Module 9
Closed Loop Strategies - Theory

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Last Update: April 2000

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9 Closed Loop Strategies – Theory

9.1 Open Loop / Closed Loop General Overview

The PGMFI system on all Hondas operate in two very different modes, the open loop (OL) mode and the closed loop (CL) mode. A good understanding of these two modes is essential to diagnosing emissions and driveability problems.

9.2 Open Loop Mode

In the OL mode the engine control module (ECM) is delivering fuel to the engine with no consideration of the actual air/fuel (A/F) ratio delivered to the combustion chamber. The ECM, using all its inputs (except for the oxygen (O2) sensor) and the internal pre-programmed information, can deliver a mixture that is close to optimum. It is just impossible to design a fuel delivery system that can deliver the perfect A/F ratio, especially over the life of the car, without actually monitoring the exhaust gas for feedback. Even if it were possible to deliver the perfect amount of fuel when a car was new, the pulse width (PW) requirements would eventually change as the car ages.

The fuel is delivered to the engine by the ECM opening the injector pintle for a specific amount of time. This all works fine as long as the pressure differential between the intake manifold and the fuel pressure stays the same, and the injector always flows the same amount of fuel for a given time. In the real world this does not happen. The fuel pressure may vary some as the pressure regulator and fuel filter age. The injectors will tend to develop a varnish around the opening and flow less fuel for a given time, as they age.

A car running slightly lean will typically exhibit drivability problems while a car running slightly rich will not. To avoid a lean condition while in OL, the engineers have to run the fuel mixture slightly rich.

To accurately deliver fuel, based on real world conditions, the ECM needs a way to actually measure the A/F ratio that is being delivered to the engine. This is accomplished by monitoring the exhaust O2 content by an 02 sensor, and using this information to trim the injector PW. This type of operation is called the CL mode.

9.3 Closed Loop Mode

When the ECM is monitoring the A/F ratio that is being delivered to the engine and making corrections to the PW to obtain the optimum mixture, the car is operating in CL. The input that indicates the A/F ratio of the engine is the O2 sensor. The O2 sensor actually indicates the O2 content of the exhaust. The ECM can use this input to determine the A/F ratio. The O2 sensor input is a voltage that varies from about .1v to .9v. A low voltage indicates a lean condition and a high voltage indicates a rich condition.

When a car first starts it will operate in OL until certain conditions are met. The main condition that must be met is the O2 sensor must be at least 600 deg F before it will produce a useable voltage signal. When a certain strategy has been met the car will start using the O2 sensor input to trim the PW, and is then in the CL mode.

9.4 The Importance of Closed Loop Operation

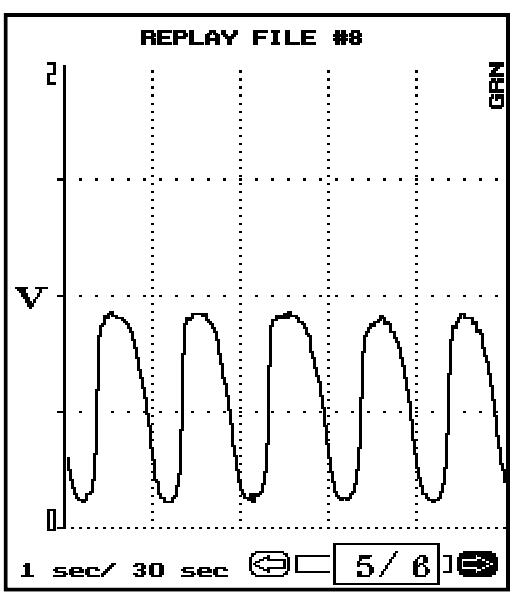
It is important, for many reasons, that a Honda goes into CL operation. Without monitoring the exhaust the ECM may be delivering a mixture that is too lean or too rich. This obviously could cause driveability problems, fuel mileage problems, and emissions problem. In some situations the constant delivery of a rich mixture could also damage the catalytic converter.

9.5 Closed Loop Overview

The O2 sensor is a major player in the CL system. It is the O2 sensor that monitors the O2 content of the exhaust system. All O2 sensors used by Honda are the standard zirconia type. The exception is the lean air fuel (LAF) sensor found on some Civics. The LAF sensor is covered in detail in Chapter 18.

