Chapter 4

Sensors—Determining Engine Operating Conditions

Contents

TABLES

1. INTRODUCTION

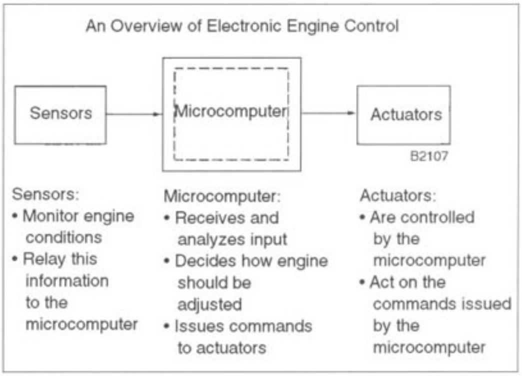
You've seen the fundamentals, enough to understand that engine control systems must manage several basic factors to satisfy many different operating conditions:

- Injected fuel
- Spark timing
- Idle rpm, and closed-throttle air
- Emissions
- Intake manifold runners (some)

To control a modern, fuel-injected engine, you need three activities, and so the parts of Ford engine control systems are divided into three categories:

- Input signals—sensors that signal information about engine operating conditions
- Computation—a control module or computer that calculates output signals based on the input
- Actuation—action or movement based on output signals from the computer. Another way to think of this is Control, based on output from the computer

Sensors send input signals, generally about "how much" of something is happening—how hot is the coolant—or "when"—when did a crankshaft reach a TDC reference point. A form of sensor is a switch that signals "yes," or "no."



Sensors:
- Monitor engine conditions
- Relay this information to the microcomputer

Microcomputer:
- Receives and analyzes input
- Decides how engine should be adjusted
- Issues commands to actuators

Actuators:
- Are controlled by the microcomputer
- Act on the commands issued by the microcomputer

Fig. 1-1. Electronic Engine Control depends on input signals from many sensors to control module. Control module acts on these input signals and sends output signals to actuators.

You will find different combinations of sensors and actuators in different engines, depending on the model and the year. You've already seen how engines use 4, 6, or 8 injectors, one for each cylinder, injecting at the intake port.

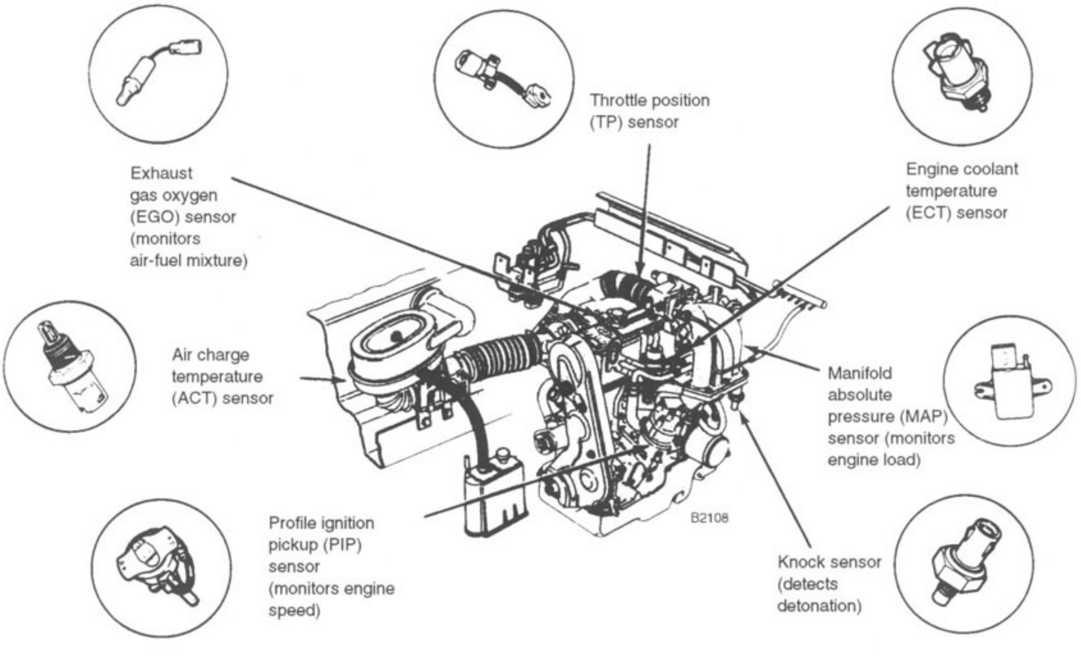


Fig. 1-2. Sensors supply input signals based on engine conditions.

Some sensors send input signals that are important to the control of many outputs or actuators in several engine subsystems. For example, the Engine Coolant Temperature (ECT) sensor is important to the control of fuel, spark timing, idle rpm, and emission control. It is also important during several operating conditions, including cranking, warm-up, cruise, idle, and acceleration.

In this chapter, I'll show you the sensors. In Chapter 5, I'll discuss control modules. In Chapter 6, you'll see the result of all this—the actuators used for engine control. In Chapter 7, I'll discuss Fuel Delivery Systems. Then, when you read Chapter 8, you'll see how these parts work together as a system to satisfy the operating conditions described in Chapter 2.

I'll concentrate on EEC systems, applicable to most Ford cars and all trucks with electronic engine control/fuel injection. I'll describe the differences you'll find in Ford/Mercury cars operating with Mazda Electronic Control Systems (MECS).

The MECS are designed to do the same things for the Mazda engines as the EEC systems do for the Ford engines. MECS-I are quite similar to Bosch L-Jetronic, or L-Motronic, controlling fuel injection (air-fuel ratio), spark timing, throttle air bypass, and emissions, as well as turbo boost.

You may see another engine control system in the 1993 Mercury Villager, a Ford/Nissan joint minivan project (also sold as the Nissan Quest). Because of the small number of vehicles involved, I won't spend much time on Nissan engine control in the Villager, but I'll summarize the differences in Sensors at the end of this chapter and Actuators at the end of Chapter 6.

When you finish this chapter, you'll know what each sensor looks like and how it operates. You'll understand the different kinds of input signals that different sensors send to the computer, and their importance under different operating conditions. First, I'll talk about generic types of sensors and switches. Then I'll discuss sensors in detail according to their purpose.

1.1 Terminology

Beginning in 1993, some of the names for the sensors were changed to comply with the SAE standard J1930 to provide common terms for the same general part throughout the automotive industry. For more information on terminology changes, see Chapter 1. This chapter uses the terminology applicable for the years 1988–1992. For reference, **Table a** lists those terms and their equivalents that changed in 1993.

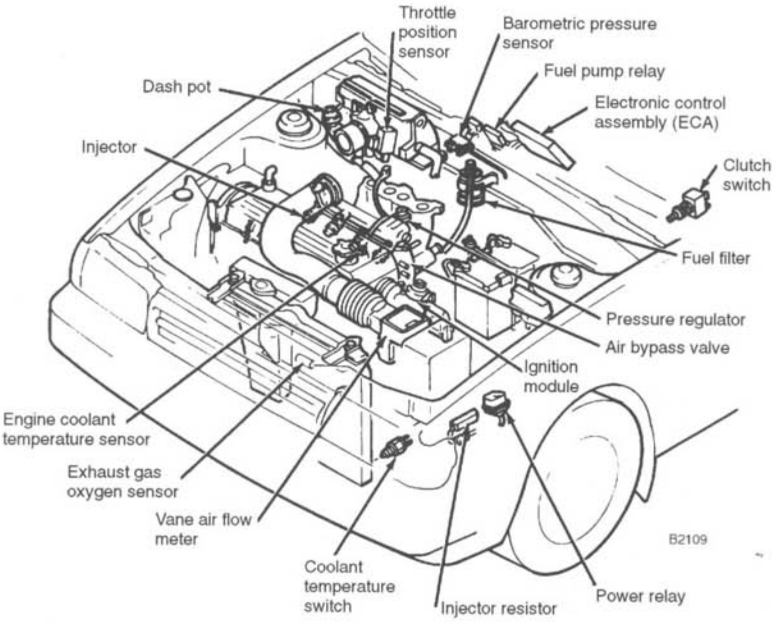


Fig. 1-3. 1988 Mercury Tracer 1.6L shows typical MECS-I. Most operate similar to those in a typical Ford EEC system. Differences include ignition coil (rpm signal for some engines), Vane Air Flow sensor (VAF) with Vane Air Temperature sensor (VAT), Electrical Load Unit (ELU), Idle Switch. Engines with Electronic Spark Advance (ESA) operate on electronic timing signals from distributor.

Why do I give you all this information about how these sensors operate? To help you understand for diagnostic purposes. Think of the sensors as the nerves of the system. Sensor signals don't take much power so sensor currents are measured in milliamps (mA). That means input signals are sensitive to the effects of corrosion, particularly at connectors.

In contrast, actuators are the muscles of the system. To do the work, output actuator currents can be a thousand times greater, up to 2 amperes. That means you can expect large voltage drops if extra resistances are involved. In both sensors and actuators, the grounds in the system are important.

In this chapter, I'll highlight **Opens & Grounds** to help you interpret readings from your DVOM or scan tool.

Table a. 1993 and Later J1930 Terminology

1988–1992 Term	1993 Equivalent
Air Charge Temperature (ACT)	Intake Air Temperature (IAT)
Barometric Pressure (BP)	BARO
Crankshaft Position (CPS)	CKP
Cylinder Identification (CID)	CID
Heated Exhaust Gas Oxygen (HEGO)	Heated Oxygen Sensor (HO2S)
Profile Ignition Pickup (PIP)	CKP/PIP
Vane Air Temperature (VAT)	IAT
Variable Reluctance (VRS)	CKP

1.2 Types Of Sensors

Six types of sensors send signals to the control module.

Thermistors are temperature-sensitive variable resistors. They operate on a reference voltage (VREF), supplied by the control module. Resistance changes with temperature, changing the signal voltage to the control module.

Potentiometers are mechanically-variable resistors, also operating on VREF. Signal voltage changes with position or rotation.

Signal Generators create a changing signal directly, without VREF. Some sensors send voltage signals; others send frequency signals.

Hall Effect Devices generate a signal that can be processed to create a digital pulse, a frequency signal changing as the shaft rotates.

Hot-wire Sensors create a voltage signal changing as the mass of the air intake changes.

Magnetic Pick Ups create an AC signal changing as a tooth passes a stationary magnet.

Table b. Sensor Type and System Affected

Sensor Type	Sensor	System Affected
Thermistor	Engine Coolant Temperature (ECT)	EGR, timing, canister purge, thermactor, idle speed, air-fuel ratio
	Air Charge Temperature (ACT)	Timing, air-fuel, turbo boost
	Vane Air Temperature (VAT)	Timing, air-fuel
Potentiometer	EGR Valve Position (EVP)	EGR, timing, air-fuel
	Vane Air Flow (VAF)	Timing, air-fuel
	Throttle Position (TP)	EGR, timing, canister purge, thermactor, air-fuel
	Pressure Feedback EGR (PFE)	EGR, timing, air-fuel
Signal generators	Exhaust Gas Oxygen (EGO/HEGO)	Air-fuel
	Knock Sensor (KS)	Timing (retard)
	Manifold Absolute Pressure (MAP)	EGR, timing, air-fuel, idle speed
	Barometric Pressure (BP)	
Hall effect devices	Profile Ignition Pickup (PIP) (also CID)	Timing, air-fuel, idle speed, fuel pump, EGR
Hot wire	Mass Air Flow (MAF)	Air-fuel ratio, timing
Magnetic pick up	Variable Reluctance Sensor (VRS)	Timing, air-fuel
	Vehicle Speed Sensor (VSS)	Idle speed, cruise control, engine fan

1.3 Types Of Switches

Three types of switches also say "yes" or "no" to the control module about conditions that could affect the engine.

Table c. Switch Type and System Affected

Switch Type	System Affected
Grounding-type	Transmission Temperature Switch (TTS) Neutral Drive Switch (NDS) Neutral Pressure Switch (NPS) Transaxle Hydraulic Switch 3–2 (THS 3–2) Transaxle Hydraulic Switch 4–3 (THS 4–3) Clutch Engaged Switch (CES) Neutral Gear Switch (NGS) Power Steering Pressure Switch (PSPS) Idle Tracking Switch (ITS)
Voltage-input type	A/C Clutch Compressor (ACC) A/C Clutch Cycling Switch (ACCS) A/C Demand (ACD) Brake On/Off (BOO) Speed Control Command Switches (SCCS)
Electrical input signals	Ignition Diagnostic Monitor (IDM) Key Power (Key On Input) Self-Test Input (STI)

Grounding switches ground a circuit to signal the control module, either a 12 v. battery voltage or VREF (5v). See Fig. 1-4. A fixed current-limiting resistor reduces current flow to the control module. A typical 2K ohm resistor reduces current flow to a tiny 6mA (milliamps). 12v. ÷ 2,000Ω (ohms) = 0.006A, or 6mA.

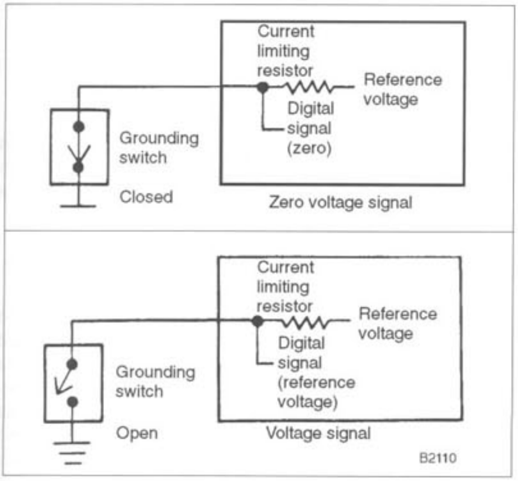


Fig. 1-4. Through a grounding switch, VREF is supplied through a current-limiting resistor. Grounded switch produces a zero signal. Open switch signals VREF at very low amps.

Voltage-input switches send a 12v. signal to the control module. See Fig. 1-5.

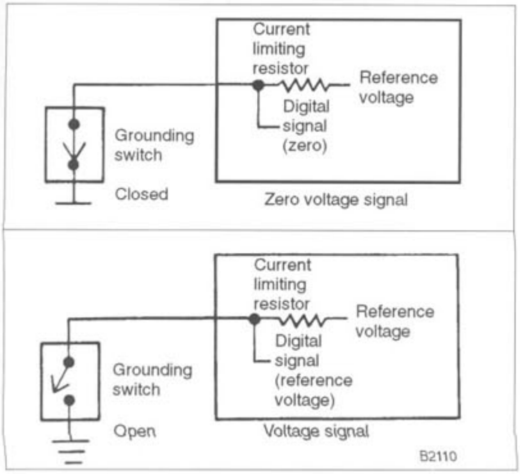


Fig. 1-5. Battery voltage (B+) is sent to control module when voltage input switch is closed.

Electrical Input switches send special signals to the control module, such as that the ignition key is ON.

2. ENGINE RPM, CRANKSHAFT POSITION AND CYLINDER IDENTIFICATION

RPM, Crankshaft Position Sensor (CPS) and Cylinder Identification sensor (CID) signals are important to fuel injection, spark timing, idle rpm, and emission control. The engine rpm sensor is probably the most important of all the sensors. Without this, the engine will not run. On the other hand, with this one sensor, rpm input signals will usually allow limp home even if signals are lost from all the other sensors.

As engine controls grew more precise, the control module needed more information than just how fast the crankshaft is turning (rpm). Now the control module needs to know the *position* of the crankshaft, relating piston to TDC, and including rpm information, and to know when No. 1 cylinder is coming up on TDC on its compression stroke (CID), to decide which injector is next in sequence to be fired, and which plug gets the spark, and when.

I'll show you five different sensors used by different 1988–93 Ford engines to signal the following:

- RPM—how fast is the crankshaft turning?
- CPS—what is the crankshaft position?
- CID—Cylinder I.D. or identification—when is #1 cylinder on its power stroke?

Of the five, the important EEC-IV technologies are the Profile Ignition Pickup (PIP) and the Variable Reluctance Sensor (VRS).

