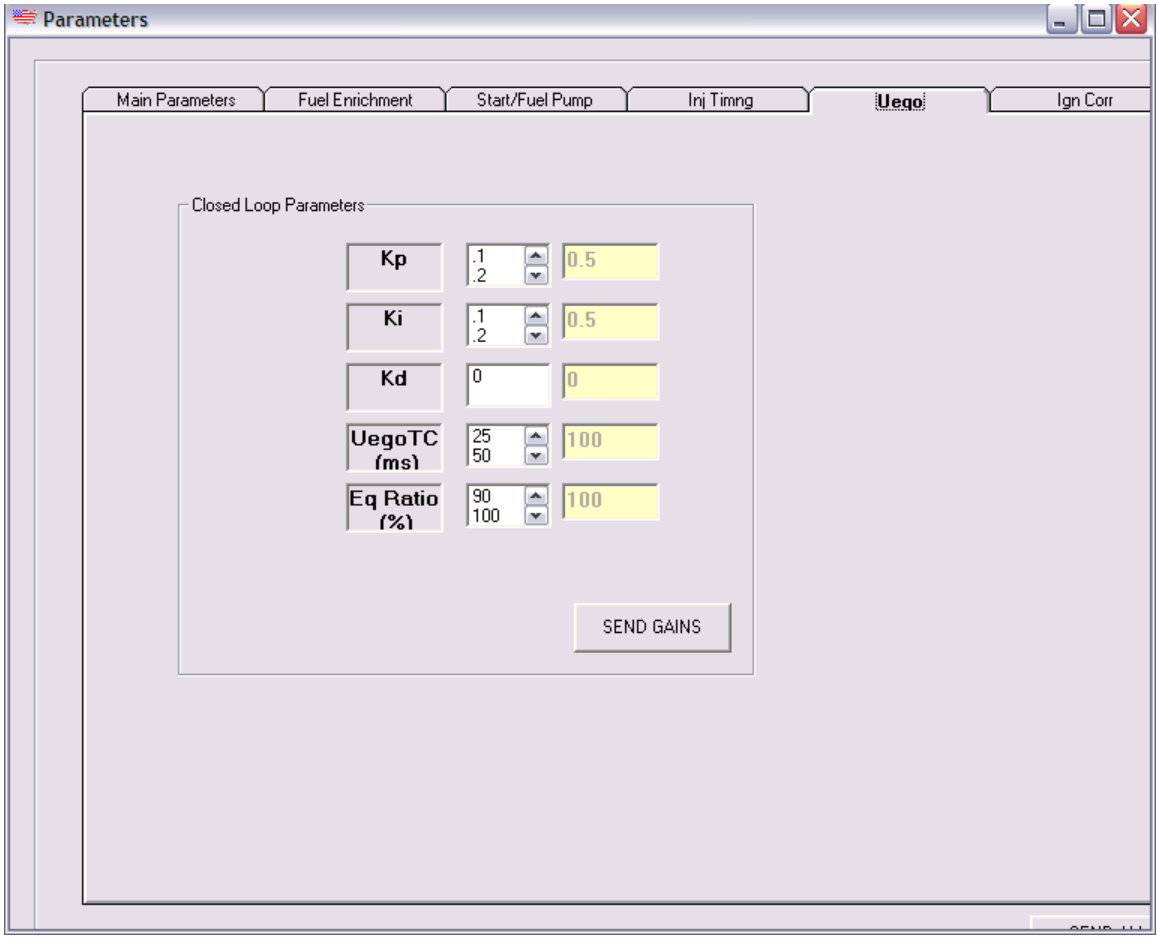
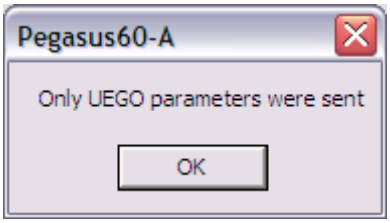


Figure 5. Air fuel ratio parameters page. No changes are needed, just click send button.