The sensor actually monitors O2 content and produces a variable voltage that indicates a high or low O2 content in the exhaust. When the O2 sensor is producing .5 volt the engine is operating at the optimum mixture of 14.7:1, which is called the stoichiometric ratio. When the car is running richer than 14.7:1, the O2 sensor voltage quickly rises up to a maximum of about 1 volt. If the mixture is leaner than 14.7:1, the voltage quickly drops to a minimum of about .1 volt.

Screen Capture 9-1



When the ECM goes into CL and trims the PW by using the O2 sensor input the system actually starts modulating with the O2 sensor voltage swinging above and below .5 volt. This happens because the PW and the O2 sensor input are always opposite when in CL. If the O2 sensor is indicating rich, the PW is trimmed lean then as the exhaust begins to lean out it will cross the .5-volt line and go too lean. The PW will then be trimmed to rich and the whole scenario repeats itself. This modulation of the O2 sensor voltage can be seen in Screen Capture 9-1, to the left. This is a screen capture from a 1990 Honda Accord in CL operation. A good O2 sensor will produce anywhere from 1-3 cross counts a second.

A pattern like the one shown in Screen Capture 9-1 is the ultimate "proof" that the vehicle is in CL. Later in this module you will also see conditions that could fix the O2 sensor voltage at full rich or full lean and still be in CL.

To analyze the O2 sensor voltage, it is best to use a digital storage oscilloscope (DSO). A digital volt-ohm meter (DVOM) can be used, but has its limitations. A DVOM works OK for quick checks to determine if the voltage is basically modulating or is fixed high / low, but you loose some of the details with this type of tester. A DSO refreshes its screen very fast and will accurately graph the voltage of the O2 sensor. A DVOM refreshes its screen a lot slower and the values being flashed on the DVOM will be O2 sensor voltages at the time of the refresh.

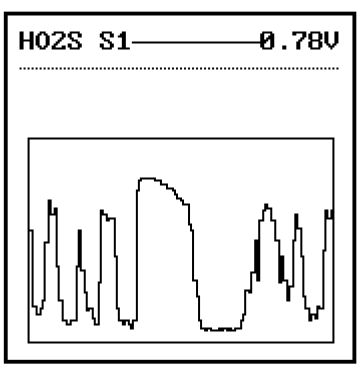
When doing emissions and driveability diagnostics, it is sometimes a good idea to test the O2 sensor and determine if it is working correctly. You test an O2 sensor by temporarily creating a lean and a rich condition in the engine and see how the O2 sensor voltage responds to the two conditions. Let's "walk through" these two tests.

9.6 Testing an O2 Sensor's Response to a Rich Condition

There are a couple of ways to create a temporary rich condition, to do a quick check on a Honda O2 sensor. You can quickly snap the throttle and the drop in vacuum will cause the manifold absolute pressure (MAP) sensor to temporarily richen the mixture. You can also temporarily unplug the vacuum hose on the pressure regulator to create a rich condition.

The best way to create a temporary rich condition is to not use an existing fuel injection component but to use an artificial fuel source. Introducing a shot of propane into the air intake will create an immediate rich mixture that is hard to duplicate. Propane will not damage O2 sensors or an exhaust analyzer's gas bench. The Screen Capture 9-2, on the left, shows the O2 sensor voltage of a Honda after a shot of propane was added to the air intake. Note the almost vertical upward line indicating the O2 sensor's response to the rich mixture. The O2 sensor's voltage should reach approx. .9 volts within 100ms, when subjected to a rich mixture. An O2 sensor that is "slower" than this should be replaced.

