REFERENCE MATERIAL:

PROGRAM CODE - undefined

- Revised 2001 -

REFERENCE MATERIALS

DDFI Part 1

Indealership Technical Training Program

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Dynamic Digital Fuel Injection

The Basics of Buell's Electronic Fuel Injection System

Buell's Dynamic Digital Fuel Injection (DDFI) enhances engine performance using advanced computer technology. A microprocessor inside the Electronic Control Module (ECM) makes hundreds of changes per second. Each adjustment allows precise fuel and ignition mapping to the Buell powerplant for the current environmental conditions. The speed that the system can change the fuel & spark delivery to the Buell powerplant is incredible. The Buell DDFI can make hundreds of changes per second. Benefits of this system include an improvement in midrange power, easy cold starts and onboard diagnostic capability. This system also compensates for altitude changes.

The DDFI system uses several sensors to provide feedback about external and internal operating conditions to the electronic "brain" of the system, or ECM.

These conditions include:

- Rider input (throttle position)
- Engine load
- External environmental conditions (outside air temperature)
- Internal engine environment (cylinder head temperature)

Each of these conditions must be known in addition to the information already "memorized" by the ECM. This is necessary for the ECM to perform the calculations necessary to deliver the optimum spark advance and fuel amount for each engine cycle for maximum performance as well as to meet government regulations for emissions.

The method of how the required amount of fuel for any combustion cycle is calculated depends on the type of the EFI system. The three types of EFI systems are open loop, closed loop and combination open/closed loop systems.

The first type of EFI system operates as an OPEN LOOP system. The ECM calculates and delivers spark and fuel based on a set of predetermined spark and fuel "maps." These "maps" provide the base information necessary to run the engine with only minor adjustments for external/internal environmental conditions. This method is accurate to the degree that the "maps" are accurate. The Harley-Davidson systems are open loop.

The second type of EFI system operates as a CLOSED LOOP system. This system not only uses spark and fuel "maps" but also feedback from an exhaust gas oxygen (O2) sensor to continually adjust the amount of fuel delivered. This offers the advantage of "learning" the behavior of the engine over time as well as responding to a wider variety of conditions encountered while riding than that of an OPEN LOOP system.

The Buell DDFI operates both as an OPEN and CLOSED LOOP system. This is necessary to adjust for all possible operating conditions. Buell's selection of high lift cams (which enhance engine performance) make it necessary for an open loop system at idle and wide-open throttle. Furthermore, when operating in open loop during cold start and idle, the system will utilize programmed fuel and spark maps in the ECM for ease of cold starting and to provide a stable idle. When the bike is at a steady cruising speed and operated under a light load, the DDFI system switches to closed loop operation. The system then continuously "tunes" the performance of the engine to compensate for changing conditions and provide maximum performance by using the O2 sensors input.

General operating parameters for open and closed loop running.

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OPEN LOOP	CLOSED LOOP
Idle and starting slow speeds under 20mph (1500 rpm) High speeds above 60mph (4,000 rpm) accelerating from low speed	Cruising between 40 - 60 mph at operating temp. (1500 to 3500 rpm)

accelerating from high speed decelerating	

How does the Buell DDFI system work?

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The ECM uses six different sensors to monitor rider demands and changing engine conditions to determine the correct fuel and spark requirements. These sensors are:

Throttle Position (TP) Sensor
Cam Position (CMP) Sensor
Intake Air Temperature (IAT) Sensor
Engine Temperature (ET) Sensor
Oxygen (O2) Sensor
Bank Angle Sensor (BAS)

The ECM needs the information from the TP and CMP sensors to calculate how much air is entering the engine. The TP sensor is attached to the throttle shaft on the left side of the throttle body. The CMP sensor is located in the gearcase cover on the right side of the engine. The TP monitors the amount of air entering the engine, by how far the throttle is open, whether it is opening or closing and how fast it is opening or closing.

The ET Sensor provides the ECM the current engine temperature. Proper fuel and spark delivery are dependent on the temperature of the engine. The ECM will provide a richer fuel mixture on start up and a higher degree of spark advance. As the vehicle warms up to operating temperature the fuel mixture will lean and spark advance will decrease.