- After sending the Uego parameters, you will see the following message: <u>Uego parameters are not sent with other parameters, only by themselves.</u>



- You can now start your engine (you still will be running open loop), and warm it up for 60 seconds.
- Click on the DATA icon to expose the data form. You will use this to verify the air fuel ratio sensor is functioning properly. Select the "getdata" checkbox to begin data acquisition. With the engine running, you should see engine RPM, throttle position, and the Uego values change as you change the throttle position. If you do not see the Uego value changing, there is a problem and you cannot continue. If everything works, close this form.

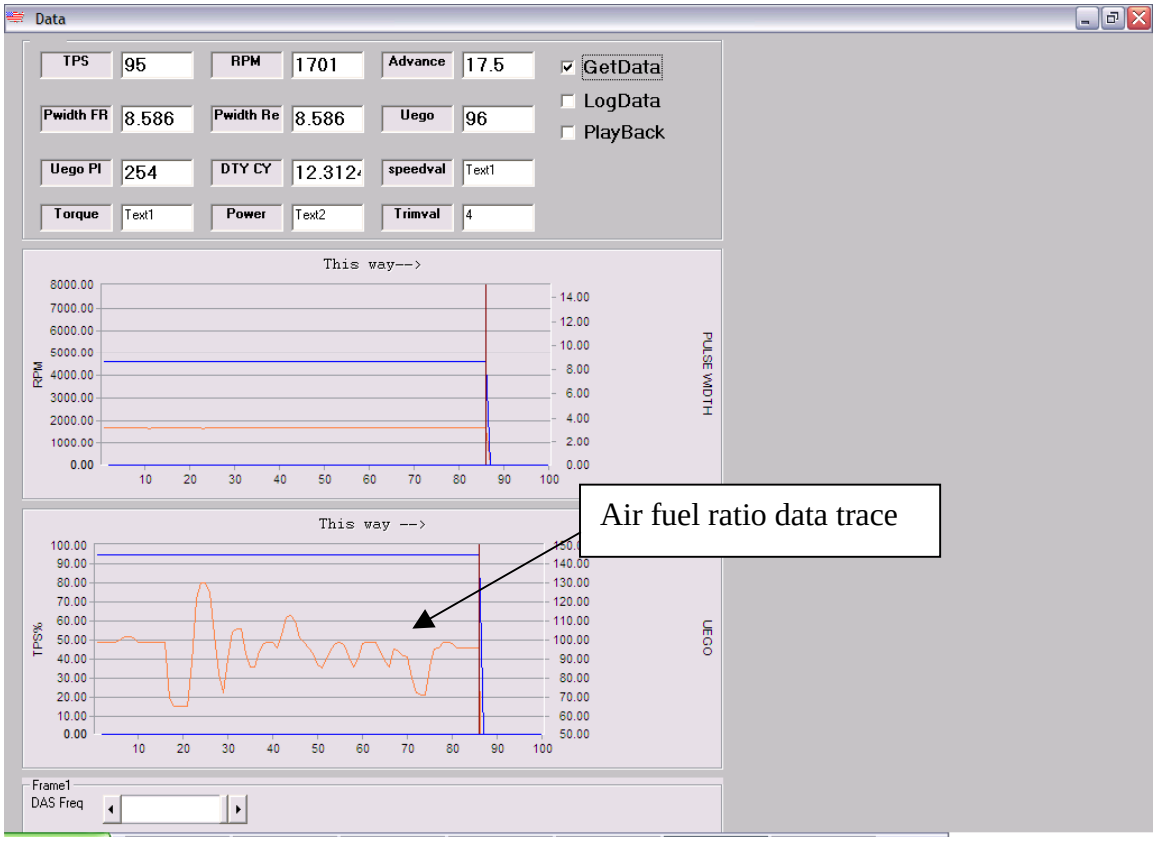


Figure 6

- Now click on the UEGO icon on the menu. This opens up the closed loop mode form. As shown in the form, you will see the following:

a) Actual Equivalence Ratio: This is the equivalence ratio read from the LM1 sensor via PFI.
b) Fuel Map Value: This is the fuel map value needed to maintain the desired equivalence ratio. Won't change until you enter the closed loop mode.
c) TPS: Throttle position sensor value.
d) RPM: Engine speed in revolutions per minute.
e) Pulse Width: Actual fuel pulse width, in milliseconds, as calculated from the fuel map value.

f) Fpulse: Fuel map value that will be written to the fuel map when data is uploaded.
g) Lookup TPS: Throttle position used when data is uploaded.
h) Lookup RPM: RPM used when data is uploaded.
i) Desired Equivalence Ratio: This is the desired equivalence ratio, or the set point. Moving the slider will show the desired value and automatically send it to the ECU. ONLY MOVE THE SLIDER WHEN THE ECU IS ON.