Profile Ignition Pickup (PIP)—Hall Effect

You'll find Profile Ignition Pickup (PIP) sensors in EEC-IV and MECS systems, based on a Hall-effect element. A Hall-effect device employs a rotary cup with tabs (sometimes called vanes). See Fig. 2-1. During rotation, each vane passes between a permanent magnet and a semiconductor device known as a Hall-effect element. Each vane acts as a shield,

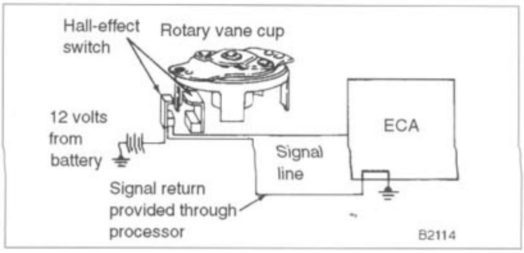


Fig. 2-1. Rotary vane cup passes through Hall-effect switch. Switch receives battery voltage. Vane passing switch signals control module. Frequency of pulses signals rpm. Timing of pulses signals crankshaft position.

A Hall-effect device takes its name from a Dr. Hall, who discovered a way to accurately switch a small current flow with no contacts and, therefore, no wear. The idea is to interfere with a magnetic field to prevent current flow through the device.

interrupting the magnetic field, which allows the Hall element to pass a small current to the control module. See Fig. 2-2. The turn-on and turn-off are very sharp, almost like a digital signal.

- Hall element sees magnetic field = Hall signal
- Magnetic field blocked = No Hall signal

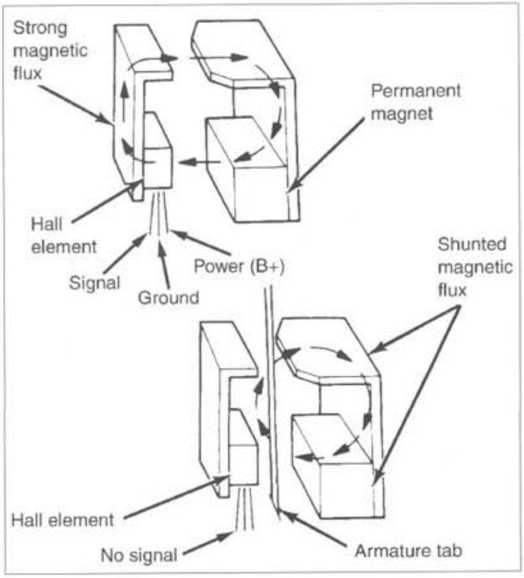


Fig. 2-2. Hall element operates on battery voltage through two of the leads, B+ and ground. Upper: When the element operates in a strong magnetic flux, as from the permanent magnet, it sends a signal through the third lead. Bottom: When the magnetic field is shunted, or cut off from the element by the tab, the signal is cut off. Magnetic field = signal; no magnetic field = no signal.

In the Ford PIP, the output of the Hall-effect device is processed—amplified and shaped. And here's what can be confusing: the signal becomes *inverted* in the process. So when the Hall element generates voltage, as when there is a window, the PIP sends no signal. And when the vane cuts off the Hall-effect voltage, the PIP sensor sends a signal. (No wonder it can be confusing!) The output from Ford PIP sensor seems to be the opposite of the signal from other manufacturers' Hall-effect sensors. And it *is*:

- Window = Hall voltage = no PIP signal
- Vane = No Hall voltage = PIP signal

A Schmitt trigger shapes the wavy output of the Hall device into square digital pulses. Square pulses are more useful to the control module because they are more precise than the Hall wave output (or of the previously-used CPS).

2.1 Distributor Mount PIP

For many Ford engines, rpm is sensed with the PIP located in the distributor, about where the centrifugal flyweights used to be. See Fig. 2-3. Signals from the Hall-effect device in the PIP are sent through the Ignition Module to the control module, corresponding to a base spark timing of 10 degrees BTDC (Before Top Dead Center). Turning at the speed of the distributor (and the camshaft), the PIP cup has one vane per cylinder. For a 4-cylinder engine, the PIP with four tabs sends four pulses for each revolution of the distributor shaft; that's two pulses per crankshaft revolution.

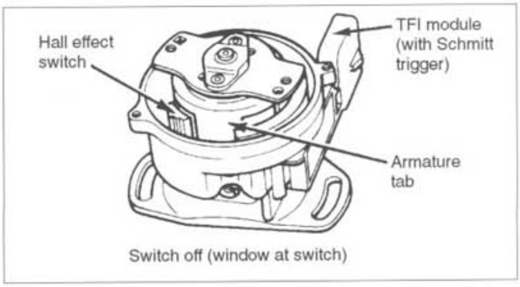


Fig. 2-3. Distributor carries TFI module. Hall-effect armature (cup) rotates on shaft where flyweights were.

The control module computes rpm by counting the pulses, and timing by when the pulses begin. At low rpm, the pulses are low frequency. The faster the engine turns, the higher the frequency of these digital pulses. If you played these pulses through your audio amplifier, starting from idle, you would hear a low growl, rising in frequency as the rpm increased.

Signature PIP is a variation used on engines with Sequential MFI. See Fig. 2-4. It provides a cylinder-identification signal to time the firing of individual injectors. With one segment narrower than the others, it sends a different signal for that segment. This provides the control module with information about which cylinder is next to open its intake valve.

When the PIP is located in the distributor bowl, it is easy to reach if it's necessary to adjust base timing. Its job is to sense crankshaft rpm and position; however, it is separated from the

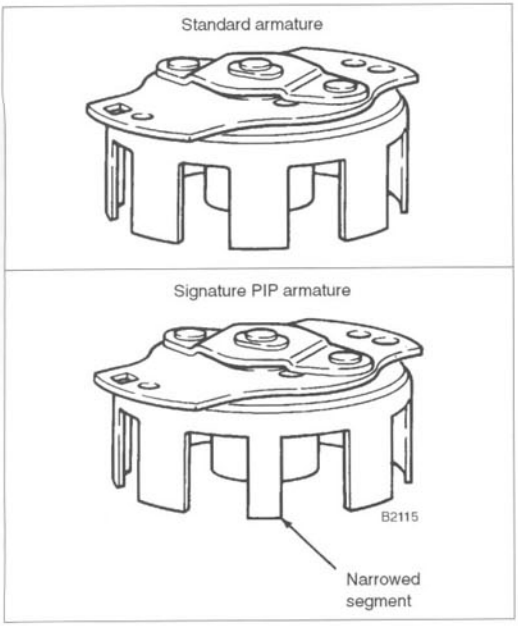


Fig. 2-4. Signal from narrowed segment, or vane of Signature PIP "looks different" to control module, providing a form of cylinder identification.

crankshaft by the timing belt and the drive gears of the distributor. Depending on the belt tension, this could introduce inaccuracies in the measurement, particularly of crankshaft position.

2.2 Distributorless Systems

To improve fuel economy, reduce emissions, and increase timing accuracy, sensor signals need greater precision. This led Ford to Distributorless Ignition Systems (DIS). DIS uses either Hall-effect devices or Variable Reluctance Sensors (VRS).

Depending on the engine, the Hall-effect devices are in different locations:

- 3.8L SC engine: CID sensor is mounted in the normal distributor location, driven by the camshaft. Timing accuracy is determined by the PIP on the crankshaft
- 3.0L & 3.2L SHO engines: the CID sensor is driven directly from the end of the rear overhead camshaft
- 4-cylinder Dual-Plug Distributorless Ignition System (DPDIS) dual-Hall sensor is driven off the crankshaft for both PIP and CID

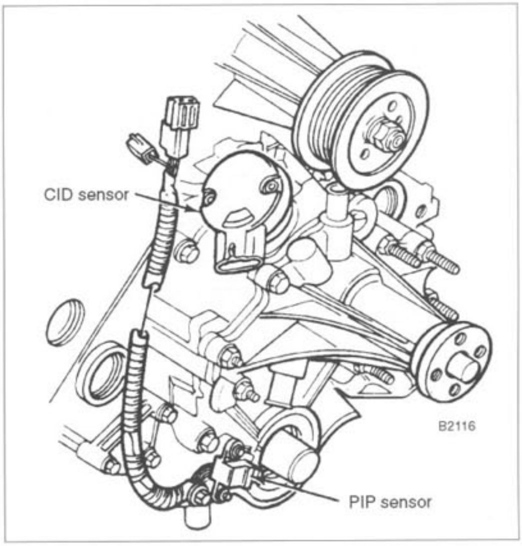


Fig. 2-5. 3.8L SC V-6 engine drives PIP Sensor directly off crankshaft. CID (Cylinder Identification sensor) is driven by camshaft through bevel gears in distributor location. On 3.0 and 3.2 SHO engines, CID is driven directly off of rear camshaft.

For the V-6 engines, the PIP sensor is mounted on the crankshaft for greatest timing accuracy, but the Cylinder Identification (CID) sensor is driven by the camshaft.

The crankshaft sensor uses three vanes turning at crankshaft speed to generate the PIP signal for the firing of the three Distributorless Ignition (DIS) coils for each crankshaft revolution. Spark timing accuracy is determined directly by crankshaft position.

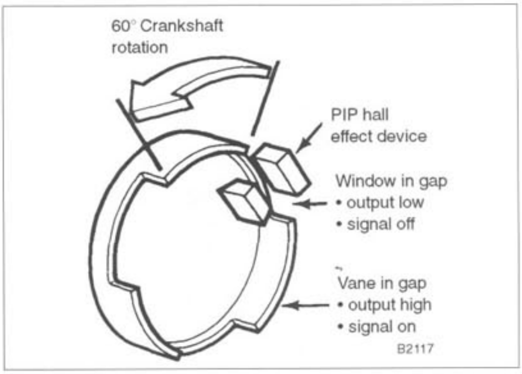


Fig. 2-6. 6-cylinder PIP on crankshaft turns twice as fast as distributor (or camshaft-driven) so it operates with half as many vanes as cylinders, here 3.

Each 6-cylinder PIP signal from the crankshaft is 60 degrees on with 60 degrees off (three for each crankshaft revolution. To look at it another way, 6 vanes pass the Hall-effect device for each two revolutions of the crankshaft (one camshaft revolution) for six cylinders.

The camshaft Cylinder Identification (CID) sensor operates with only one vane and one window, turning at camshaft speed. See Fig. 2-7. Its job is to identify the cylinder. Spark timing accuracy is not affected by the inaccuracies of the camshaft drive because the crankshaft PIP determines timing. The CID only determines which coil to fire. The CID signal also identifies which cylinder is on compression stroke for the sequential injection of fuel to that cylinder.

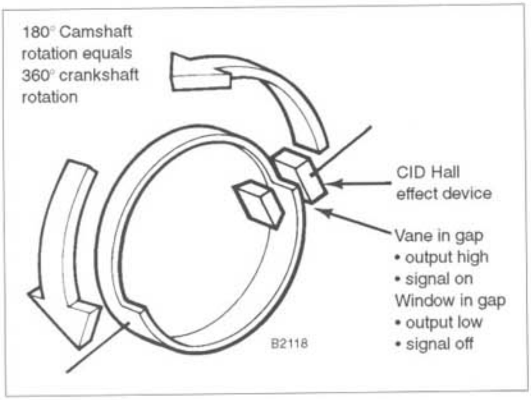


Fig. 2-7. Camshaft CID signal is on for 180 degrees of camshaft rotation, or for 360 degrees of crankshaft rotation.

Dual-Hall Crankshaft Sensor

You'll find some 4-cylinder models with Dual-Plug Distributorless Ignition System (DPDIS). Look for one crankshaft-mounted sensor signalling both PIP and CID. See Fig. 2-8. This sensor is a Dual-Hall sensor.

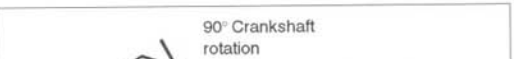


Fig. 2-8. In Dual-Hall Crankshaft Sensor, outside sensor operates as PIP to signal rpm and Crankshaft Position. Inside Hall sensor operates as CID to identify which coil should be fired.

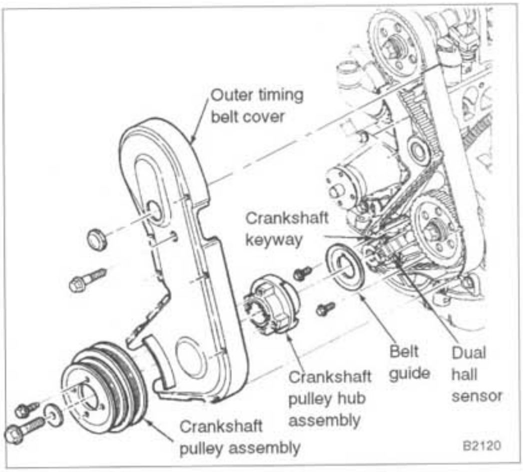


Fig. 2-9. Dual Hall sensor is located on the crankshaft under the outer timing belt cover—2.3L DP. Two rotary vane cups are mounted on the damper, one for each of the two Hall-effect sensors.

The DPDIS Dual-Hall sensor is located on the front of the crankshaft, as in the original CPS, where it can sense even small changes in crankshaft rotation rate.

PIP cup, with two vanes on the crankshaft, turns at twice the rpm of a PIP in the distributor. Two vanes send the proper signal rate for four cylinders, two for each crankshaft revolution.

CID has one vane, 180 degrees around. While the CID vane is passing the second Hall-effect device, it sends voltage, identifying the coils for cylinders 2 and 3. When the vane is clear, the lack of battery voltage signal from CID identifies cylinders 1 and 4.

Variable Reluctance Sensor (VRS)

On models with Electronic Distributorless Ignition System (EDIS) you'll find a single crankshaft sensor known as the Variable Reluctance Sensor (VRS). Applications include:

- 1990 and later 1.9L 4-cylinder Escort
- 4.0L V-6 Ranger/Bronco/Aerostar
- 4.6L V-8 in 1991 and later Lincoln Town Car, 1992 and later Ford Crown Victoria/Mercury Grand Marquis, and the 1993 and later Mark VIII

The VRS is a passive electromagnetic device that generates AC voltage using a a stationary sensor and a toothed wheel mounted on the front of the crankshaft. See Fig. 2-10. As teeth pass through the sensor's magnetic field, they generate a voltage signal that increases with engine rpm. The wheel has a tooth every 10°, with one tooth missing (35 teeth). Using the signal difference caused by the missing tooth,

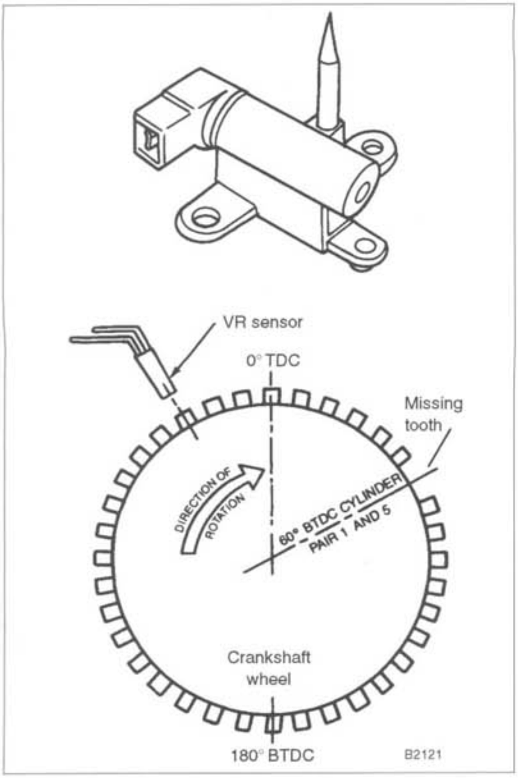


Fig. 2-10. Variable Reluctance Sensor (VRS) senses movement of toothed wheel past point of sensor. 36-minus-one toothed wheel signals 60 degrees BTDC. (V-8 shown)

this one sensor can supply the signals for the control module to compute rpm, crankshaft position, and cylinder identification. One tooth is missing so control module can identify which cylinder is coming up to be fired.