The IAT sensor, mounted in the Helmholz Volume Power System (HVPS) air box, measures the temperature of the air entering the engine, when combined with the TP and CMP data the ECM can determine the density of the air entering the engine. The ECM also monitors the CMP sensor to determine the exact position of both cylinders in the combustion cycle and the engine speed.

The fifth sensor is the Oxygen Sensor (02). It is desirable to operate the engine at or near stoichiometric, or approximately 14.6 parts air to one part fuel. The inclusion of the 02 sensor allows the ECM to ensure a proper air/fuel mixture is delivered to the engine by monitoring the final combustion efficiency in the exhaust system. This ensures optimum engine performance at any altitude.

The sixth input is the Bank Angle Sensor (BAS). This sensor provides the input to the ECM that the vehicle is not leaning greater than a 55 degree lean angle. If the vehicle exceeds a 55 degree lean angle the BAS will interrupt the operation of the ignition system and the fuel supply.

How does the O2 sensor measure the fuel mixture?

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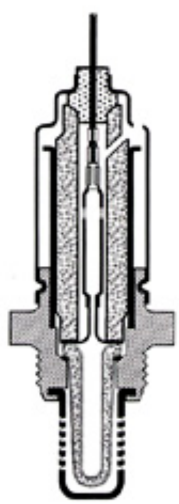
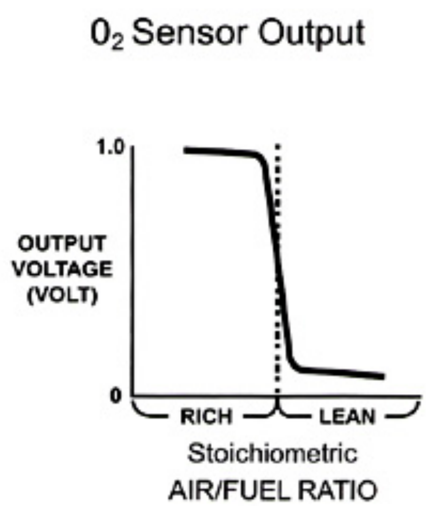
An Oxygen sensor is a chemical generator. It is constantly making a comparison between the Oxygen inside the exhaust system and air outside the engine. A Zirconium stabilized yttrium oxide ceramic shell is coated with a layer of platinum. When the nose is heated the platinum will begin to react with the exhaust gasses and a voltage potential will form between the inner and outer layers. The sensor does not begin to generate it's full output until it reaches about 600 degrees F. Prior to this time the sensor is not conductive. This voltage output of the sensor is usually between 0 and 1.1 volts. A rich mixture leave very little free oxygen and the reaction will send out a voltage greater than 0.45 volts. If the engine is running lean, all fuel is burned, and the extra oxygen leaves the cylinder and flows into the exhaust. In this case, the sensor voltage goes lower than 0.45 volts. Usually the output range seen seen is 0.2 to 0.7 volts. The mid point is about 0.45 volts. This is neither rich nor lean. A fully warm O2 sensor will not spend any time at 0.45 volts. The O2 sensor is constantly in a state of transition between high and low voltage. Manufacturers call this crossing of the 0.45 volt mark O2 cross counts. The higher the number of O2 cross counts, the better the sensor and other parts of the computer control system are working. It is important to remember that the O2 sensor is comparing the amount of oxygen inside and outside the engine. If the outside of the sensor should become blocked, or coated with oil, this comparison is not possible. Also if the exhaust side of the sensor has been contaminated by using leaded fuels or gasket sealers which are not specifically identified as being approved for use with oxygen sensors the sensor can be permanently damaged.





ADAPTIVE FUEL VALUE

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The Buell DDFI system has the ability to “learn” the engine fuel mixture needs. When the motorcycle is running in the closed loop mode and operated in a specific engine speed and load range, the system will compare the feedback from the O2 sensor to the base programming stored in the ECM. If a difference in these values is detected, the ECM will recalibrate the system program to compensate. This correction is termed the adaptive fuel value or AFV.