- With the engine running in neutral and the engine RPM steady at about 2000 RPM, click the "get data" check box. You should see the data changing.
- You are now ready to go closed loop! With the desired equivalence ratio set at 100, click the "uego servo on" radio button to begin closed loop operation. You should see all data changing, plus you should see the actual equivalence ratio slowly move towards 100 (it may bounce around, but the average value will be 100, and depends on the time constant).
- Now SLOWLY MOVE THE THROTTLE until the engine RPM goes to 2500. Again, you should see the actual equivalence ratio converge to 100.

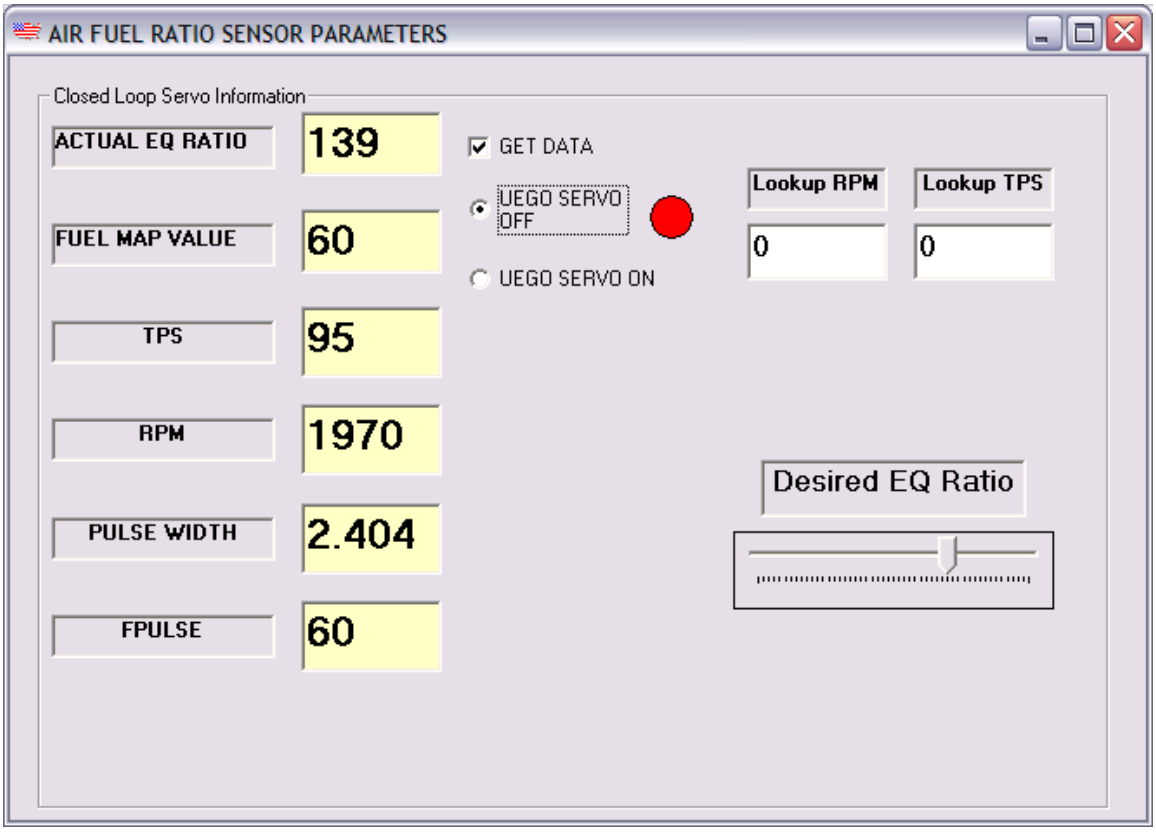


Figure 7. Closed loop mode form. In this picture, the get data mode is checked, but closed loop servo is still off, as indicated by the red stop light.

- When PFI is in the closed loop mode, the system cannot respond to abrupt changes in throttle position. This is because the loop is "slow" and designed to create maps.