But wait a minute. In Fig. 2-10, the missing tooth corresponds to two cylinders. How does the module make cylinder identification? By a 1-revolution trial and error. During crank, the control module tries to fire cylinder #1. If that doesn't start the engine, it tries cylinder #5 on the next revolution. Then the control module notes which of the two cylinder pairs worked, and remembers for as long as the engine runs. Of course, if it knows the 1-5 pair, it knows the other cylinder pairs. For the next engine start, the module makes another trial.

Opens & Grounds

An open between Hall device and control module results in constant 5v. signal at control module. A short-to-Ground in same circuit results in constant 0v. signal at control module.

2.3 Mazda Engine Control Systems (MECS) PIP, CID, CPS

I've shown you two different types of sensors, Hall-effect and Variable Reluctance, used by EEC-IV to signal rpm, crankshaft position, and cylinder identification. Some MECS-II engines also use Hall-effect devices. Other MECS systems may use one or more of these three different sensors:

- Old-fashioned breaker points
- Magnetic sensor pickup coils
- Optical sensor with slotted disc

Mazda Engine Control Systems (MECS) differ significantly from the EEC systems. And the 1993 and later MECS-II differs from the MECS-I used in 1988–92 models. MECS-II is used in '93 and later V-6, also '93 2.0L with automatic (4EAT). Remember, EEC-IV is on '93 2.0L manual transmission, and all '94 and later 2.0L.

MECS-I 2.2L non-turbo engines in the Probe and 1.6L engines in Capri use the outmoded ignition timing called Distributor-Mounted Ignition Module with Vacuum Advance (DMIVA)! The ignition coil lead senses rpm, with ignition timing varied by the flyweights and vacuum advance.

In other MECS-I engines, you'll find Electronic Spark Advance (ESA). In the distributors, you'll find a Crankshaft Position Sensor (CPS) and two Cylinder Identification Sensors (CID).

MECS-I RPM Signal

On 2.2L turbo models, the Crankshaft Position Sensor (CPS) in the ESA distributor base uses a magnetic sensor pickup coil next to a wheel with 24 teeth. See Fig. 2-11. This generates 24 pulses every rotation of the distributor shaft (every two revolutions of the crankshaft). Turning 720 degrees in two crankshaft revolutions, 24 teeth (720 ÷ 24) = 30 crankshaft degrees per pulse.

MECS-I Cylinder Identification

In 2.2L turbo engines, a separate rotor for the two Cylinder Identification Sensors (CID) rotates on the same distributor shaft. In Fig. 2-11, you can see the CID rotor, looking like a twisted teardrop. One pickup, shown on top, signals TDC for cylinder #1. The other pickup, shown below, signals TDC for cylinder #4. Recall that cylinder #1 rises to TDC on its compression stroke at the same time #4 rises on its exhaust stroke. With signals from these two sensors, the computer identifies which cylinder gets the spark timing, and which gang of two injectors gets the injection pulse.

1.8L and 1.3L engines use a slotted disc. A Light Emitting Diode (LED) shines through the slots to a photo sensor. This is sometimes called an optical system. See Fig. 2-12. The disc has one inner CID slot that generates 1 pulse for every two revolutions of the crankshaft. Another LED shines through the CID slot to a CPS photo sensor. On a disc that rotates once for

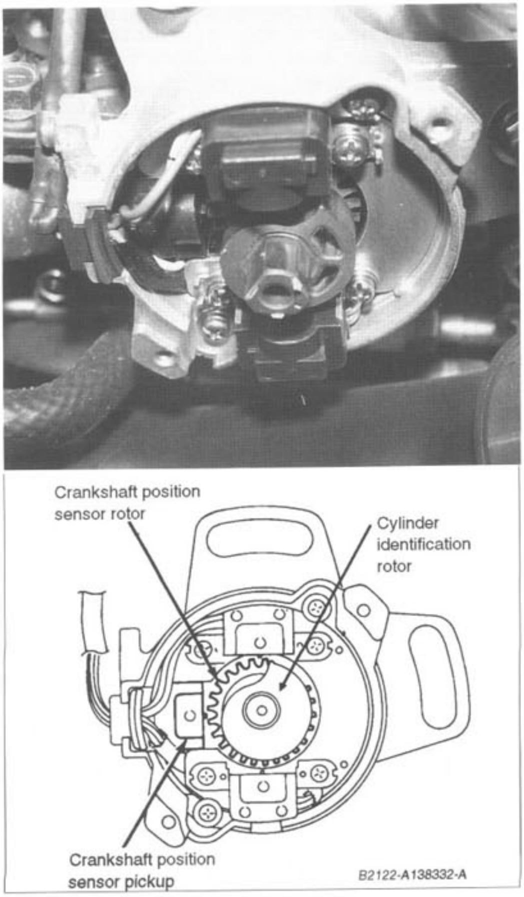


Fig. 2-11. MECS-I 2.2L Turbo ESA distributor includes sensors for CPS and CID.

each two crankshaft revolutions, it takes only one CID signal to signal TDC of #1 cylinder.

- 1.3L and 1.8L engines use Transistorized Ignition Module 3-pin type, TI3, that relays spark timing from the ECA to the coil
- 2.2L turbo uses 5 pin, TI5, that relays spark timing, grounds the coil negative and returns feedback signal to the ECA

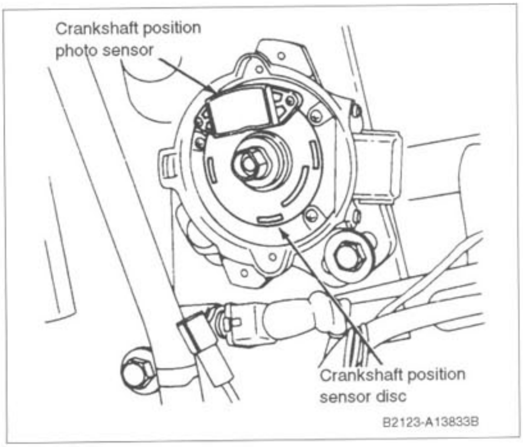


Fig. 2-12. MECS-I 2.2L/T, 1.3L and 1.8L ESA distributor includes sensors for CPS and CID.

MECS-II

To provide the timing necessary for sequential fuel injection (SFI), '93 and later MECS-II provides improved crankshaft position and cylinder-identification signals to the control module.

V-6 2.5L engines use two sensors, one in the distributor, and the other on the rear of the crankshaft pulley.

On 2.0L MTX, the EEC-IV distributor drives an optical disc with four equally-spaced outer slots. These slots generate 4 pulses for every turn of the distributor shaft (two revolutions of the crankshaft). See Fig. 2-13.

On 2.0L 4EAT, the MECS-II distributor uses a 4-vane Hall-effect sensor, similar to PIP in EEC.

On 2.5L MTX and 4EAT, the MECS-II distributor uses a 6-vane Hall-effect sensor, similar to PIP in EEC. Call it Crankshaft Position (CKP1) sensor. The second Crankshaft Position sensor (CKP2) mounts directly on the crankshaft. See Fig. 2-14.

CKP2 is particularly valuable at the higher rpm's of this little V-6, over 100 revs every second. Avoiding the camshaft belt that drives the distributor, CKP2 accurately signals crankshaft position. CKP1, in the distributor, sends backup crankshaft position signals, and also CID signals of cylinder #1 compression TDC.

CKP2 provides increased accuracy at higher rpms. This increased accuracy increases torque about 3% above 5,000 rpm. CKP2 detects changes in crankshaft rotation rate during acceleration, improving the accuracy of ignition timing.

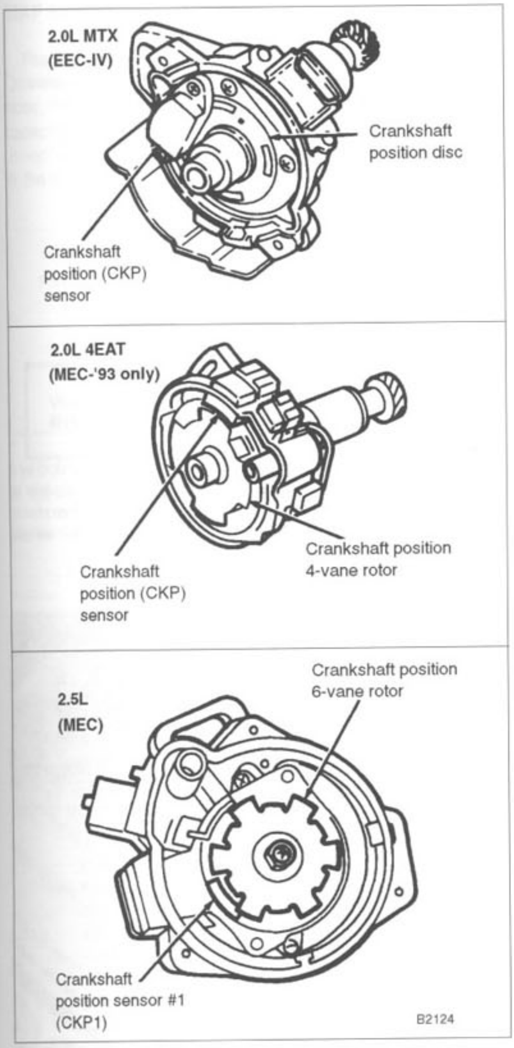


Fig. 2-13. Compare different 1993 Mazda Crankshaft Position (CKP) sensors: 2.0L MTX slotted disc for light signals, similar to 1.3L and 1.8L; '93 2.0L 4EAT MECS 4-vane rotor for Hall effect; 2.5L 6-vane rotor for Hall-effect.

Cylinder identification signals are sent by a second Hall-effect sensor. A single blade, under the CKP cup, rotates at camshaft speed, similar to the CID sensor in 3.8L EEC systems.

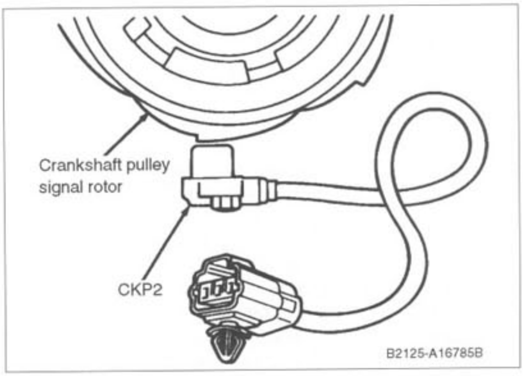


Fig. 2-14. 1993 and later 2.5L V-6 uses two crankshaft position sensors, CKP1 and CKP2. CKP2 sends accurate signals of compression TDC of each cylinder.

2.4 Summary—RPM, PIP, CID

In summary, in 1988–93 Ford vehicles, different Ford engines use different combinations of sensors to signal for computation of crankshaft rpm and position, and cylinder identification.

1. Hall-effect devices operate a rotary cup with one or more vane and windows:
    - When a vane interrupts a magnetic field from a permanent magnet, the Hall switch (or element) closes, sending a current signal
    - When a vane passes, a window allows the field to reach the Hall switch, opening it and preventing current flow
2. Distributor-mounted Hall-effect devices use a rotary cup with one vane for each cylinder. Ford calls it Profile Ignition Pickup (PIP).
3. Distributorless systems (DIS and EDIS) use Hall-effect devices directly on the crankshaft:
    - V-6 engines provide Cylinder Identification (CID) signals from a separate Hall-effect device, driven at camshaft speed
    - 4-cylinder DPDIS dual-vane Hall-effect cups are driven directly from the crankshaft. The PIP cup supplies crankshaft speed. The CID cup supplies cylinder identification
4. Variable Reluctance Sensors (VRS) are used on EDIS systems. A crankshaft-mounted missing-tooth wheel signals pulses. The control module can use these signals to compute rpm, crankshaft position, and cylinder identification.

5. MECS engine-rpm sensors
    - Distributor Mounted Ignition, Vacuum Advance (DMIVA), rpm signal from coil
    - Electronic Spark Advance (ESA), distributor signals, CPS from rotor and coil, CID from teardrop rotor and two coils
    - ESA, distributor signals from disc and LED/photo sensor, CPS from four slots, and CID from a single slot
    - ESA, CKP & CID PIP signals from Hall-effect sensors in distributor
    - ESA, CKP signal from crankshaft position sensor (#1), and from distributor Hall-effect sensors, one for CID and the other for backup CKP.

3. ENGINE LOAD

To measure engine load, 1988–93 Fords use three different load sensors relying on three different measurements:

1. Manifold Absolute Pressure (MAP) sensor—Speed-density. Refers to measuring engine speed and measuring air pressure in the manifold by sensing MAP.
2. Mass Air Flow (MAF) sensor—Air mass. Refers to measuring the mass or weight of intake air by the MAF.
3. Volume Air Flow (VAF) sensor—Air volume. Refers to measuring the volume of intake air by the Vane Air Flow (VAF) sensor, or by the Measuring Core Volume Air-Flow Sensor (MC-VAF).

MAP is the simplest and the most indirect measurement. It is being phased out, virtually all supplanted by the MAF, first seen on the 1989 3.0L SHO engine. MAF is probably the most accurate measurement of engine load, and is also on '93 Probe 4-cylinder with MECS.

3.1 Manifold Absolute Pressure (MAP) Sensor

The Manifold Absolute Pressure (MAP) sensor measures the positive increase in manifold pressure from absolute zero to barometric. (Remember what I said in Chapter 2 about thinking positive instead of negative, i.e., vacuum.) The MAP sensor is usually mounted on the engine bulkhead away from the vibration of the engine.

The MAP sensor is connected to the manifold in a manner similar to a vacuum gauge. But if you think in terms of negative pressure (vacuum measured as less than atmospheric), you'll have trouble understanding engine load and boost. Think positive, absolute pressure from zero:

- At idle and deceleration, MAP is least, typically 30 kPa
- At WOT, MAP is close to barometric, typically 95 kPa

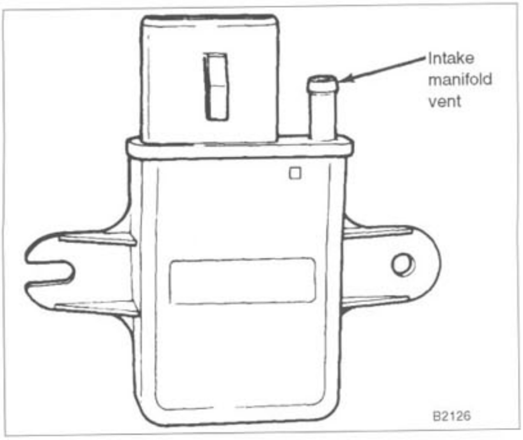


Fig. 3-1. MAP sensor is connected to intake manifold by a hose. MAP sensor may also be switched over to measure barometric pressure, or barometric pressure may be measured by a similar sensor, called BP or BARO.

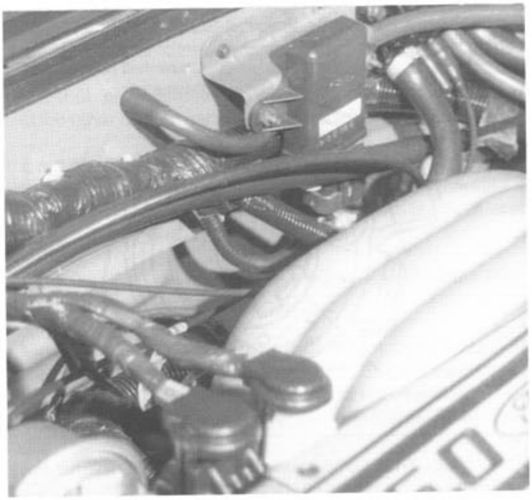


Fig. 3-2. MAP/BP sensor installation on 5.0L high output engine senses barometric pressure.

> Those of you familiar with Bosch systems will recall their term "map". That is not MAP. A Bosch map refers to their visualization of a three-dimensional map of data points in the memory, what Ford calls "Look Up Tables"—more about that in Chapter 8.

MAP Sensor Design and Operation

The MAP sensor is a pressure-sensitive disc capacitor. One side of the disc is connected to the intake manifold by a hose. As manifold pressure is applied to the disc, it changes capacitance. These electrical capacitance signals are "conditioned" to be translated into changing frequencies. The greater the manifold pressure, the faster the frequency.

