An Introduction to Harley-Davidson Electronic Sequential Port Fuel Injection (ESPFI) By Dave Bickford "Ultraboy"

In this segment, we'll attempt to explain the components and operation of the ESPFI systems offered on 2001 and later Softail, 2002 and later Touring, 2004 and later Dyna, and 2002 and later V-Rod motorcycles. Ready? OK, let's start out with some terms.

The Harley-Davidson ESPFI system is known as a **Speed/Density**, **Open Loop**, **Sequential Port Fuel Injection** system, that controls both fuel flow, and spark timing.

Let's further explain those three terms.

Speed/Density – An Electronic Control Module (ECM) monitors manifold air pressure, air temperature, throttle position and engine rpm to manage fuel delivery.

Open Loop – The ECM monitors sensors positioned on the intake side of the engine and does not monitor the end result of internal combustion at the exhaust.

Sequential Port Fuel Injection – Injector nozzles are positioned in the manifold near the intake valve and are precisely timed to deliver fuel to each cylinder.

Still with me? OK, let's dig into the components that make up the system, what they do, where they are, and what they are commonly called.

SYSTEM COMPONENTS

ECM – Electronic Control Module – Sometimes called an ECU, or Electronic Control Unit, this is a small microprocessor-controlled box, or "the brains" of the system that collects all of the input signals from the sensors, and makes decisions based on those sensor inputs, and then sends output signals to deliver fuel and spark to the engine. On Softails, it's located under the seat, on Baggers it's under the side panel.

CKP – Crank Position Sensor – This sensor provides input signals to the ECM that indicate engine rpm, the ECM also uses these inputs to determine what stroke the engine is in so it can deliver the fuel and spark at the desired time. It's located on the front of the motor. It's that thing that's in the way when you change your oil filter.

MAP – Manifold Absolute Pressure – This sensor provides input signals to the ECM and reacts to intake manifold pressure and ambient barometric pressure. Intake manifold pressure reflects changes in engine speed and load. Ambient barometric pressure reflects changes in atmospheric pressure caused by weather conditions or changes in altitude. The ECM uses the inputs from this sensor to help calculate how much air is entering the engine. It's located in the intake manifold on top, just behind the throttle body.

IAT – Intake Air Temperature – This sensor provides input signals to the ECM as it reacts to the temperature of the air entering the engine. For example, hot air contains less oxygen in it than cool air. The ECM uses the inputs from this sensor to help calculate how much oxygen exists in a quantity of air. It's located in the throttle body.

ET – Engine Temperature – This sensor provides input signals to the ECM as it reacts to the engine temperature of the front cylinder head. The ECM uses the signals from this sensor to determine if the engine is at operating temperature, or still warming up. It's that probe in the front Cylinder head, on the left side.

TP – Throttle Position – This sensor provides input signals to the ECM as it reacts to throttle shaft rotation, telling the ECM where the throttle is, as well as if it's opening or closing, and how fast it's opening or closing. It is at the rear end of the throttle blade shaft.

VSS – Vehicle Speed Sensor – This sensor provides input signals to the ECM to indicate if the bike is moving or sitting still. It is used mostly to assist the control of idle speed.

BAS – Bank Angle Sensor – This sensor is located in the turn signal module and it sends a signal to the ECM if the bike leans over more than 45 degrees. If the ECM gets this signal for more than one second it assumes that the bike fell over and it will immediately shut down both fuel and ignition.

Ion Sensing System – This system uses ion-sensing technology to detect detonation or engine misfire in either the front or rear cylinder by monitoring the electrical energy at the spark plug after every timed spark. If an abnormal level of energy is detected across 2 or 3 spark firings the ECM responds by retarding spark timing in that cylinder as needed to eliminate it. Basically, the spark plugs are being used as knock sensors.

Fuel Injectors – The fuel injectors are nothing more than electric valves that open and close to deliver a high-pressure spray of fuel pointed directly at the intake valve. They are controlled by output signals from the ECM to open at a precise moment. If more fuel is needed, the ECM will signal the injector to remain open longer. The period of time is known as the injector "pulse width" and is measured in milliseconds. (1/1000th of a second) They are in the intake manifold near each cylinder head.