Screen Capture 9-2

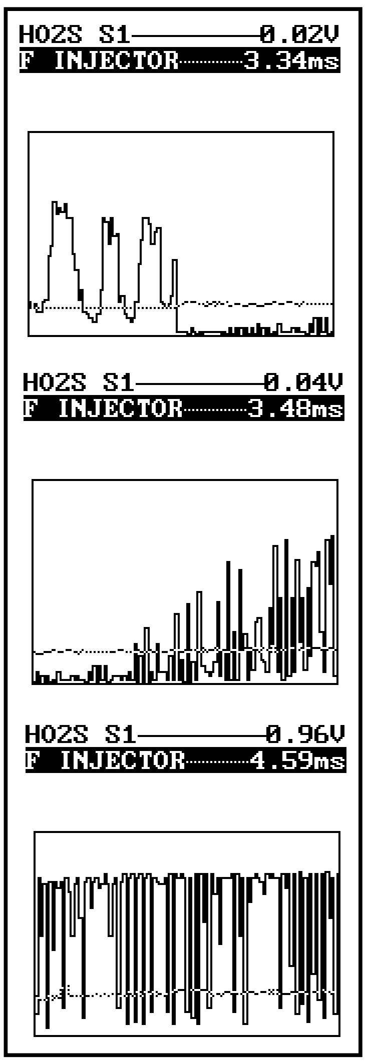


9.7 Testing an O2 Sensor's Response to a Lean Mixture

An O2 sensor should also be tested to see how it responses to a lean condition. Since all Hondas are speed / density type injection systems, you cannot create a significant lean condition by pulling a vacuum line. A speed / density system does not actually measure the airflow, but injects fuel based off engine speed and manifold vacuum. Pulling a vacuum line on a Honda, for the most part, just causes the RPMs to increase.

The quickest and best way to create a temporary lean condition is to unplug an injector. The top frame in Screen Capture 9-3 shows the O2 sensor voltage after an injector was unplugged. Unplugging an injector creates an immediate lean condition, as can be seen by the vertical drop in the O2 sensor voltage. If the O2 sensor voltage does not drop to approx. .1 volt within 100ms, the sensor is slow and should be replaced.

Screen Capture 9-3



We can also check an ECM's ability to make corrections to the fuel, while in CL, with one injector unplugged. You can see this over these three consecutive screen captures. In the top screen capture one injector is unplugged and instantly that cylinder is pumping air into the exhaust. This obviously created an instant and significant lean condition. The O2 sensor responded immediately by dropping to near 0 volts, but as you look at the O2 sensor voltage over the remainder of the screen captures you will see something interesting going on.

When the ECM gets a low voltage reading (lean condition) signal, it attempts to deliver more fuel by driving the PW wider. You can see the ECM "fight back" and eventually delivery enough fuel through the other plugged up injectors to make up for the one unplugged injector. It takes the car a couple of minutes to recover since the PW of the other injectors is only allowed to widen a little at a time. The authority for the PW to go wider and wider is issued by the ECM through a "block learning" approach. By the third screen, the ECM is delivering a "fairly normal" O2 sensor voltage waveform using just three injectors. Notice that the PW has increased to 4.6ms in an attempt to deliver enough fuel.

9.8 Conditions to Go into Closed Loop

Due to at least two "physical limitations" of the zirconia O2 sensor, a vehicle cannot always operate in the CL mode. These limitations actually affect every internal combustion engine built utilizing a zirconia type O2 sensor. Lets first look at two basic conditions that have to occur and then look at some of the schemes used by the ECM to monitor these conditions.

9.8.1 The Oxygen Sensor Must Be Warmed Up

The O2 sensor does not respond to the O2 content until it warms up. An O2 sensor needs to reach approx. 600 deg F before it can be used for feedback. When a car is started cold it will take some period of time for the O2 sensor to heat up. The earlier O2 sensors (single wire units) were unheated and relied on the exhaust gases to heat them up to their operating temperature. The later O2 sensors (4 wire units) have an electric heater to heat the sensor up faster. A heated O2 sensor can reach operating temperature very quickly (some as quick as 30 seconds).

9.8.2 The Engine Must Be Able to Run on 14.7:1 Ratio

A standard zirconia type O2 sensor is incapable of indicating any ratio other than 14.7:1; therefore the ECM cannot use its input until the engine conditions are such that the engine will run on that mixture.

When a car is first started it needs a richer mixture to make sure enough fuel gets vaporized. As the engine warms up and more of the fuel being injected is getting vaporized it can start leaning down toward the 14.7:1 mixture. The car must be warmed up adequately enough to run on a ratio close to 14.7:1 before it can enter CL.

9.9 How Does The ECM Determine These Conditions?

Lets take a look at some of the schemes used by the ECM, to determine when these basic conditions have been met. The strategies vary among different years and models. With the introduction of heated O2 sensors the strategies seemed to have standardized somewhat.

While the actual strategies may be varied and complex, there are three inputs that are typically used on all models to determine if the system should go into CL. They are:

9.9.1 Time

The ECM is equipped with various timers. These timers can be used in many different strategies, and are typically used within the CL strategies. Since the ECM basically has to wait for the O2 sensor to heat up, it can just wait a certain amount of time.

The time element is probably used to a certain degree in all CL strategies, and is obviously used in the heated O2 sensor models. Since the O2 sensor is being heated by ECM controlled heaters, time can easily be used to determine when the O2 sensor is adequately heated up.