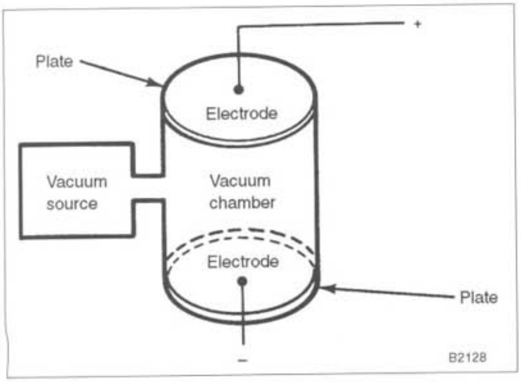


Fig. 3-3. Variable capacitor in MAP or BP sensor changes capacitance as pressure varies between two electrodes, or plates.

In the MAP or BP sensor, changing capacitance is converted by a frequency generator into a series of digital pulses, changing from reference voltage to zero. The greater the pressure, the faster the frequency.

CAUTION —
Ford MAP and BP sensors measure frequency—the signal is digital pulses of reference voltage. That's different from pressure sensors in most other cars. You cannot measure frequency with a voltmeter. Do not test for resistance with an ohmmeter. You may damage the sensor.

Speed Density

When you hear the term "speed-density," that's one way an engineer refers to the basic factors that determine the output of the engine, and therefore the amount of fuel injected at any moment.

Speed is, of course, engine speed, or rpm. The higher the rpm, the more times per minute the cylinders fill with air-fuel mixture.

Density refers to the pounds of air that move into the cylinders per intake stroke. Density relates to Manifold Absolute Pressure (MAP), and also to temperature of the intake air. (Performance-oriented people know that cold air = more density = more pounds = more fuel needed = more power!)

MAP/BP Opens & Grounds

An open or short to ground between the MAP or BP and the control module results in a constant zero v. signal at the control module.

A poor connection between the sensor and control module results in a weak signal that cannot be recognized by the computer frequency-to-voltage converter.

3.2 Mass Air Flow (MAF) Sensor

The Mass Air Flow (MAF) sensor is the most direct method of measuring engine load because it measures the mass of air intake without needing corrections for temperature or pressure. Although you'll see Speed-Density on most Ford engines of the 1980s, MAF is the choice in Ford engines of the '90s, and in performance modifications (see Chapter 9).

MAF depends on the measurement of current flowing through heated wires to measure air flow. It is also known to Bosch guys as the "hot-wire" sensor because of its heated-wire design. It has several advantages over vane-type air-flow sensors.

1. It measures air mass, or weight, so it requires no air-fuel-mixture ratio correction for changes in density due to temperature or altitude. Measuring mass reduces correcting computations in the control unit.
2. It has no moving parts. That means mechanical simplification. Measurements follow changes in air mass in 1 to 3 milliseconds.
3. It offers insignificant resistance to the passage of air. Even at maximum air flow, drag force on the wire is measured in milligrams.

MAF Sensor Design and Operation

Between the air cleaner and the manifold, you'll see a simple cylinder with an electronic box, as shown in Fig. 3-4 and Fig. 3-5.

The EEC-IV hot-wire system depends on measurement of the cooling effect of the intake air moving across the heated wires. Suppose you had a fan blowing across an electric heater. With a small movement of air past the heated wires, the cooling effect is small. With more air moving past the heated wires, the cooling effect is greater.

MAF control circuits use this effect to measure how much air passes the hot wire. The hot wire is heated to a specific temperature *differential* of 200° Celsius above the incoming air. That's twice the temperature differential of the Bosch hot wire of 100°C. Notice I did not say it was heated to 200°C, but rather to 200°C above the temperature of the intake air. I'm going to offer a rough approximation of the 200°C hot-wire temperature differential as 360° Fahrenheit, but you'll understand the principle better if I stay with a single unit of measurement, Celsius.

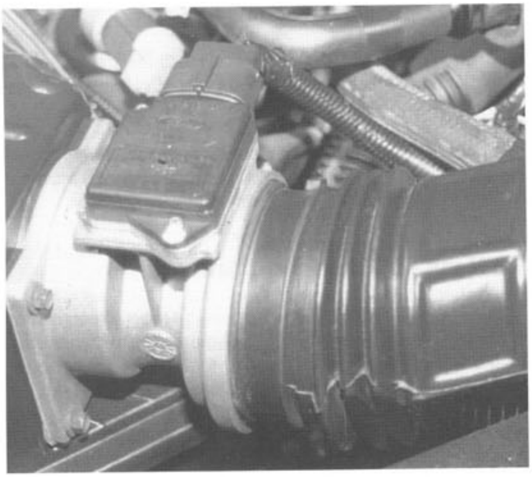


Fig. 3-4. Mass Air Flow (MAF) sensor mounts between air cleaner and intake manifold. 4.0L Explorer shown.

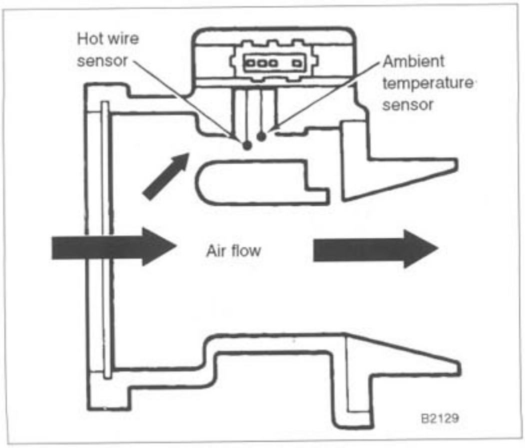


Fig. 3-5. MAF sensor uses a hot-wire system to signal mass of air intake.

Two wires are exposed to a proportion of the airflow:

- The Ambient Temperature Wire is also called the "Cold Wire" because it is not heated. Ambient means "surrounding", so the cold wire operates at the temperature of the surrounding air. The cold wire serves as a reference temperature
- The Hot Wire is heated by the MAF control circuits to be 200°C above the ambient air. If it is freezing outside, 0°C, the hot wire will be heated to 200° hotter, or 200°C. If it is a hot day out, say 40°C, the hot wire will be heated to 240°C

Think about it, 40°C temperature is about 100°F, so the Cold Wire is "cold" only because it is unheated. We call it cold only because it is 200°C colder than the hot wire.

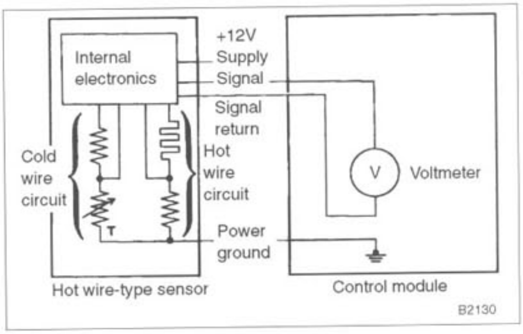


Fig. 3-6. By comparing voltage drop across hot-wire element to voltage drop across cold-wire element, sensor electronics send a DC voltage signal directly proportional to mass of air flow through sensor. Vehicle power, 12v. is supplied, not VREF. Output is much less.

As soon as air flows over the wire, both wires are cooled. The control circuits then apply more voltage to keep the hot wire at the original temperature differential, 200°C. This creates a voltage signal monitored by the control unit. The greater the air flow and wire cooling, the greater the signal. Cooling depends on the mass of the intake air and on its temperature so no additional corrections are needed. MAF input signals to control module are directly related to intake air mass.

The typical voltage output, increasing as speed increases are 0.20v, idling to 1.5v. max, engine running, or 0.70v. max, KOEO (Key On, Engine Off).

If you're familiar with the Bosch Hot-Wire Sensor of LH-Jetronic/Motronic systems, you'll notice a major difference in the Ford sensor. Ford measurement takes place in a separate bypass above the main flow, while the Bosch measurement takes place in a centrally-mounted set of wires. What does this mean to you?

- The air flowing through the Ford bypass, past the measuring wires must be closely proportional to the total intake air flow, otherwise the measurements will be false, distorting the air-fuel mixture. In the design of the sensor and its ducting, Ford considers the delivery of air into the sensor to be even-flow, "laminar" is the term. If you plan any rework of the sensor mounting or its duct work, consider the importance of the even flow of intake air.

- With the measurement wires separated from the main flow, they are less likely to collect dirt. The Ford sensor does not require the Bosch circuitry for hot-wire cleaning at shut-off.

MECS-II MAF Sensor

Mazda Engine Control Systems (MECS-II) for 1993 4-cylinder 2.0L with automatic transmission (4EAT) use a MAF different from the EEC-IV MAF. The '93 2.0L Manual Transaxle (MTX) and all '94 and later 2.0L use a regular EEC-IV MAF.

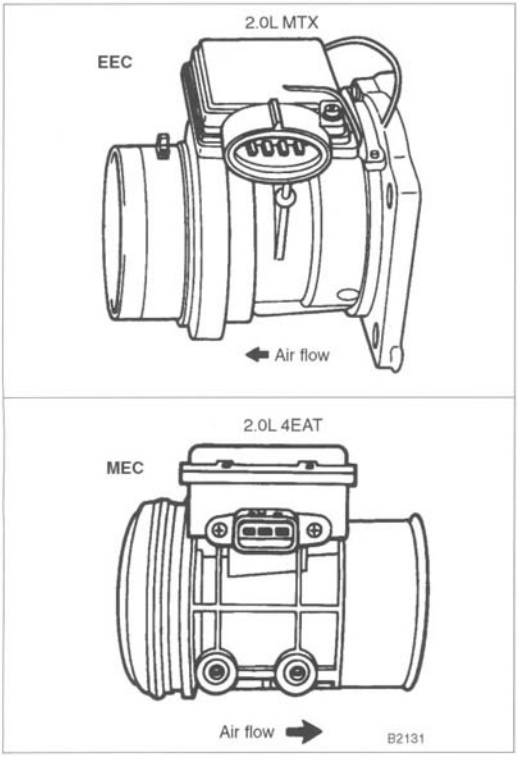


Fig. 3-7. Compare MAF for EEC-IV system on Probe 2.0L Manual transmission (MTX) with MAF for Probe 2.0L Automatic Transmission (4EAT). Contrast appearance to insure that you are using proper data for working on engine.

This MECS-II MAF mounts the heated resistor plate in a central passage, a location similar to most Bosch "hot-wire" AFS. In contrast, Ford EEC-IV MAF measures the air flow through a hot wire in a side bypass. The MECS-II sensor also differs from the FORD EEC-IV MAF in using a heated-resistor plate instead of a fine wire.

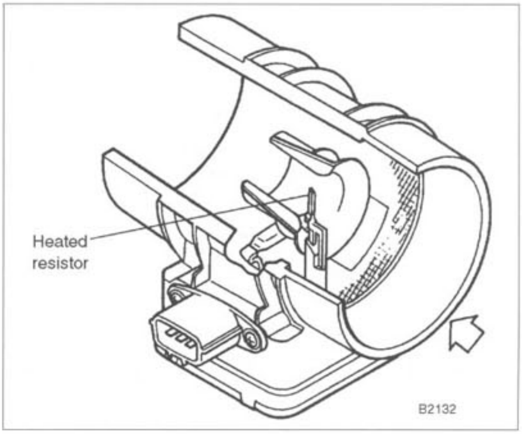


Fig. 3-8. Heated-resistor plate (not wire) measures air mass flowing through central passage. 1993 and later Probe 2.0L 4EAT engine.

3.3 Vane Air Flow (VAF) Sensor

Some early Ford engines and the 1988–92 Mazda Engine Control System (MECS-I) engines use the Vane Air Flow (VAF) sensor. See Fig. 3-9.

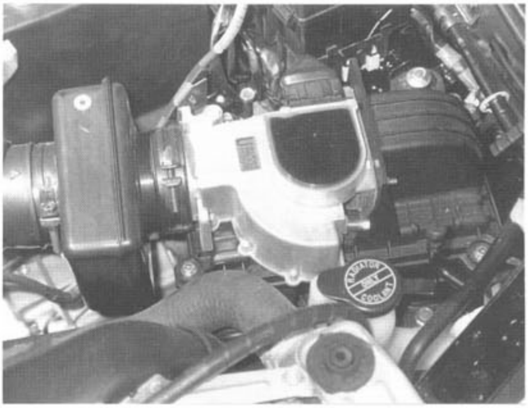


Fig. 3-9. Vane Air Flow (VAF) sensor in this 1.8L engine is a Bosch air flow sensor, as used in L-Jetronic or Motronic.

The VAF sensor is called a vane-type because its internal vane moves as air is drawn into the engine. The sensor measures the air volume controlled by the regular throttle valve. (Its new name is Volume Air Flow sensor, still VAF.) The sensor does not regulate the air flow. The air vane, also called an air flap, is lightly spring-loaded, and pivots by the force of the air flow as the throttle opens to admit more air.

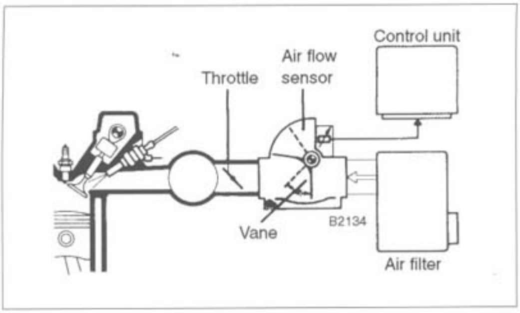


Fig. 3-10. Air flow sensor air vane/flap measures intake air; throttle controls intake air.

VAF Sensor Design and Operation

If you could remove the cover of the air flow sensor, you would see the air vane and the damper flap. See Fig. 3-11. The air vane is pushed by the incoming air. In the curved portion of the housing, and mounted on the same shaft as the air vane, the damper flap operates to dampen, or cushion the movement of the air vane by pressing against the air in the chamber. The damper reduces flutter caused by manifold pressure variations from the opening and closing of the intake valves.

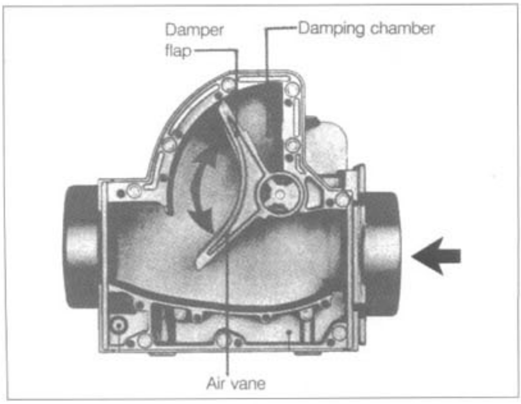


Fig. 3-11. Backfires and pulsations cancel out as opposite forces on the air vane.

During sudden throttle openings, the air vane assembly will rotate clockwise rapidly, but its final movement will be cushioned by the damper flap as it squeezes the air in the damping chamber.

The shape of the housing surface opposite the end of the air vane is calculated so the relation between the air passing through and the angle of the flap is logarithmic. That is, a doubling of the air vane angle indicates that air flow has increased 10 times. That means that the most sensitive measurements are at low air flows; at low speeds, measurements are more critical. Maximum air flow is 30 times the minimum.

A moving electrical contact called a wiper is mounted on the same shaft as the air vane. As the vane rotates, the wiper also rotates, crossing a series of resistors and conductor straps on a ceramic base, increasing resistance. See Fig. 3-12.

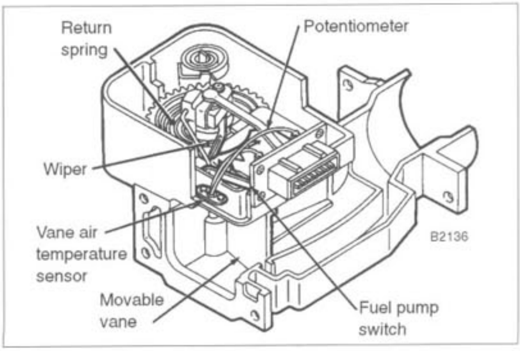


Fig. 3-12. VAF meter includes vane sensor and potentiometer, Vane Air Temperature (VAT) sensor, and fuel pump switch. Potentiometer wiper rotates on wiper track. Signal is based on VREF of 5 v. from control module.