Electric Fuel Pump – A 12-volt high-pressure fuel pump, (located in the fuel tank) supplies fuel under pressure to the fuel rail on the intake manifold. The fuel injectors will always have pressurized fuel ready and waiting for the ECM command to open.

Fuel Pressure Regulator – Also located in the fuel tank, the regulator controls fuel pressure between 55 and 62 PSI by returning excess fuel from the fuel pump back to the fuel tank. The return is also located in the tank, hence only one line (supply) coming out of the tank.

IAC – Idle Air Control – An electric valve that's threaded, one turn of the valve is called a "step." It's controlled by output signals from the ECM to open and close as needed to allow enough air into the engine for starting and idle operation. (Throttle closed) The more steps, the greater the amount of air enters the engine through the IAC passages. It's that ugly looking black thing you can see just inside and over the top of the air cleaner.

OK, so now that you know all of the players in the system, let's get it started. We'll go through a typical start-up, warm-up, and run. And all you carburetor guys try to keep up will ya?

As mentioned earlier, the ECM is the brain of the ESPFI system. And, like our own brain, it has memories and it makes decisions. "Last time I drank 22 beers, I had…" well, you get the idea. The ECM memories are located in "Look-up tables." There are several different Look-up tables, which allow the ECM to make decisions on fuel delivery and spark timing. For most of us, these are referred to as "Maps." The Maps that are more or less in continuous use by the ECM are the **VE** (Volumetric Efficiency) **AFR** (Air/Fuel Ratio) and the **Spark Advance** table. But there are "others."

These "other" tables are for temporary conditions, like when the motor is being cranked by the starter, (**Cranking Fuel Table**) or when the motor is colder than operating temperature, (**Warm-Up Enrichment table**) or when the throttle is closed and the motor is coming up to temperature (**Idle RPM Table**) and another one for throttle closed, the (**Intake Air Table**) to allow enough air into a cold motor (by the IAC) to allow it to idle.

OK, so the motor is cold, and you turn the ignition on, flip the start/run switch to run. The first thing you hear is the in-tank fuel pump pressurizing the fuel rail. If you listen real close, you'll hear the IAC (remember the IAC?) "stepping" into position. Even if you are real fast, the ECU already knows everything it needs to know from all of the sensors. You hit the starter button, the motor begins to crank over. The ECU sees the low RPM, and quickly goes to the **Cranking fuel Table**, increasing the Injector pulse width, allowing more fuel to get the motor started. At the same time, the ECU tells the IAC to open, allowing enough air into the motor for start and idle. (Throttle body blade is closed)

The motor starts to run, and the ECU sees the higher RPM from the CKP, and switches over to the **Warm-Up Enrichment Table**. This table eventually decays to nothing, as the motor comes up to full operating temperature.

So now, your motor is running, and you blissfully head on down the road, never having to bother about sitting there playing with the choke like the carb guys, or playing with it for a mile or so down the road until the motor will idle on it's own. Great stuff!

Now that the motor is warmed up, the ECU is going to use the **VE, AFR,** and **Spark Advance Tables**.

What is the **VE** (Volumetric Efficiency) table? This is actually a percentage of how much air is flowing through a running motor, versus its theoretical capacity. OK, so now we have got to use some theory here. Let's take an 88 cubic inch motor running at 5600 RPM at WOT; this motor would have a theoretical airflow capacity, or VE of 100%, when it is flowing 143 CFM. If the same motor flowed 107 CFM at 5600 RPM and WOT, it would have a VE of about 75%. Conversely, it the motor was equipped with some high performance airflow mods, like pipes, air cleaner, cams, and the like, and flowed more than 143 CFM at that 5600 RPM and WOT; it would have a VE of MORE than 100%. That's why you have to do something to the ECU Maps when you put on pipes, air cleaner, etc. as the stock ECU doesn't know about this extra stuff, and you'll be running too lean.

There are VE tables for both front and rear cylinders, and Spark Advance tables for both cylinders.