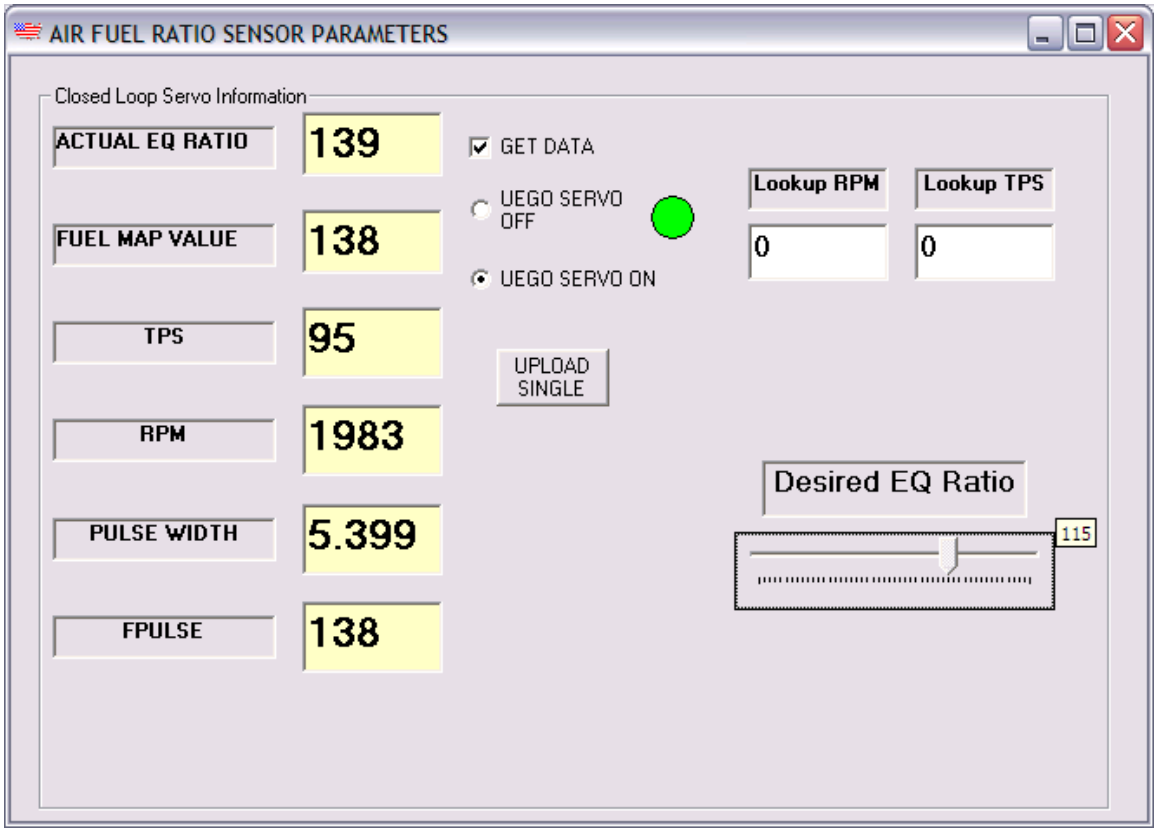


Figure 8. With the "uego servo on" radio button selected, PFI is running closed loop. Note the "upload single" button is now exposed.

- With the “servo on” still active click on the “upload single” button. You will see the lookup RPM and the lookup TPS textboxes lock on a value. What does this do?
- When “upload single” is selected with “servo on” the fuel map data at the current throttle position and RPM is uploaded into the fuel map in your computer. This is how fuel maps are created using closed loop model!