Most VAF signals increase in voltage as vane opens. See Fig. 3-13. Exception: 1.8L voltage falls as vane opens. This is similar to early L-Jetronic AFS (Air Flow Sensor).

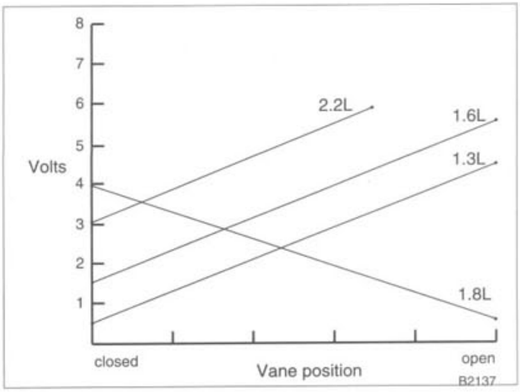


Fig. 3-13. VAF voltage changes as vane opens and closes.

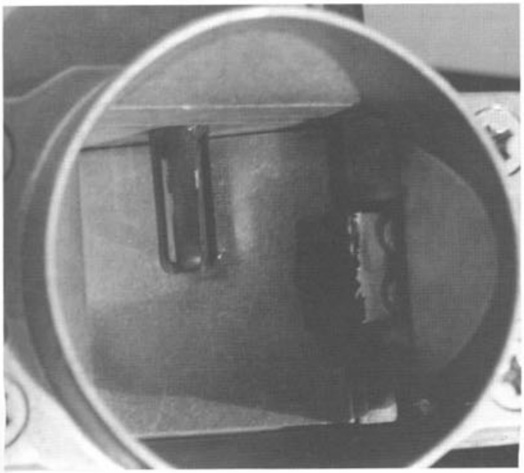


Fig. 3-14. Air Charge Temperature (ACT) sensor in VAF signals temperature of incoming air. Together with pressure signals from BP, these measurements can be combined in control module to calculate air mass.

The vane can be damaged by backfires. The best advice to help prevent this damage when starting the engine, is to keep your foot off the accelerator. Ford calls this "No-Touch Starting."

When you put all these signals together, VAF + ACT + BP, the control module can calculate a mass air flow number. But it takes more computing time—time that is valuable during changing conditions such as stomping on the accelerator. The computer: "Let's see, this much air flow volume, corrected for this much air temperature, corrected for this much barometric pressure—Oops, the measurements just changed; start over!"

MECS-I Vane Air Flow Sensor

MECS-I VAF sensors differ from previous Ford VAF in two ways:

- Non-turbo engines use a closed-vane switch to open the fuel pump relay power and stop the pump if the engine stops. During deceleration, a charged condenser supplies power momentarily to the relay to keep the pump running as the vane closes. Turbo engines signal the control module with ignition pulses as a sign the engine is running
- 2.2L Turbo engines use a full-open vane switch to signal the control module about excess engine speed and load. When the control module detects an unsafe combination of air flow, rpm, and boost, it sounds a warning chime for the driver. If excess conditions continue, the control module cuts back fuel injection

MECS-II Measuring-Core Volume Air Flow (MC-VAF) Sensor

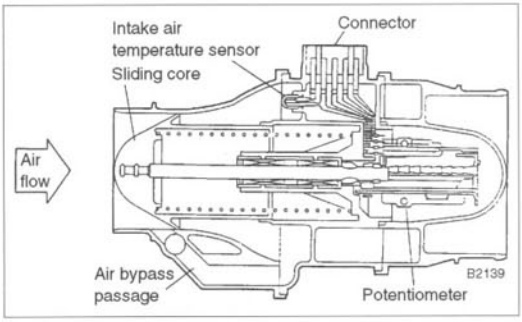


Fig. 3-15. Measuring-Core VAF (MC-VAF) measures air volume flowing through sensor. Used beginning 1993 Probe V-6.

The 1993 V-6 2.5L uses the Measuring-Core VAF (MC-VAF), also known as Sliding-Core AFS. The measuring-core sensor measures air volume by the movement of the sliding core under pressure from the intake air. You might say, MC-VAF substitutes the sliding core for the vane in the Volume Air Flow sensor. In the diagram, notice the bullet-shaped core piece. As the air enters, it pushes the core straight back, compressing the long spring. The core moves in a curved cone, curving out to increase its size. Just as in the vane meter, this increases sensitivity with a relatively large motion at lower speeds where the measurement is more critical, and relatively less motion at high speeds and greater air flow.

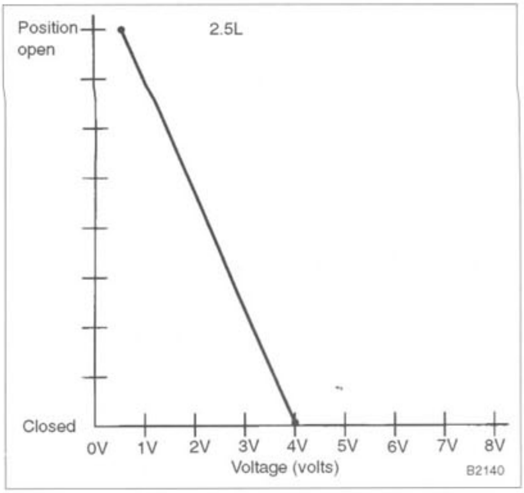


Fig. 3-16. Output curve shows that MC-VAF sensor signal is 4.0v. when closed, falling in straight line to 0.35v. when open.

In the rear of the sensor, motion is translated by a potentiometer into changing resistances. Beginning with a fixed reference voltage, (VREF), this sensor signals the computer with a voltage drop, increasing as the air volume increases.

The Intake Air Temperature (IAT) Sensor signals the computer, permitting calculations to convert air volume into air mass, as in VAF.

The MC-VAF is made largely of plastic, smaller and much lighter than the vane-type VAF sensor.

3.4 Summary—Engine Load

So you've seen three types of sensors used in 1988–93 EEC-IV and MECS Fords to measure engine load:

- Manifold Absolute Pressure (MAP) sensor—EEC-IV Fords only. Sensing MAP and rpm to then calculate air mass intake, corrected for temperature with ACT, corrected for pressure with BP
- Mass Air Flow (MAF) sensor—Both EEC-IV and MECS. Directly sensing the mass of intake air with MAF sensor. MECS MAF (2.0L 4EAT) uses different air mass measurement method
- Volume Air Flow (VAF) sensor—Sensing the volume of intake air with a moving vane or core, correcting it to air mass with input signals from ACT and BP. Early EEC-IV Fords use a Vane Air Flow sensor, with a moving vane. MECS Fords use a Vane Air Flow Sensor and a Measuring Core VAF, sensing volume with a moving core

4. AIR CHARGE TEMPERATURE (ACT)

Temperature is an important factor in air density. As I discussed in Chapter 2, air density affects air-fuel ratios. The control module uses temperature signals, along with pressure signals, to help calculate air mass. The Air Charge Temperature (ACT) sensor signals the control module about the air temperature. The ACT is usually located in the intake manifold, but may also be in the air cleaner. See Fig. 4-1. MECS ACT is usually in the air flow sensor.

The ACT is a thermistor, a thermal transistor. As a solid-state device, it has less resistance when warm than when cold. That is the opposite of most resistors that increase resistance when warmer, and so you may hear Bosch guys refer to the thermistor as "NTC" (Negative Temperature Coefficient). See Fig. 4-2.

When I first looked at thermistor graphs like this, I said, "Wait a minute. is this Ohm's Law in reverse? When the thermistor is warm, resistance is less, and voltage is less. How can that be? I'd think, with less resistance, voltage should be more!" What they don't tell you, but I will, is that the thermistor circuit includes a fixed resistor in series. The voltage signal is the VREF minus the voltage drop across the resistor and the thermistor. The voltage drop is proportional to the resistance, so as the resistance changes, that changes the signal. See Fig. 4-3.

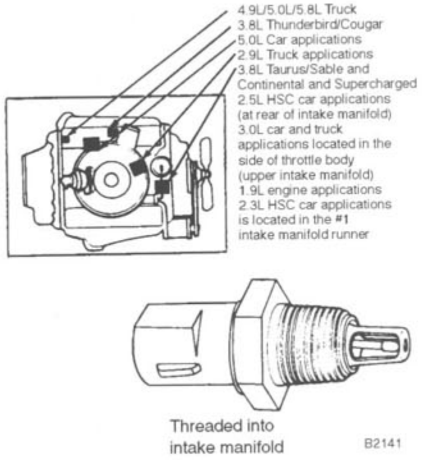


Fig. 4-1. Air Charge Temperature (ACT) sensor mounts in manifold or in air cleaner. It holds a thermistor, a solid-state thermal transistor.

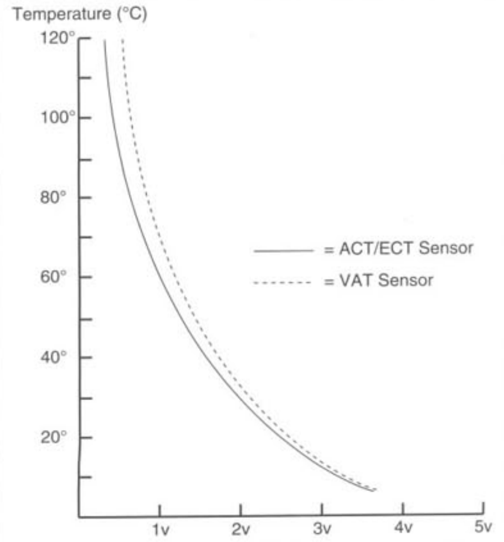


Fig. 4-2. As temperature increases, ACT thermistor resistance decreases. Based on VREF of 5v., at shop temperature, 20°C (70°F), resistance will measure about 37Kohms, which will give voltage readings of about 3v.

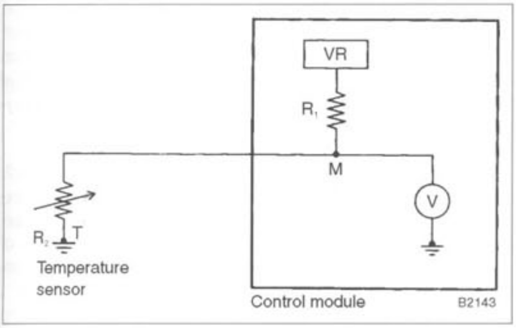


Fig. 4-3. Thermistor circuit includes a fixed resistor in series. The voltage signal is VREF minus the voltage drop across the resistor and the thermistor.

ACT Opens & Grounds

An open between thermistor and control module results in constant 5v. signal at control module.

A short-to-ground in the same circuit results in near-zero v. signal at control module.

Extra resistance in the circuit, such as corrosion at the connectors results in higher-then-normal voltage because the signal is based on voltage drop. Extra resistance could cause hard cold starts.

5. ENGINE COOLANT TEMPERATURE (ECT)

Engine temperature is one of the most important modifiers to the calculations of engine speed and load. It affects air-fuel ratio, spark timing, idle rpm, and emission control. You'll find the Engine Coolant Temperature (ECT) sensor usually in the heater outlet fitting of the engine, as shown in Fig. 5-1.

The ECT is similar to the ACT, a thermistor in a housing, operating from Voltage Reference (VREF) of 5v.

ECT resistance decreases as it gets warmer so the voltage-drop signal decreases as it gets warmer. If you measure the resistance by measuring the voltage drop at shop temperature, say 20°C, a typical voltage reading would be 3 v., while at normal engine temperatures, say 90°C, it might be 0.6v. See the description of the Air Charge Temperature sensor for an explanation of what seems like Ohm's Law in reverse.

ECT Opens & Grounds

An open between thermistor and control module results in constant 5v. signal at control module.

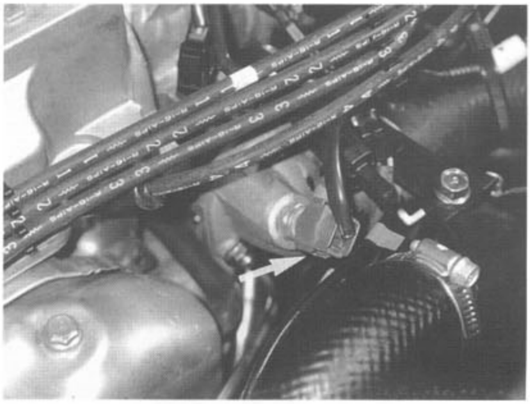


Fig. 5-1. Engine Coolant Temperature (ECT) sensor is located in coolant system in heater outlet fitting, near flywheel in 2.3L, and 3.8L Taurus/Sable and Continental; opposite flywheel in others.

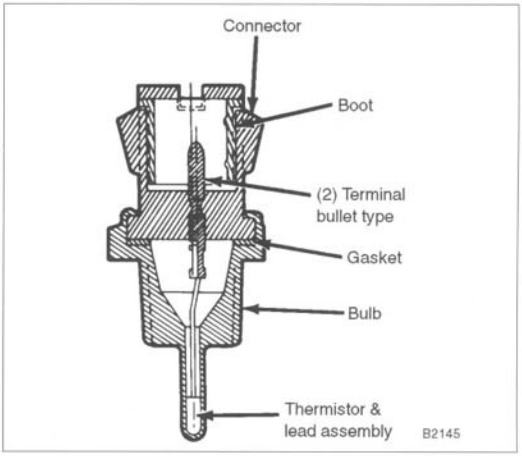


Fig. 5-2. ECT sensor is a thermistor in a housing, similar to ACT. ECT is important to air-fuel ratio, spark timing, idle rpm, emission control.

A short-to-ground in same circuit results in near-zero v. signal at control module.

Extra resistance in the circuit, such as corrosion at the connectors results in higher-then-normal voltage because the signal is based on voltage drop. Extra resistance could cause hard cold starts.Low coolant level causes a false rich signal, leading to a warm stumble.

Low coolant level causes a false rich signal, leading to a warm stumble.

6. EXHAUST GAS OXYGEN (EGO)—OXYGEN SENSOR

You'll remember from Chapter 2 the discussion of the ideal air-fuel ratio and its relation to emissions. The air-fuel ratio for best emission control is achieved by sensing the oxygen content of the exhaust gas. The oxygen sensor signal is monitored by the control module so it can adjust pulse time to maintain the ideal air-fuel ratio. The system operates closed-loop. The oxygen sensor affects emissions but has no effect on spark timing or idle-rpm control.

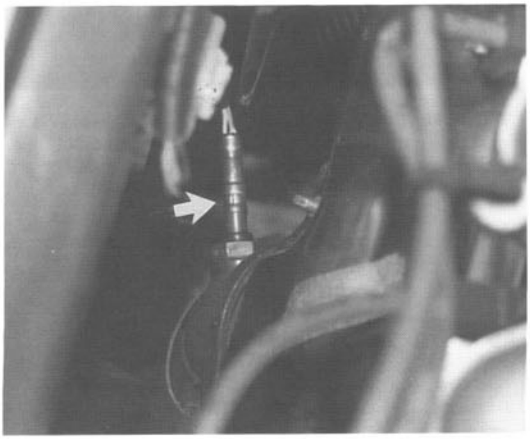


Fig. 6-1. Oxygen sensor generates its own voltage when air-fuel ratio is rich, but only when sensor is hot. Oxygen sensor threads into exhaust manifold where it samples oxygen content in hot exhaust gasses.

Oxygen Sensor Design

The oxygen sensor is something like a small battery. When it's hot, it generates a voltage signal based on the differential between the oxygen content of the exhaust gas, and the oxygen content of the ambient air.

A cutaway view of the oxygen sensor is shown in Fig. 6-2. On the right, the tip of the sensor that protrudes into the exhaust gas is hollow, so that the interior of the tip can be exposed to the ambient air, coming from outside. Both sides of the ceramic tip of the sensor are covered with metal conductive layers.

The ceramic sensor body is a solid electrolyte that generates a voltage only if the ambient air has a higher oxygen content than the exhaust. The ceramic material must be hotter than about 300°C (570°F). On a cold engine, it may take 90 to 120 seconds for an unheated oxygen sensor to get hot enough to start generating voltage.