So, when you crack that throttle open, the VE tables tell the ECM how much air is flowing into the motor, while the IAT and MAP sensors tell the ECM roughly what the air density is, so that the **AFR** table can tell the ECM what **Air Fuel Ratio** should be required at that instant. (Hang in there!) Working along with everybody else, the Front and Rear Spark Advance Tables, are also telling the ECM the advance required for that specific load. Happens real fast too.

Let's do that again, just to clarify it all one more time. With the motor running, a typical sequence of events follows:

1. The ECM is constantly monitoring CKP, TP, IAT and the MAP, which tell it RPM, Throttle Position, Intake Air Temperature, and Manifold absolute pressure.
2. The ECM will then look at the VE tables using throttle position and RPM, and it now knows the volume of air that should be going through the motor, at this exact moment.
3. At the same time #2 above is happening, the ECM takes a glance at IAT and MAP and calculates the air density. Remember, that is the way the ECM figures out how much oxygen is in the air entering the motor.
4. Now, armed with all the above wonderful knowledge, the ECU can go directly to the AFR table, knowing exactly how much oxygen is coming into each cylinder, and sends the correct pulse width to the injectors to achieve the AFR it has been programmed (mapped) to achieve at that particular moment, based on load and RPM.
5. Don't forget the Spark Advance Tables, as the ECU looks at these at the same time, and, for the same conditions, sends the coil the appropriate timing signal for front and rear cylinders.

Clear as mud, right?

Only one more thing to mention, and we're done. (For now)

The last thing on the agenda to talk about is the "Heat Management System" incorporated in the Harley ESPFI systems.

This system is used to control excessive heat, and operates in three "Phases."

In Phase 1, if the ECM sees engine temperature (cylinder head temp.) above 300 degrees F., while the bike is either moving, or standing still, it will reduce idle speed. Theory being that a lower idle has less sparks, producing less heat.

In Phase 2, if the ECM sees an engine temperature that is still climbing from Phase 1, it will richen up the AFR. Richer mixture has a cooling affect.

In Phase 3, if the ECM sees that the temperature is still going up, and the bike is sitting still, it will go ahead and skip-pulse the injectors, not delivering fuel on each intake stroke. Again limiting combustion and producing less heat. Phase 3 is only active when the bike is sitting still.

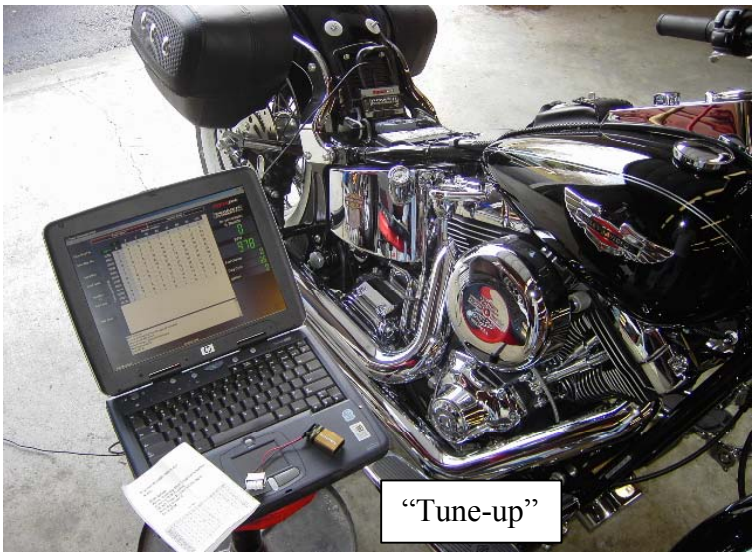
These 3 Phases pass from one to another without pause, and you may not even feel or notice it.

That's all for now, I hope that no one got lost or bogged down, and you are coming away with a bit better understanding of how the Harley-Davidson Delphi ESPFI system works.

And remember, it won't be long, and carburetors will be gone from our Harley's forever!

Next episode, we'll get into tuning your ESPFI system, using the Power Commander PC-III-usb unit.

Later,
Ultra



"Tune-up"