This compensation value allows the system to adjust to different altitudes, air densities, and to some degree engine variations and wear. The normal AFV ranges based on altitude are between 85 and 115. The higher values are found at lower altitudes and the lower values at higher altitudes.

The AFV correction is only applied to the fuel mixture during OPEN loop operation. During closed loop operation the O2 sensor signal is the primary compensation method.

The AFV will be learned when the bike is operated at engine speeds between 2500 and 3500 rpm at road speeds in the 40 to 60 mph range under a steady light load (no down grades or steep upgrades, decelerating or accelerating) for 2 to 3 minutes.

The AFV can also be reset to 100 by using the scanalizer at any time. The AFV value can be a valuable diagnostic tool. Compare the AFV values of bikes in your area which are running fine during routine services. When you are working on a bike which may have a DDFI problem, compare the values.

If the AFV is higher than normal, the system is trying to correct for a situation which is causing the mixture to be too lean. Look for intake manifold or injector O-ring air leaks, incorrect ignition timing and TPS zero setting, low fuel pressure or a fuel line restriction as well as a sensor malfunction.

If the AFV is lower than normal, the system is trying to correct for a situation which is causing the mixture to be too rich. Look for incorrect ignition timing and TPS zero setting, high fuel pressure or a leaking injector as well as a sensor malfunction.

The O2 sensor can also cause the AFV to be set incorrectly. Internal shorts in the lead, poor electrical contact with the exhaust system or contamination can all affect sensor performance.

O2 SENSORS CAN BE CONTAMINATED BY SILICONE SEALERS!!! ONLY USE SEALERS WHICH ARE LABELED O2 SENSOR SAFE IN ANY LOCATION WERE THE VAPORS CAN COME IN CONTACT WITH THE SENSOR. (top end of engine)

IGNITION SYSTEM TIMING ADJUSTMENT

- Cam position sensor adjustment (section 1.23 in 99/00 X1 service manual)

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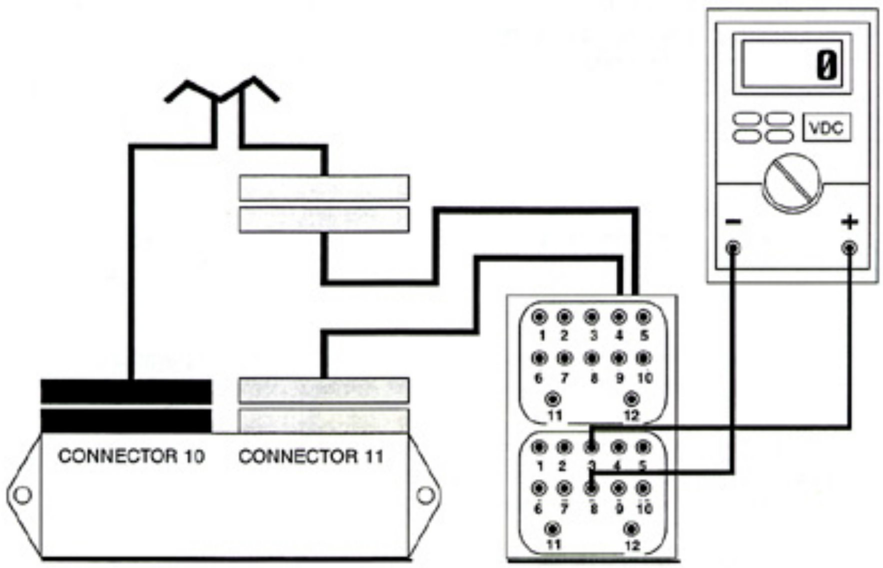

The adjustment of the CMP sensor will effect fuel ratios and ignition timing over the full operating range.

With the breakout box installed at the gray connector at the module, measure the voltage at pins 3 and 8 in the gray section of the breakout box. When the front cylinder timing mark is centered in the inspection hole, loosen the plate and turn it counterclockwise until the voltage drops to 0 vdc. Now slowly turn the plate clockwise until the voltage shifts to 5 vdc and tighten the plate. Keep the two plate attachment screws snug when performing this adjustment to reduce play. Take your time, recheck, accuracy is important.