In most 1988–93 EEC systems, and beginning with '93 MECS, you'll find electrically-heated oxygen sensors to improve emission control. During engine warm up, mixtures are rich because the system is operating open loop, not controlled closed-loop. The sooner the oxygen sensor becomes hot enough to send proper signals, the sooner the engine can operate closed loop for better control. A heated sensor may be

Ford has been the only manufacturer to call the oxygen sensor "EGO". The Ford Heated Exhaust Gas Oxygen sensor was "HEGO". Bosch-speak is "Lambda" sensor, from the Greek letter L, the German "Luft", referring to the "air" in the exhaust. New term O_2S from the chemical symbol for oxygen, O_2. The Heated Oxygen Sensor is "HO_2S".

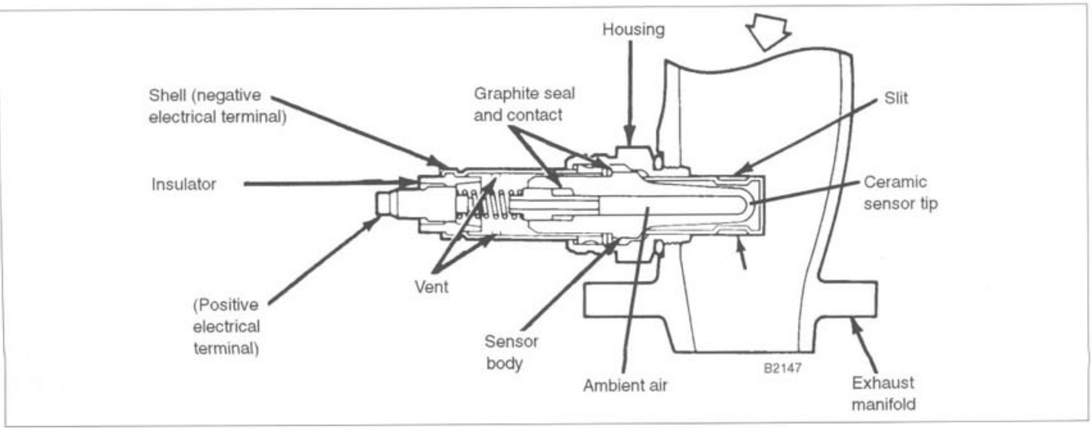


Fig. 6-2. Cutaway view of oxygen sensor. Oxygen sensor generates voltage when oxygen content of ambient air inside center tube is greater than oxygen content in exhaust gasses outside.

hot enough after 10 to 15 seconds. V-type engines usually have two oxygen sensors, one for each bank.

Oxygen Sensor Operation

- Oxygen in the exhaust is a sign of a lean mixture because the exhaust has excess air—air is left over after all the fuel is burned
- Lack of oxygen in the exhaust is a sign of a rich mixture because all the oxygen was burned with fuel—fuel is left over

When the air-fuel mixture is lean, the exhaust gas has oxygen, about the same amount of oxygen as in the ambient air, so the oxygen sensor will generate less than 400mv. Remember, lean = less voltage.

When the mixture is rich, there's less oxygen in the exhaust than in the ambient air so voltage is generated between the two sides of the tip. The voltage is greater than 600mv. Remember rich = more voltage.

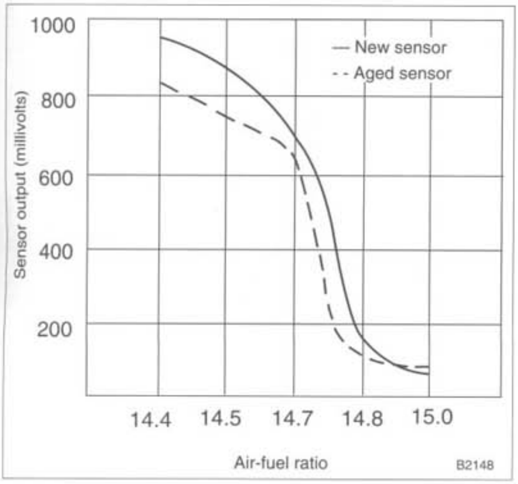


Fig. 6-3. Air-fuel ratio changes oxygen sensor voltage signal. Rich mixture and low content of oxygen in exhaust causes voltage output from oxygen sensor. Remember, rich = voltage. As oxygen sensor ages, its voltage changes are less.

Here's a tip: the newer the sensor, the more the voltage changes, swinging from as low as 0.1v. to as much as 0.9v. As an oxygen sensor ages, the voltage changes get smaller and slower—the voltage change lags behind the change in exhaust gas oxygen.

Because the oxygen sensor generates its own voltage, never apply voltage, and never measure resistance of the sensor circuit. To measure voltage signals, use an analog voltmeter with high input impedance, at least 10 Megohms. Remember, a digital voltmeter will average a changing voltage.

EGO Opens & Grounds

An open or a short-to-ground between the sensor and the control module results in a 0v. signal, similar to a lean mixture signal, so the engine runs rich.

A poor connection increases the resistance, dropping the voltage signal to the computer, with a similar lean signal, rich-running condition.

Failure of the oxygen sensor or its circuit is the leading cause of failure to pass emission tests.

6.1 Closed-Loop Control

In Chapter 2, I discussed open-loop/closed-loop systems. The oxygen sensor and the control module form the air-fuel ratio closed-loop system that continually adjusts the mixture by changing fuel-injector pulse time. In normal warm operation, the oxygen sensor generates a higher voltage because the mixture is rich, so the control module reduces pulse time to lean the mixture. Oxygen sensor voltage falls, so the control module increases pulse time to enrich the mixture. Sensor voltage increases, and so on....

The oxygen sensor voltage is always fluctuating as shown in Fig. 6-4, so it is hard to maintain the exact point at which the air-fuel ratio is ideal. Instead, the ratio tends to oscillate to either side of the ideal ratio. The oscillation is so fine—about 0.1 total oscillation around 14.72, that is 14.67 to 14.77—that it is not noticeable in engine performance.

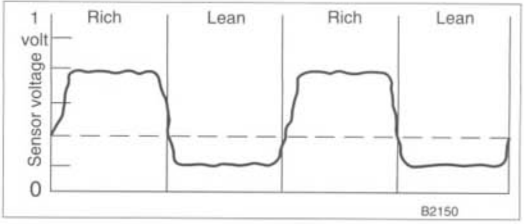


Fig. 6-4. Closed-loop oxygen sensor voltage cycles back and forth from slightly rich to slightly lean. Cycling increases with engine rpm and sensor temperature.

The rate of the air-fuel ratio oscillation, from lean to rich and back (sometimes referred to as "cross-counts") is related to how much exhaust passes a sensor. At idle, the cycle may take about 1 second. At cruising speed, the cycle may happen several times a second. Cycling is fastest when an oxygen sensor is hot, and new; cycling slows down as a sensor ages from mileage and/or time, or by coatings deposited by fuel.

Closed-loop air-fuel ratio control operation is known as "short-term" trim. It must operate quickly and continuously to maintain air-fuel ratios as close as possible to the stoichiometric. Later, I'll discuss "long-term" air-fuel ratio control, known

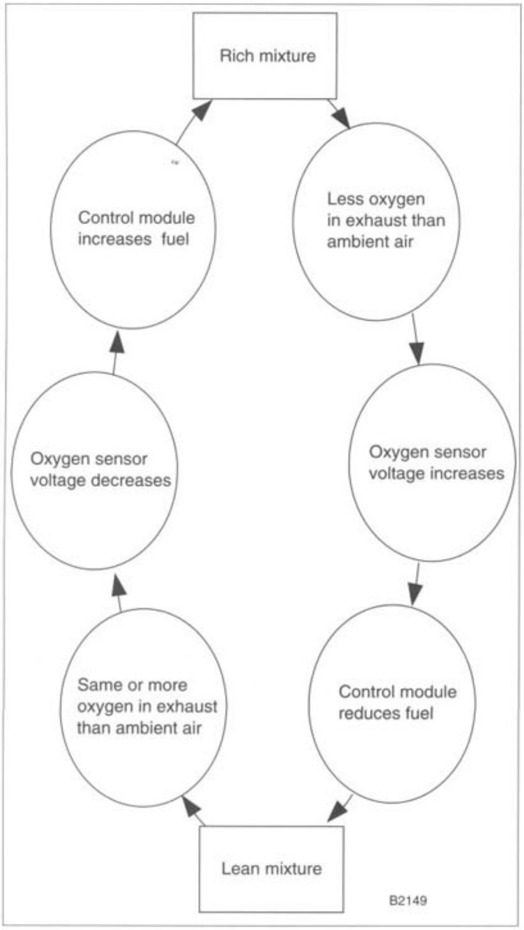


Fig. 6-5. Ford engine controls operate closed-loop most of the time.

as adaptive strategy. Ford uses Adaptive strategy in all vehicles since 1986.

This closed-loop system can adapt to compensate to some degree for changes in the engine over time. For example, if a valve is leaking slightly, or if there is an intake air leak, the oxygen sensor senses the change in combustion and brings the system back within its design limits. Changes beyond the system's range, though, can still lead to driveability problems.

Before the oxygen sensor is heated enough to generate a proper voltage signal, the control module is programmed to operate open-loop at programmed injection rates. While it's cool, even while the engine is warm, the oxygen sensor voltage signals are meaningless and the control module is programmed to ignore them, operating the system open loop. The same thing happens if you disconnect or cut the oxygen sensor wire, or if the sensor is fouled by leaded gasoline. This becomes important when you are trying to make closed-loop adjustments at idle, and the unheated sensor cools off because not enough exhaust is passing it. Many service procedures depend on closed-loop operation, so remember that the oxygen sensor has to be warm enough.

7. THROTTLE POSITION (TP) SENSOR

The Throttle Position (TP) sensor signals the control module about intentions of the driver (or throttle actions as actuated by the Cruise Control). The TP sensor mounts directly on the throttle body, and rotates with throttle shaft to signal the position of the throttle plate.

Fig. 7-1. Throttle Position (TP) sensor (arrow) sends a feed-forward signal to control module of just what you would expect—throttle position. Movement signals what driver expects engine to do.

Movement causes feed-forward signals. For example, when you step on the accelerator, the TP signal increases before the manifold air pressure or the air flow increases. In a way, it contributes to the calculations about load, signalled by other sensors I've described earlier, the MAP for Speed Density, the MAF for Mass Air Flow, and the VAF for Volume Air Flow. The TP signal can cause enriched mixture as the throttle opens, something like the accelerator pump of a carburetor. The control module interprets signals from the TP in six ways:

1. Amount of throttle opening—how far is accelerator depressed? Amount is important to Cruise Strategy.
2. Rate of throttle opening—how fast is the accelerator being depressed? Rate is important to Acceleration Strategy.
3. Closed-throttle position—idle or deceleration.
4. Wide-Open Throttle position—acceleration enrichment, A/C cutout, de-choke on crank.

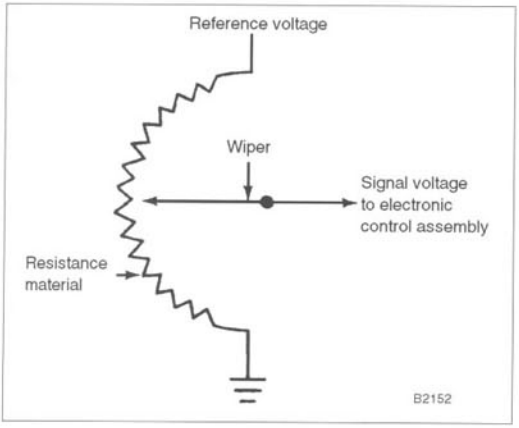


Fig. 7-2. TP operation: VREF is supplied to grounded resistor. As wiper turns on its shaft, a variable voltage signals control module about shaft position.

5. Failure of MAF signal—TP helps control module to calculate air intake based on throttle opening and rpm.
6. Transmission-shift signals for electronic automatic transmissions (transaxles).

The TP potentiometer operates from VREF of 5v. The TP signals affect injected fuel, spark timing, idle rpm, and emissions. The TP sensor is an important sensor.

Recent Ford systems, all EEC since 1988, use a Rotary TP. The potentiometer increases resistance as the throttle shaft rotates. It is not adjustable, but the control-module programming compensates for any differences in sensors, readjusting to a base voltage when the throttle is closed.

The TP sensor signal voltage increases directly with rotation of the throttle shaft. Actual values vary with engine application and are given in specs. Fig. 7-3 is a typical signal curve.

TP Opens & Grounds

An open results in a 0v. signal if there is a fault in one of the following: a) VREF; b) signal return; c) sensor itself; d) VREF side of wiper

An open results in a 5v. signal if the open is in the ground line, or on the ground side of the wiper.

A short-to-ground in either VREF or signal return results in 0v. signal.

Higher than normal resistance in VREF results in lower voltage input, tending to cause lean mixtures and misfire.

Higher than normal resistance in the ground results in higher voltage input, tending to cause rich mixtures.

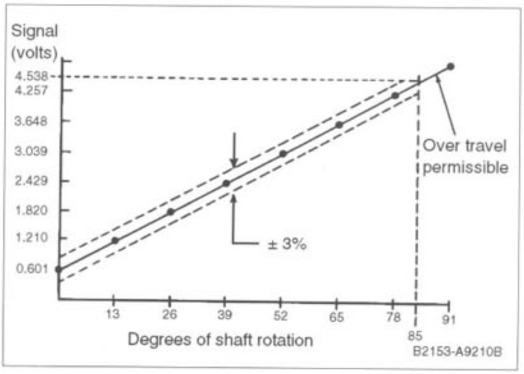


Fig. 7-3. As throttle shaft rotates, signal voltage increases in straight line. Values vary according to application so do not apply these numbers to a specific engine.

MECS Throttle Sensors and Switches (TP)

Some MECS Throttle Position sensors are quite similar to the EEC TP sensor. The potentiometers signal the full range of throttle plate movement. In addition, the control module in most MECS systems depends on a separate signal that the throttle is closed. Although referred to as Idle, the closed-throttle signal is also important to deceleration, when the engine is far from idle. I find it less confusing to refer to it as a closed-throttle switch. In this book, I'll say CTS (idle).

In the 1.8L Automatic Transaxle (ATX) and 1.3L, the CTS (idle) switch is integrated with the potentiometer in the TP sensor. See Fig. 7-4. In the 2.2L engines, the CTS (idle) switch is separate. See Fig. 7-5. The switch is closed when the throttle

Fig. 7-4. MECS 1.8L and 1.3L style TP.

plates are closed. For good engine control, it is important that the switch open as soon as the primary throttle plates open.

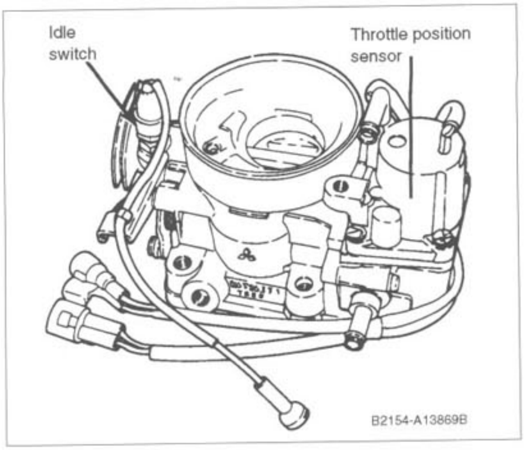


Fig. 7-5. Some MECS Throttle Position (TP) sensors have so-called Idle Switch. "Idle" Switch is separate from the TP sensor in 2.2L engines.

In the '93 and later 2.5L V-6, the throttle body carries the TP sensor on the main shaft. The TP sensor includes a potentiometer and an integral CTS (idle) switch. See Fig. 7-6.

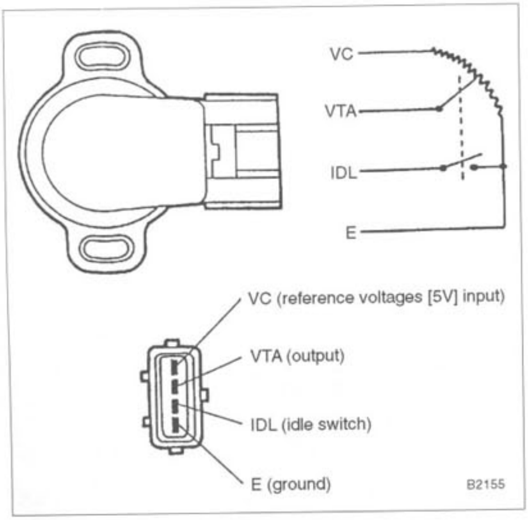


Fig. 7-6. In 1993 and later 2.5L V-6, TP sensor mounts directly on throttle shaft, with no dashpot.