A Honda, with heated O2 sensors, will go into closed loop at 60 seconds if the engine temp is above approximately 100 degrees.

9.9.2 Engine Temp

The engine coolant temperature (ECT) sensor input is used by the ECM to determine when the engine has warmed up enough to run on A/F mixtures close to 14.7:1. Honda information puts this point at 85 deg F, but I have observed it to be more like 100 deg F on many models.

9.9.3 O2 Input

On models with unheated O2 sensors the amount of time it takes for the O2 sensor to warm up varies widely. It is dependant on ambient temperature, how far the sensor is located from the combustion chamber, and the RPM / load of the engine.

The ECM uses a clever technique to determine if the O2 sensor is hot enough to report O2 changes in the exhaust. It monitors the O2 sensor's voltage at start up, but does not enter CL mode until there is activity on the input wire.

During normal driving conditions the exhaust's oxygen content is constantly varying. When a load is encountered the A/F ratio goes rich and the oxygen content drops. During deceleration the injectors are cut off and the oxygen content goes up. The O2 sensor's voltage will start swinging rich-lean-rich when it has reached its working temperature due to these changes in the exhaust's oxygen.

You should be aware of this requirement of the un-heated O2 sensors when performing some diagnostic procedures. A fully warmed Honda running in a shop bay will not enter CL mode until you snap the throttle. Snapping the throttle causes the exhaust's O2 content to swing which causes the O2 voltage to swing.

9.10 Closed Loop Diagnostic Procedure

So lets review the CL requirements. On all Hondas, the engine must be warmed up, and depending on the type of O2 sensors used (heated or unheated) either a certain amount of time has transpired or the ECM sees an O2 sensor voltage swing. Some models also take into account engine RPM, engine load, and throttle position. Use the following procedure when trying to enter CL mode.

Follow this routine to be safe on all models:	
Let car warm up to at least 100 deg F	This will satisfy the warm engine requirement and on many models will satisfy the O2 sensor timer requirement. Is the car in CL? If not proceed to next step
Snap the throttle	This will satisfy the requirement of some systems to see a lean / rich / lean O2 sensor voltage swing Is the Car in CL? If not proceed to the next step
Check these inputs: • RPM • MAP sensor • ECT sensor • TP sensor**:**	To totally encompass all strategy requirements, these inputs should be confirmed as good. According to Honda literature any of these inputs can be included in the CL strategy on any given car. Is the Car in CL? If not proceed to the next step
Substitute a known good ECM	If all the conditions above have been met, and the car has failed to enter into CL. It is probably an indication of a faulty ECM. The ECM should be substituted with a known good ECM.

9.11 Conditions to Drop Back Out of Closed Loop

Typically when a Honda goes into CL operation it will stay in CL operation, except for two special occasions. If a model is equipped with unheated O2 sensors it can drop out of CL if the sensor cools down. Heated O2 sensors has virtually eliminated CL dropout due to low O2 sensor temperature.

There are two situations in which a Honda will purposely switch back to OL. Those conditions are:

Deceleration
If the RPM is greater than 1100 and TP Sensor signal showing closed throttle (under .5 volt) the ECM will go into OL and cut the fuel injectors off.

High RPM/ Heavy Loads
During periods of heavy loads, the ECM will enter OL and deliver the fuel based on inputs and internal tables. The MAP is the main input that causes this switch.

Most PGMFI models appear to drop out of CL at idle but apparently the OS sensors cool off to the point that they work much slower. For this reason it is better to observe O2 sensor waveforms at higher RPMs. Always test O2 sensors at 2000 RPM or higher to produce a nice traditional looking O2 sensor waveform.

9.12 How to Determine if The Car is in CL

Many times you will need to determine if a Honda has entered CL operation before you proceed with diagnostics. The process falls into two main categories scan tool diagnostics and non-scan tool diagnostics.

9.12.1 Scan Tool Diagnostics

When diagnosing a Honda with a data link connector (DLC) a scan tool can be used to determine if the vehicle has gone into CL operation.

Beginning with 92 Civics / Preludes and 1994 Accords a 3-pin connector was available for ECM serial data retrieval. This information is available using a Mastertech tool with a Honda / Acura program card with a 3-pin adapter cable. Other scan tools may be able to retrieve data from this DLC, consult your scan tool manual.