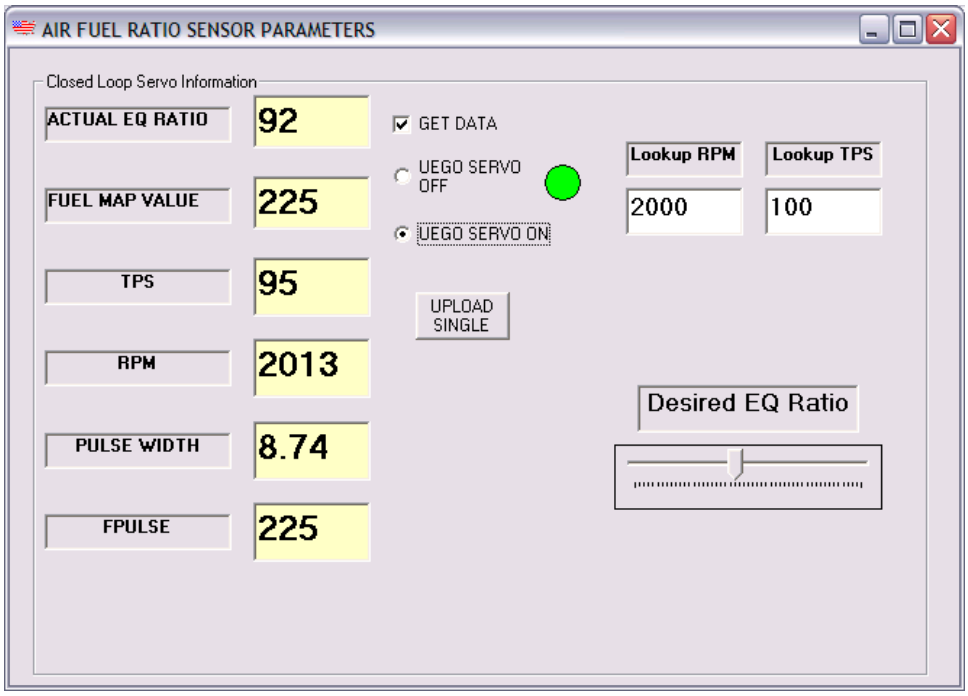


Figure 9. Uego servo on means closed loop mode. Upload single has uploaded the current data into the fuel map.

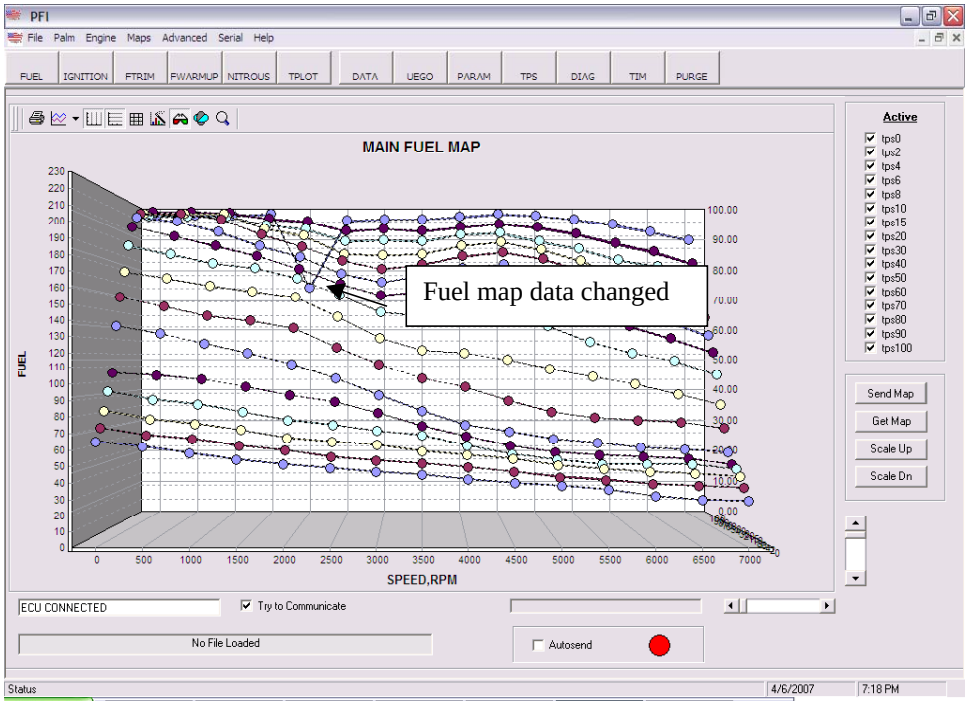


Figure 10. Because the "upload single" button was selected while in the closed loop mode, the current fuel map data was uploaded into the fuel map.

- The changes to the fuel map are not reflected inside the ECU. This means the ECU fuel map has not been altered in any way. If you want to keep your changes, use the FILE-SAVE menu items to save the changes to a file.