In the '93 2.0L system, the TP sensor signals potentiometer voltage drop as throttle is opened. This TP sensor lacks an CTS (idle) switch, differing from the '93 2.5L V-6. The TP sensor helps the control module calculate intake air if the MAF sensor fails.

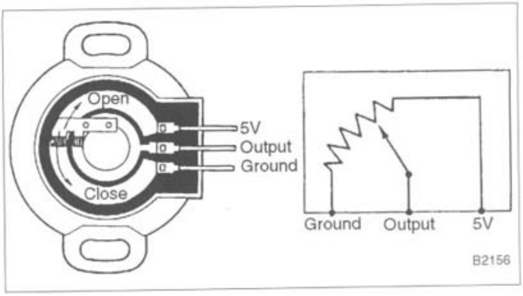


Fig. 7-7. TP sensor of '93 2.0L includes potentiometer but no CTS (idle) switch. TP sensor is not adjustable.

In the other MECS systems, the 1.8L Manual Transaxle (MTX), the 1.6L and 1.3L engines, two switches signal closed (idle) and Wide Open Throttle (WOT). This is described as integrated with the TP sensor. However, with no potentiometer, the idea of "integrated" stretches the definition of a Throttle Position Switch. In signalling only closed and WOT, the two-position switch is similar to early Bosch fuel-injection control.

8. KNOCK SENSOR (KS)

The Knock Sensor (KS) is a feedback signal used for control of spark timing and wastegate, not for fuel injection, idle rpm, or emission control. You might think of the KS as an insurance policy, allowing the spark timing to be more advanced with less concern that harmful knocking will destroy the engine. In other words, the engine designer is reasonably sure he can protect against engine destruction from knocking. As a result, he can program more timing advance than if he had to provide a cushion against the possibility of uncontrolled destructive knocking. Some V-type engines use a separate knock sensor on each bank. Check the wiring schematics in Chapter 12.

KS Design and Operation

The KS is a tuned vibration sensor accelerometer mounted on the engine block. The KS is something like a tuning fork that vibrates most at a certain narrow band of frequencies. When the KS vibrates, its crystal generates a small voltage (about 1v.) that changes with the frequency of the engine vibrations.

Depending on the engine, knock may be signalled at frequencies of about 6 Khz—5450, 5700, 6000, 6150, and 6400

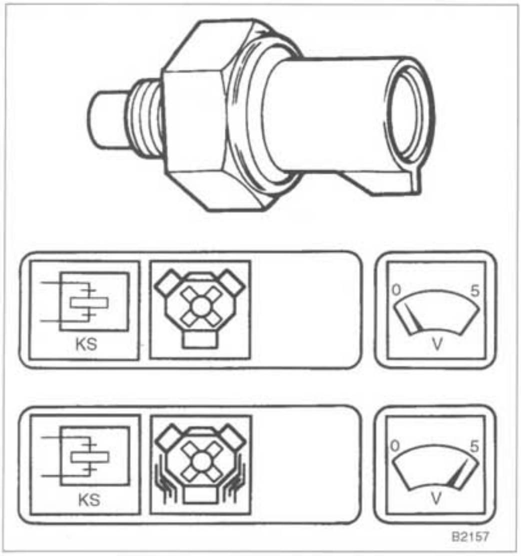


Fig. 8-1. Knock Sensor (KS) converts engine vibrations directly into a signal for control module to control spark timing.

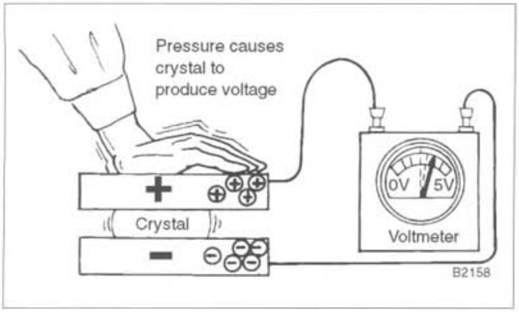


Fig. 8-2. Engine-knock vibrations force KS crystal to vibrate, generating voltage signals.

Hz (cycles per second). Some engines require a different knock sensor because they have a different resonant frequency—9,500 Hz for some 4.9L, 5.0L, 5.0L Econoline/Broncos. Those would be pretty high musical notes. Based on engine dynamometer tests, those specific vibrations are chosen because they are known to indicate engine knocking. The control module can be programmed to ignore other vibrations.

When knocking occurs, the KS signals in the design frequency range cause the control module to retard the timing. If that reduces or eliminates the knock, then after a few seconds the control module again advances timing. If knocking continues, the control module opens the wastegate to reduce boost.

You can see that the KS supplies a feedback signal for timing, similar to the EGO feedback signal for fuel injection. That means the KS operates closed-loop. With input signals from cylinder-identification sensors, the control module can identify the individual cylinder that is knocking (one cylinder usually starts knocking before the others). EEC-IV has the computing power for individual-cylinder knock control, retarding the spark only for the knocking cylinder(s).

In some engines, the KS acts as a limited-range automatic octane selector, advancing timing for increased power when the engine is burning fuels with higher anti-knock index. With lower octane fuel, timing is automatically retarded, with corresponding lower power outputs.

For years, drivers have known that using higher-octane fuel did not add to engine power unless spark timing was adjusted at the distributor to take advantage of the improved anti-knock index. Now, with knock sensors and closed-loop spark-advance control, power output can depend on the anti-knock index of the fuel being burned. I have even seen engine-power specifications include the anti-knock index of the fuel to be used.

It may even be less than desirable to use fuel with a higher octane rating than called for in the owner's manual. Recent advancements in emission control may depend on so-called "fast-burn" to reduce emissions. If you burn 92 RON when the engine is designed for 87 RON, the higher octane fuel burns slower, and may add deposits to the combustion chamber.

With precise control of spark timing and turbo boost, engines can be designed with higher compression ratios for greater power output. On all engines, the knocking limits depend on many factors:

- Intake air temperature
- Engine temperature
- Engine deposits
- Combustion chamber form
- Mixture composition—air-fuel ratio, and stratification
- Fuel quality
- Air density, altitude and weather

MECS Knock Sensor (KS) and Knock Control Unit (KCU)

The MECS-I Knock Sensor (KS) is similar to that of the EEC systems. The principle difference is the Knock Control Unit (KCU). Where the EEC control module receives and calculates knock signals directly, the MECS-I KCU filters the vibrations and signals the control module only when the vibrations indicate engine knocking and not just engine vibrations.

In 1993 2.5L V-6, the knock sensor sends vibration signals directly to the engine computer, eliminating the Knock Control Unit. The 2.5L engine computer determines if the vibrations are knocking signals. The engine computer can retard timing up to 6 degrees, depending on the severity of the knock. This

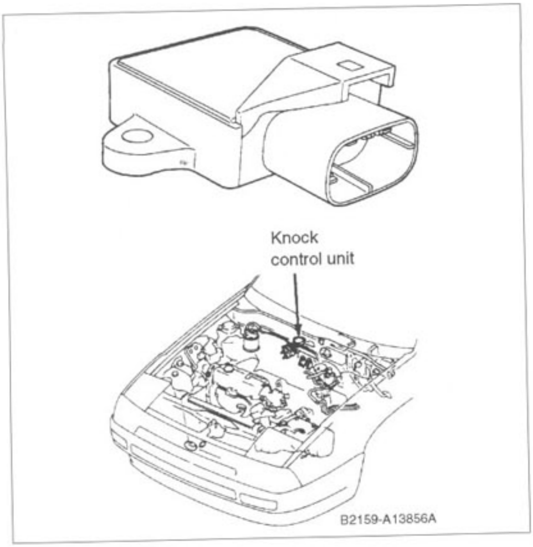


Fig. 8-3. MECS-I KCU (Knock Control Unit) filters engine vibrations and signals control module when vibrations indicate engine knocking. 2.2L turbo shown, 1.6L turbo similar.

KS operates between 750 and 5500 rpm, but its torque improvement is greatest below 3000.

KS Opens & Grounds

An open or short-to-ground results in a 0v. signal to the control module.

Poor connection between sensor and control module may drop the signal voltage to hide the knock.

9. OTHER SENSORS

9.1 Octane Switch

The Octane Switch in some engines adds a feed-forward signal for spark timing and turbo boost. When the Octane Switch is in place in the underhood socket, it shorts the contacts in a circuit to the control module for normal spark timing. If the engine is knocking with the fuel being used, you can change to a higher octane fuel, or you can remove the switch from the socket to retard the timing by about 3 degrees, and reduce the maximum boost.

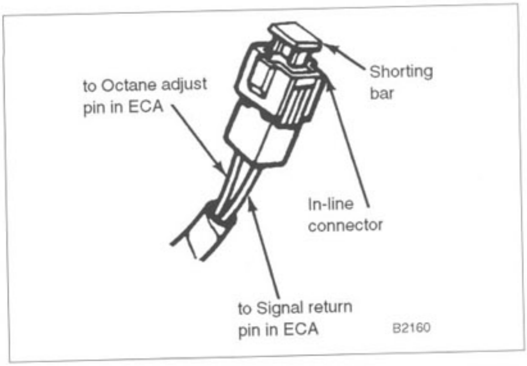


Fig. 9-1. Octane Switch shorting bar closes a circuit to control module providing normal spark advance for fuels of recommended octane. Removing shorting bar signals control module to retard spark about 3 degrees to handle fuels of lower octane.

> Bob Stelmaszczak of Ford SVO (Special Vehicle Operations) told me of the beginnings of the Octane Switch. In qualifying the Ford original 2.3L turbo to California regulations, he ran up against a requirement that the engine control provide for operation on regular fuel. The turbo engine was set up for premium, and it was pretty late to change the engine control. Simple solution: The Octane Switch, which continues in current applications.

9.2 Barometric Pressure (BP)

The Barometric Pressure (BP) sensor generates a frequency signal that changes with pressure. It looks and operates like the MAP. The only difference is that the MAP is connected to the manifold, while the BP is vented directly to the atmosphere, or barometric pressure. See earlier Fig. 3-2.

The BP is used by the control module as part of control of fuel injection, spark timing and emission control. The BP is most important when the vehicle is driven at altitudes significantly above sea level.

- In some engines, BP (Barometric Pressure) is measured by the MAP sensor, switched over during conditions of engine-off and Wide Open Throttle
- In other engines, BP is measured by a separate similar sensor open to the atmosphere. It may be called BAP or BARO. Look for a separate BP on MAF engines

MECS Barometric Pressure (BP)

Most MECS employ Barometric Pressure (BP) sensors to help in controlling air/fuel ratio and idle speed. In most systems, the BP sensor is integrated into the ECA. The exception is the 1.6L engine with its separate BP sensor. Late model MECS do not use BP sensors.

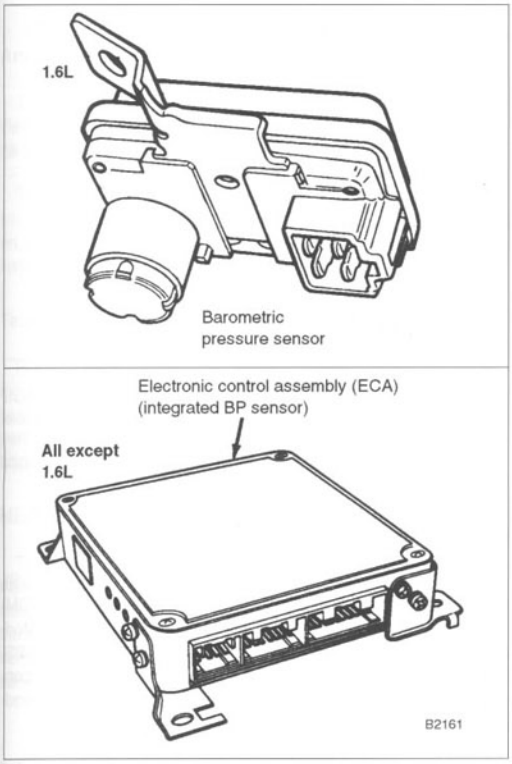


Fig. 9-2. Most MECS mount BP in control module for direct input. 1.6L systems mount a separate BP sensor on cowl.

9.3 EGR Feedback

The EEC system receives feedback signals about the exhaust gasses that are diluting the air-fuel mixture flowing into the combustion chambers. EGR feedback changes the air-fuel mixture calculations and the resulting injection pulse times. Ford has used several different types of monitors, but in the latest vehicles, you'll want to know about these three.

Pressure Feedback EGR (PFE)

Pressure Feedback EGR (PFE) is a closed-loop EGR system that senses the pressure drop across an orifice or opening in the EGR passage to determine EGR flow. See Fig. 9-3. The PFE transducer senses a controlled pressure input and signals the EEC module. The module sends a duty-cycle signal to the EGR Vacuum regulator(EVR), controlling the intake vacuum that operates the EGR valve. By regulating the pressures that control the EGR valve, PFE balances the changing pressures in the intake manifold and the exhaust manifold so the EEC module can compute the proper EGR flow rate.

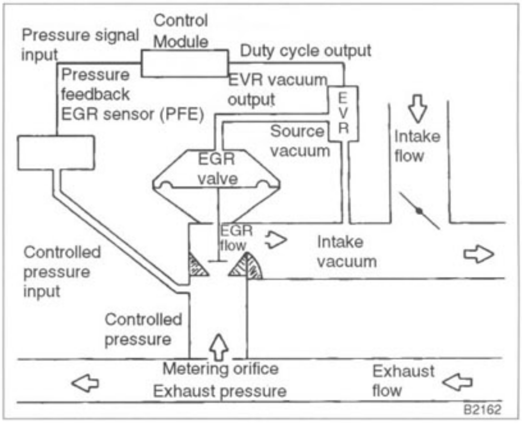


Fig. 9-3. Pressure Feedback EGR (PFE) system controls EGR flow rate by monitoring pressure drop across metering orifice.

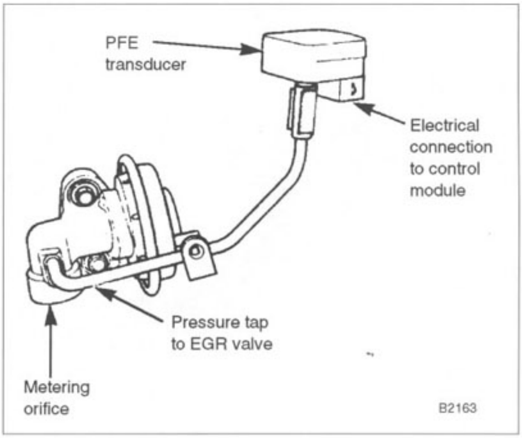


Fig. 9-4. PFE transducer senses exhaust pressure, converts that to an analog voltage signal to EEC module.

Delta Pressure Feedback EGR (DPFE) sensor

Delta is the engineering term for "difference", from the Greek letter "delta". DPFE is similar to PFE except that it measures the difference between the exhaust pressure in the exhaust system and the pressure at the EGR metering orifice. DPFE is applied to the newer engines beginning in 1991.

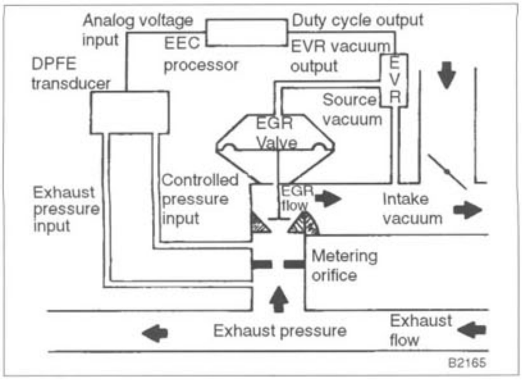


Fig. 9-5. Delta Pressure Feedback Electronic (DPFE) EGR system controls EGR flow rate by monitoring difference between exhaust pressure and pressure drop across metering orifice.