THROTTLE POSITION SENSOR ADJUSTMENT - TPS ZERO (not required when resetting idle speeds after initial calibration)

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FROM PAGE 4 OF BULLETIN B-017- section 4.33C in the 99/00 X1 service manual

Verify Throttle Position Zero Setting

1. Back out idle screw until it no longer touches the throttle plate stop. Back out idle screw one to two additional turns. Visually confirm that the throttle plates are fully closed.
2. Connect scanalyzer to data link connector [91] with cable (Part No. HD-42921).
3. Turn the ignition/light key switch to IGNITION. Turn the handlebar mounted Engine Stop Switch to the RUN position(but do not start the engine).
   NOTE: Observe that step 4 uses the standard diagnostic application cartridge and NOT the recalibration cartridge used previously.
4. Insert diagnostic application cartridge (Part No. B-41325-99) into scanalyzer. During the next few seconds, the Scanalyzer sequences through a series of screens that reflect a power-on self test, the system copyright, and then an attempt at communications

with the ECM. Once communications is established, the Diagnostic Menu appears on the Scanalyzer data display.

5. Press number “3” key (Data Monitor) on scanalyzer and scroll down to last screen which has 3 Throttle Position (TP) readings.
   a. Open throttle to wide open throttle (95-100% open on first scanalyzer TP reading) and release throttle, allowing it to snap shut.
   b. Record Throttle Position Sensor voltage reading from scanalyzer.
   c. Repeat steps a and b a total of 3 to 5 times, recording voltage reading after each.
   • If the readings differ by less than 0.02V, go to step g.
   • If the readings differ by 0.02V or more, go to Step d.
   d. Open the throttle then gently force the throttle closed.
   e. Record Throttle Position Sensor Voltage reading from scanalyzer.
   f. Repeat steps d and e a total of 3 to 5 times, recording the voltage reading after each.
   • If the readings differ by less than 0.02V, go to step g
   • If the readings differ by 0.02V or more, replace the throttle body and repeat procedure from Step 1.
   g. Select mode #7 on scanalyzer menu. Select #1 re-zero TPS. A “calibration successful” message will appear.
   h. Press the mode key to return to Options Data Screen. Scroll to TP degrees. Turn idle adjustment cable clockwise until TP degree reading reaches 5.8.
6. Press the mode key and press #3 to return to the diagnostic menu. Disconnect the Scanalyzer and turn the Ignition/Light Key Switch to OFF or LOCK. Turn the handlebar mounted Engine Stop Switch to the OFF position.

Reset Warm Idle Speed

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New Rev limit function: Incorporates a skip spark feature. Resulting in extreme "hit", "miss" engine restriction.

The ECM will now utilize the cylinder head temp as part of the equation to alter spark and fuel delivery.

The MY2000 1/2 DDFI ECM protects the engine from extended operation at or near its limits for engine speed and cylinder head temperature by reducing available power and flashing the engine light on the instruments.

- This reduction in power occurs in successive stages: a mild (soft) spark/no-spark pattern, and an aggressive (hard) spark/no-spark pattern.
  "Soft" limit (speed or temperature): The ECM initiates a mild spark/no-spark cut. The ECM will also flash the Check Engine Lamp (CEL) to alert the rider when the engine temperature has exceeded a "soft" limit.
  "Hard" limit (speed or temperature): The ECM initiates the aggressive spark/no-spark pattern.
- If the rider should operate the engine near the "soft" limit the ECM will begin a

countdown. If the rider persists in operating the engine near this "soft" limit and the countdown expires, the ECM will begin to operate as if the "soft" and, after another countdown, "hard" limits had been exceeded.

Previous models offered only over rev protection by restricting fuel and backed spark advance down to '0' advance, resulting in lower performance. The new ECM does not retro fit to earlier models (pre-2000 MY).

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Glossary of Terms:

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Bank Angle Sensor (BAS)

The Bank Angle Sensor senses if the motorcycle exceeds a 55-degree lean angle. The ECM uses this signal to shut off both spark and fuel delivery.