Screen Capture 9-4

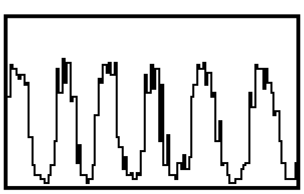
FSS	CLOSED
HO2S S1 HEATER	ON
HO2S S2	0.49V
HO2S S2 HEATER	ON
BATTERY	14.4V
ELD	8.2A
ALTERNATOR	32%
ALT CTRL	14.5V
PNP SWITCH	P-N
BRAKE SWITCH	OFF
SHIFT LOCK	HIGH
A/C SWITCH	OFF

Beginning in 1996 (1995 for V-6 Accord) the DLC was changed to an industry standard OBD-II 16-pin connector. Loop status is an OBD-II defined parameter and therefore is available with any OBD-II compatible generic scan tool (GST). In Screen Capture 9-4 we see the fuel system status (FSS) parameter is "CLOSED". This vehicle is in CL.

9.12.2 Non Scan Tool Diagnostics

Many Hondas do not have a DLC, or your shop may not have a scan tool capable of pulling parameters from the Honda DLC. In this case you have to observe two engine inputs to determine if the Honda is going into CL.

Screen Capture 9-5



The first engine input to check will be O2 sensor input voltage. You can check the voltage with a DVOM or a DSO. With a DVOM, look for the O2 voltage to be sweeping between about .1 and .9 volts. Since the refresh rate of a DVOM is fairly slow it may not give the most accurate indication of what the O2 Voltage is doing, but it will give you an indication if it is modulating.

A DSO will allow you to look at the O2 sensor voltage waveform in a graphical format and the voltage at any time can be observed. When you get a waveform that looks like the one in Screen Capture 9-5 the car is in CL. If you are getting a waveform like this you do not need to test any more inputs.

If the waveform does not look like this (voltage modulating between .1v and .9v) it does not necessarily mean the car is not in CL. Remember the definition of CL operation is that the ECM starts monitoring the O2 sensor input. In some cases the car could be in CL operation (monitoring the O2 input) but still have a fixed rich or fixed lean O2 sensor voltage. A fixed lean voltage will be close to .1v and a fixed rich voltage will be close to .9v.

If you find a fixed rich or lean O2 sensor voltage it is first a good idea to confirm the sensor is good. If the voltage is lean (low) give it a blast of propane and see if it responds by going rich. If the voltage is rich (high) pull an injector connector and see if it responds by going lean. You can always use an exhaust analyzer to confirm that what the O2 is indicating is in fact true.

If the O2 sensor voltage is fixed high or low and the O2 sensor has been tested and known to be good, you will need to check the PW signal to determine if the car is in CL. When the O2 voltage goes rich, the PW is driven lean and when the O2 voltage goes lean, the PW is driven rich. If the O2 sensor and the PW parameters are opposite of each other then the car is in CL, however not in control.

For example if the O2 voltage was fixed at .9 volts (indicating a rich condition) and the injector PW was at 1.5ms (a lean PW) the signals would be opposite and it would indicate that the car is in CL. This may seem confusing now, but we will cover many different reasons for this later in this module.

9.13 Adaptive Learning

Another concept that is related to OL/CL operation is the ability of the ECM to "learn" an engine's PW requirements. The ECM's ability to learn an individual engine's PW characteristics is called adaptive learning by Honda. The deviation of the injector PW from the factory default base PW is stored in the ECM. PW requirements are only learned while the Honda is operating in CL operation. The information is stored as the parameter long term fuel trim (LT FT).

Screen Capture 9-6

```
ENGINE SPD........703RPM
VSS.....................0MPH
ECT SENSOR..........0.84V
IAT SENSOR..........3.08V
MAP SENSOR..........0.94V
CLV........................29%
BARO S..................2.77V
TP SENSOR...........0.49V
HO2S S1..............0.68V
ST FUEL TRIM........1.03
LT FUEL TRIM........0.97
 WAITING FOR TRIGGER
```

LT FT is given as a number with 1 being no fuel trim. When the PW is wider than the factory default the number of 1 is increased by that percentage. When the PW is narrower than the factory default the number of 1 is reduced by that percentage.

For example, a Honda whose PW was 10% wider than the factory default would have a LT FT of 1.1 and a Honda whose PW is 10% narrower than the factory default would be .9. Screen Capture 9-6 is showing a Honda with a LT FT of .97, which means the PW is running 3% leaner than the factory default.

LT FT is stored in the ECM and used to trim fuel even when the engine is operating in OL. The LT FT parameter is lost if power to the ECM is lost. If the LT FT parameter is lost it may take several trips to re-learn the fuel requirements.