EGR Valve Position (EVP) sensor for Electronic EGR (EEGR)

The EGR Valve Position (EVP) sensor signals the position of the EGR pintle valve. See Fig. 9-6. The Electronic EGR (EEGR) system operates the EGR valve by a duty-cycle output to the EGR valve-regulator solenoid (EVR).

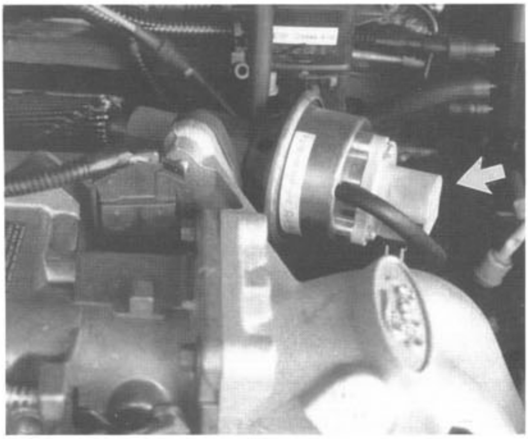


Fig. 9-6. EGR Valve Position (EVP) sensor on EGR valve signals EGR valve movement to EEC module.

9.4 Vehicle Speed Sensor (VSS)

The Vehicle Speed Sensor (VSS) uses a magnetic pickup, usually mounted on the transaxle, to signal the control module about the vehicle speed. The VSS is important for control of speed (Cruise) control, idle-air bypass, transmission torque-converter lock-up, and engine cooling fan (Ford cars cut off the electric fan at about 45 mph).

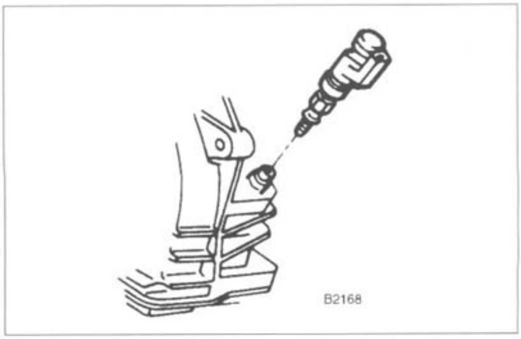


Fig. 9-7. The VSS (Vehicle Speed Sensor) is driven from the transmission to signal the control module about vehicle speed.

Programmable Speedometer/Odometer Module (PSOM)

On EEC-IV vehicles with Anti-Lock Brake Systems (ABS), the Programmable Speedometer/Odometer Module (PSOM) delivers vehicle speed signals to the Powertrain Control Module. PSOM uses the same toothed-wheel sensor as the ABS. In addition to providing vehicle speed data for powertrain control, PSOM also sends vehicle speed signals to the speed-speed control (Cruise Control).

MECS vehicle speed is signalled by a sensor (VSS) located in the speedometer of the instrument panel.

9.5 Feed-forward Switches

Feed-forward switches signal the control module to anticipate that a load will be added to the engine. Feed-forward switches are the opposite of feedback sensors, which signal the control module what has happened. Generally, feed-forward switches are important to control of idle rpm. You'll remember from Chapter 2 that idling at the lowest rpm is important for fuel economy and emissions, so feed-forward switches prevent stalling when load is added.

Following are examples of feed-forward switches, most of them designed to prevent engine stall at idle, not all found on all cars.

Control of idle-air bypass for control of idle rpm depends on the loads carried by the idling engine. I divide those into three categories:

- Drive loads, such as A/T in a drive gear, or M/T applying power
- Continuing accessory loads such as air conditioning
- Other temporary loads, such as power steering during parking

Accessory Loads

The Air Conditioner Clutch (ACC) feed-forward signal advises the control module when the AC clutch is about to be engaged, anticipating adding load to the engine.

The Heated Rear Window switches and Heated Windshield switches are feed-forward signals to the control module, when on, to anticipate idle-rpm drop from the extra load on the alternator.

Temporary Loads

Power Steering Pressure Switch (PSPS) signals the control module when the power steering system is operating at high-pressure—above 400–600 psi such as during a sharp turn in parking, usually with engine idling. When PSPS closes, it anticipates the PS load and calls for idle rpm increase.

MECS Electrical Load Unit (ELU)

The Electrical Load Unit (ELU) collects signals of the electrical load to assist in control of Idle RPM. When any of these loads is added to the electrical system, the additional drag of the alternator could drop idle rpm to unstable or rough conditions. To prevent this, the ELU signals the ECA to call for additional bypass air to maintain the target idle rpm.

- Rear defroster
- Engine Cooling Fan
- Heater/Air Conditioner Blower
- HeadlampsYou can appreciate that the smaller *MECS engines would be more affected by these* electrical loads than, say a 5.0L engine.

See **Table c** at the beginning of this chapter for additional switch types and systems.

Brake On/Off Switch

The Brake On/Off (BOO) signal comes from the stoplamp switch. When the brakes are applied, the BOO signal to the control module can cause:

- Short-time brake application—3 to 5 seconds cut off of AC compressor circuit and engine cooling fan
- Longtime brake application—idle cut-off of AC compressor circuit; also increased idle rpm

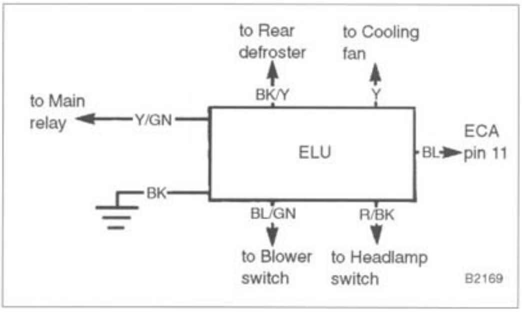


Fig. 9-8. Electrical Load Unit (ELU) collects signals relating to electrical load for input to the ECA.

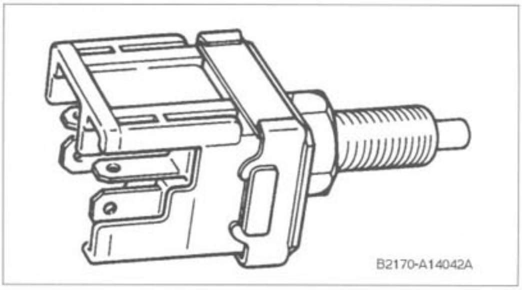


Fig. 9-9. Brake On/Off (BOO) switch signal to control module can affect air conditioning and engine cooling fan.

This is one of those "gotchas" because a burned out stoplamp bulb, or open circuit can cause engine control problems. And you would never think to check that circuit, would you? When they called this the BOO switch, someone at Ford had a sense of humor.

Drive Loads

The Automatic/Transaxle Neutral Drive Switch (NDS) signals when the transaxle is in Neutral or Park, a no-load condition. A shift out of P or N sends feed-forward signals to the control module to anticipate a drive load on the idling engine.

In manual transmissions (M/T), the Clutch Engaged Switch (CES) and the Neutral Gear Switch (NGS) work together to sense load on the engine. If transaxle is in any drive gear (other than N), and if clutch is engaged, that feed-forward signal anticipates that the engine is being loaded.

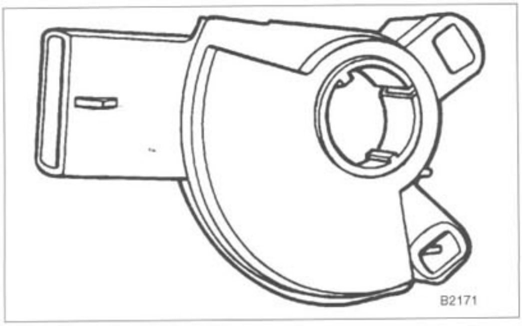


Fig. 9-10. Neutral-Drive Switch sends feed-forward signals to control module, anticipating when automatic transmission will load the engine. This prevents a drop in idle rpm which could stall engine.

10. POWERTRAIN

10.1 Automatic Transmission/Engine Control

I want to mention the interactions between electronic engine control and the electronic control of automatic transaxle and transmissions. I will not cover the control of the transaxle, but rather show how much engine and transaxle depend on each other. Look for increasing use of what Ford calls AXODE (Electronically Controlled Automatic Overdrive Transaxle) in Ford-engine cars, and EAT (Electronic Automatic Transaxle) in Mazda-engine cars. In some vehicles, electronic control of both engine and transaxle is in the same computer whose name is now Powertrain Control Module (PCM). In others, control is in two computers that communicate with each other.

The following transaxle signals are important to engine control:

- Manual Lever Position Switch (MLPS)—engine can crank only if in Neutral or Park
  - increased throttle-air bypass to increase idle rpm for engine load if in Neutral or Park
  - in most vehicles, a variable-resistance rotary-switch, mounted on the shift linkage, indicates shift lever position to the ECA
  - in Escort/Tracer EAT, the shift lever positions OD, D, L, R, N or P are signaled to the EEC-IV computer by a series of switches. Similar for MEC cars with EAT
  - several vehicles have electronic control of shifting: rear-drive Crown Vic/Grand Marquis/Town Car (AOD-E); front-drive Taurus/Sable/Continental (AXOD-E); E/F Series/Bronco (E4OD). These signal position through a single lead, MLP.
- Vehicle Speed Sensor (VSS)
- Transmission Speed Sensor (TSS)
- Transaxle Oil Temperature (TOT)
- Forcing downshift or unlocking Torque Converter Clutch if transaxle is overheating

The following engine signals are important to transaxle control:

- Throttle Position (TP)—Downshift when driver wants more power
- Engine Coolant Temperature (ECT)—Restrict Torque Converter Lockup until engine is warm

In addition, a Powertrain Control Module (in distinction from Engine Control) signals the automatic transaxle (ATX) to upshift according to several factors including engine temperature, throttle position, and vehicle speed.

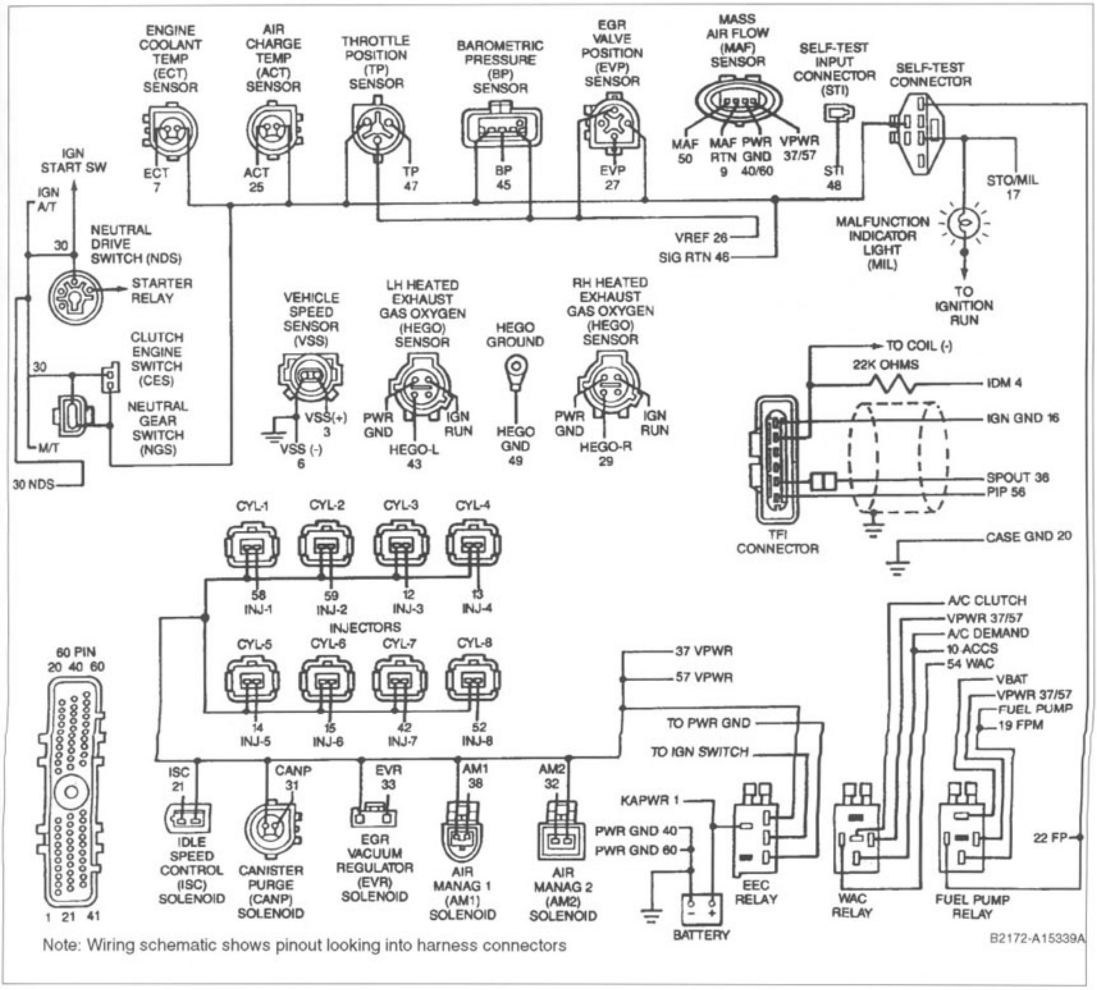
In advanced powertrain controls, the electronic engine control (EEC) operates with the ATX control to reduce the load during shift. Whether the operation is one computer or two linked computers, it works like this:

1. ATX computer determines proper time to shift, advises EEC that transaxle is about to shift.
2. EEC retards spark for about 20 milliseconds, just enough to reduce power briefly. EEC advises ATX computer that it has retarded spark. NOTE, if engine is cold, EEC will not retard and will not signal ATX.
3. ATX shifts during power reduction.
4. EEC advances spark timing to normal. Driver experiences a smooth shift. ATX experiences less load on clutches, extending transaxle life.

11. CONCLUSION

You've seen six types of sensors that monitor conditions and send input signals to the control module. Many of these are returned as signals referenced to VREF = 5v. You've seen typical switches, many of them feed-forward switches that signal the control module to anticipate engine loads that would cause the idling engine to stall.

When you look at the electrical schematic in Fig. 11-1, or at the large number of pins in the connector to the control module, you begin to appreciate the large number of sensor signals going to the computer. In the next chapter, I'll discuss what happens to those signals in the control module.



Note: Wiring schematic shows pinout looking into harness connectors

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Fig. 11-1. Typical wiring diagram shows number of sensors with input signals to control module. (Outputs shown at lower left.)

12. NISSAN ELECTRONIC CONCENTRATED ENGINE CONTROL SYSTEM (NECCS) ('93 Mercury Villager)

The sensors of this 3.0L Nissan engine in the Mercury Villager are quite similar to those in Ford EEC systems. The major exception is the Crankshaft Position sensor (CKP).

The Crankshaft Position (CKP) sensor uses light pulses passing through slits in a rotor plate in the distributor. With one set of 360 slits in the outside of the plate, engine speed is measured once for each degree of distributor rotation—2 degrees of crankshaft rotation. This signals the control module with great frequency, ensuring rapid response to acceleration—changes in engine speed.

A second set of six slits signals once for each cylinder to assist in timing of spark and sequential injection. One of these slits is oversize, signalling the timing of cylinder #1.

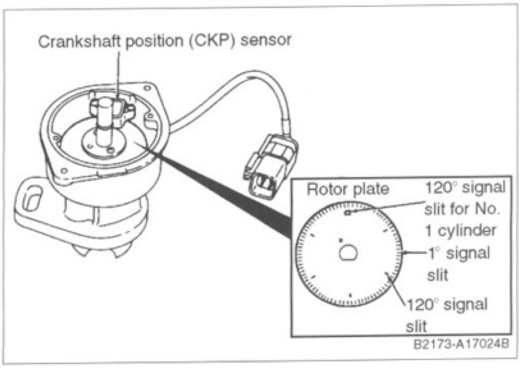

Fig. 12-1. NECCS Crankshaft Position (CKP) sensor in distributor housing uses Light Emitting Diodes (LED) and photo diode to count slits in rotor plate.