Cam Position Sensor (CMP)

The Cam Position Sensor consists of a Hall-effect device, magnet and plate. The plate is mounted over a rotating cup ("rotor cup") attached to the end of the camshaft. As the rotor cup turns inside the gearcase, six asymmetric "teeth" on the rotor cup sequentially break the magnetic field between the magnet and the Hall-effect device. The edges of these teeth are cut to correspond to specific positions of the camshaft during the engine cycle such as TDC for the front cylinder. The output of the CMP sensor is used by the ECM to determine engine position and calculate engine speed. This method of measuring camshaft position provides accurate information on engine position down to zero engine speed.

Electronic Control Module (ECM)

The ECM receives signals from the ET, IAT, CMP, 02, TPS and BAS. The ECM contains all the information needed to provide the proper fuel and spark mapping sequentially and individually to the front and rear cylinders of the engine at the proper time.

Engine Temperature Sensor (ET)

The Engine Temperature Sensor is located on the rear cylinder head near the spark plug. This sensor sends a signal to the ECM proportional to the current engine temperature.

Fuel Pressure Regulator Valve

Located on the fuel pump inside the fuel tank. The fuel pressure regulator maintains a constant 49-PSI fuel supply to the fuel injectors. The unused fuel is relieved inside the fuel tank.

Helmholz Volume Power System (HVPS)

Helmholz was a scientist who developed theories on air and sound motions. The Buell air box uses Helmholz principles combining his theories with the tuning of the intake duct and also effectively controlling the acoustics inside the air box. The Helmholz Volume Power System allows a small chamber volume to simulate a large area in terms of air movement, enhancing the engine performance, while reducing unwanted frequencies.

Induction Module

The Induction Module is located between the two cylinder heads. The Induction Module consists of a (43mm) single bore throttle body and intake manifold. The throttle body contains the TP sensor, manual idle speed adjuster, throttle plate and linkage for the throttle cables. The intake manifold contains the fuel rail and two fuel injectors. There is one fuel rail connecting the feed line to the injectors. Excess fuel is relieved by the Fuel Pressure Regulator inside the fuel tank.

Intake Air Temperature Sensor (IAT)

Located inside the Helmholz Air Box, this sensor sends a signal to the ECM proportional to the temperature of the air entering the engine.

Manual Idle Speed Adjuster

The idle speed is adjusted manually by turning the screw located on the right side of the throttle body.

Pulse Width

Pulse width is the amount of time a fuel injector is held open by the ECM. It is usually measured in milliseconds.

Relative Air Density

Air density effects how much oxygen is present within it. Air density is dependent on altitude (atmospheric pressure), temperature and relative humidity. Cool, dry air at lower attitudes contains more oxygen than warm, moist air at high attitudes. Horsepower is directly related to air density.

Returnless Fuel System

The Buell DDFI System is a returnless system, i.e.; there is no fuel return line from the fuel rail to the fuel cell. If fuel pressure should ever exceed 49 PSI, the excess fuel pressure is relieved inside the fuel tank by the Fuel Pressure Regulator Valve.

Single Fire Coil

The ECM controls the independent, primary windings of the spark coil. The ECM is thus able to provide sequential and independent firing of the spark plugs.

Stoichiometry

A branch of science that deals with the application of the laws of definite proportions and the conservation of matter and energy to chemical activity. Stoichiometric proportions are used with the 02 sensor.

Throttle Position Sensor (TP)

The TP sensor is located on the left side of the throttle body and is attached to the end of the throttle shaft. The TP sensor sends a signal to the ECM proportional to the current throttle position. The ECM is then able to determine how far the throttle is open, whether it is opening or closing and how fast it is opening or closing.

Oxygen (O2) Sensor

The O2 sensor, located near the rear cylinder head in the exhaust header, sends a signal to the ECM proportional to the amount of fuel remaining after combustion. The ECM then uses this signal as feedback in order to modify the amount of fuel delivered per engine cycle. Thus, the DDFI system maintains the optimum air/fuel mixture for complete combustion. The 02 sensor allows the system to compensate for changes in barometric pressure or altitude.

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