How to Create a Fuel Map using Closed Loop Mode

In order to create a fuel map using the closed loop mode, you must have a dynamometer with load control.

The fuel map is nothing more than a lookup table with rows of constant throttle position and columns of constant RPM. For each TPS/RPM point, there is a unique fuel map value the ECU uses to fuel the engine. With 16 RPM columns and 16 TPS rows, you have 256 main jets!!

You don't have to map all points in the map because many points are unreachable under normal driving conditions. For example, you would never operate at 2% throttle at 7000 RPM.

The most important points are

1. Wide open throttle
2. Cruise
3. Idle
4. Low speed driving

When a dyno has load and speed control, it is possible to maintain a constant engine RPM regardless of throttle position (a dyno has a closed loop speed mode). This means that you can hold engine speed fixed and vary throttle position, and this is the basis of our map creation technique.

The throttle has the following row values:
0,2,4,6,8,10,15,20,30,40,50,60,70,80,90,100 %

While the RPM has the following column values:
0,500,1000,1500,2000,2500,3000,3500,4000,4500,5000,5500,6000,6500,7000

You must have adequate cooling on the engine to avoid overheating.

It usually requires two people to perform this operation: one to run the bike and the other to run PFIcomm.

Begin the session by warming up the engine in open loop mode, then enter closed loop mode, and hold the RPM fixed at 1500 in 4^{th} gear. Remember, you must move the throttle slowly.

- Make sure you are in the closed loop mode and the form is visible.
- Make sure you have checked the "get data" checkbox, and the data is changing (including the WEGO).

- Set the desired equivalence ratio to 100 (you can change this value any time you want to any value, but 100 is a good starting place).
- Enter the closed loop mode.
- Set the dyno desired speed value to 2000 RPM, then slowly increase the throttle until you just reach 2000 RPM. Whatever throttle position it takes to JUST reach 2000 RPM is the lowest throttle position you will be able to alter in the map.
- You must now stop at each throttle position column, and hold the throttle fixed. The dyno control will maintain the engine RPM at 2000.
- For example, move the throttle to 10 percent, and hold. The actual equivalence ratio will slowly converge on the correct value. When it does, click the "upload single" button to upload the fuel value into the map. This is your first point.
- Repeat for each throttle point. Make sure to slowly increase the throttle, then hold it when you get to a new TPS row value. Upload data at each point before moving on….it only takes about 1 minute to complete the entire column!!
- This will complete the 2000 RPM column. Return to open loop mode, then throttle down to reduce engine load and let the motor cool. SAVE YOUR DATA TO A FILE AFTER EVERY COLUMN.
- Repeat this procedure for 3000 and 4000 RPM. Don't forget to close the loop each time before beginning a new RPM column.
- To map 1000 RPM, you only have to map up to 20 percent throttle, although you can map the entire column if you want. This is because 20 percent is actually wide open throttle at 1000 RPM on most motorcycles (make sure you don't enter idle mode during the 1000 RPM test).
- Now it is time to set the cruise part of the map. Determine what RPM/throttle positions are used under normal cruise conditions (for example, 2500-3500 RPM and 5-10% throttle is typical)
- Before repeating the mapping at these points, change the equivalence ratio to whatever value you desire during cruise. A value of 85-90 yields excellent gas mileage.
- You can map every possible RPM column, but you don't have to. You can just "fill in" the other columns (for instance, 1500, 2500, 3500, etc) by hand, unless you are trying to create the "perfect' map.
- With the fuel map complete, you can now try some wide open throttle dyno pulls to look at the power and torque numbers. This is always performed in the open loop mode. However, you can look at the data screen to track air fuel ratio and find any rich/lean points.
- Don't' forget about idle. PFI has an idle mode and you can't go closed loop in it, but the air fuel ratio data can help you set the idle.

Conclusions

PFI has a novel way of creating fuel maps closed loop, then using the fuel map to run open loop. You can create a map that will yield great drivability, power, torque, and cruise all at the same time!!

The LM1 is an excellent device and every shop with a dyno should have one.

If you are a bike builder an are using PFI to create a “special” map for all your bikes, you should make a map for every cam/displacement/exhaust combination.