2006 MY OBD System Operation

Summary for Hybrid Electric Vehicles

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Introduction Hybrid Electric Vehicles

HEV Powertrain Description

A hybrid electric vehicle is powered by a conventional engine with an electric motor added for enhanced fuel economy and reduced emissions. The electric motor can also be used to boost power and enhance performance (like an extra "charge"). Daily recharging plug-ins aren't needed. This type of vehicle is well suited for the environmentally aware driver who wants better fuel economy and fewer pollutants, but doesn't want the hassle of plug-ins.

A vehicle can be "more" of a hybrid than another. There are two levels of "hybridization," mild and full.

Full hybrids have all of the functions and capabilities of a mild hybrid, plus more advanced features. With both, the engine turns off when it is not needed, reducing fuel waste, and instantly restarts when the need for power is detected. In addition, both hybrids provide electric assist, in that the gasoline engine gets a boost of electric power from the battery pack. This provides additional acceleration performance when needed, without additional use of fuel. However, a full hybrid usually has a substantially higher powered battery than a mild hybrid.

A full hybrid also gives you regenerative braking (meaning vehicle energy that would otherwise would be wasted, is collected during braking to recharge the battery) while a mild hybrid has only mild regenerative braking. And only a full hybrid provides an electric launch. In full hybrid systems only, the electric motor can power the vehicle, even while the engine is off. The electric motor can be used to drive in pure electric mode even when accelerating from a complete stop. An easy way to tell the difference between a mild and a full hybrid is that a full hybrid gets better mpg in the city than on the highway.

Benefits of Hybrid Electric Vehicles

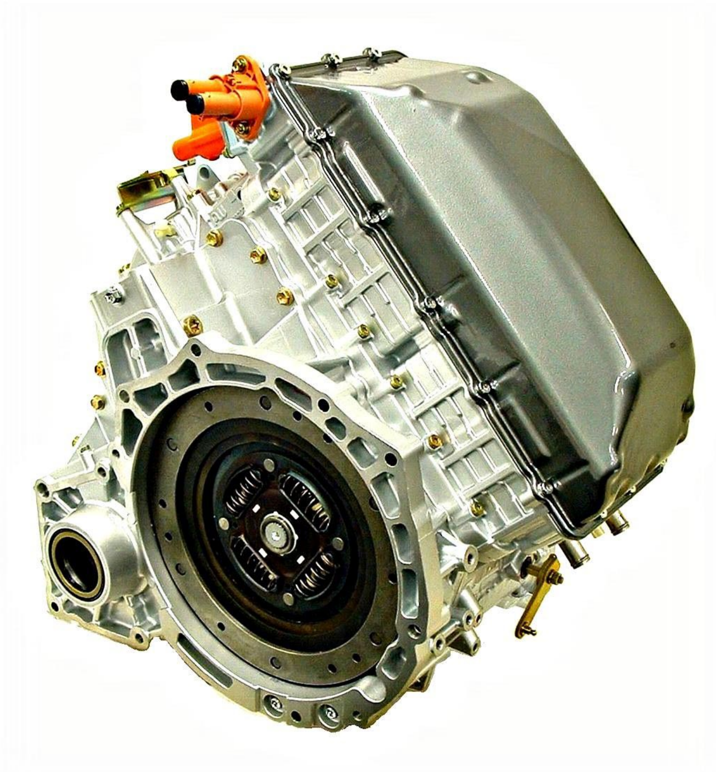
- Reduces emissions by increasing average engine efficiency.
- Engine shuts down, when the vehicle is stopped.
- Electric motor boosts acceleration performance.
- Regenerative brakes recapture energy, to recharge the battery.
- Improved fuel economy stretches a tank of gas further, saves you money, and helps you conserve our limited petroleum resources.
- Driving performance is optimized because both the gas engine and electric motor are working for you.
- No battery plug-ins required.
- An HEV offers all the conveniences of conventional vehicles: spacious seating, storage room, creature comforts, and extended driving range.
- The Ford Escape HEV will be delivered, sold, and serviced at local Ford Dealers.

Key Powertrain Components

Engine

- 2.3L I-4 Gasoline Engine
- Electronic Throttle Control
- Atkinson Cycle to improve efficiency by reducing pumping losses
- For Otto Cycle, expansion ratio equals compression ratio
- Atkinson Cycle expansion ratio greater than compression ratio
- Leaves intake valve open longer during compression stroke pushing air back into intake manifold
- Operates with less vacuum and greater throttle opening to maintain air charge

Transaxle



- 36 kW Permanent Magnet AC Generator Motor
- 65 kW Permanent Magnet AC Traction Motor
- Power Electronics / Voltage Inverter
- Planetary gear set and final drive gears
- Connected to front 2-wheel or all-wheel driveline

Battery

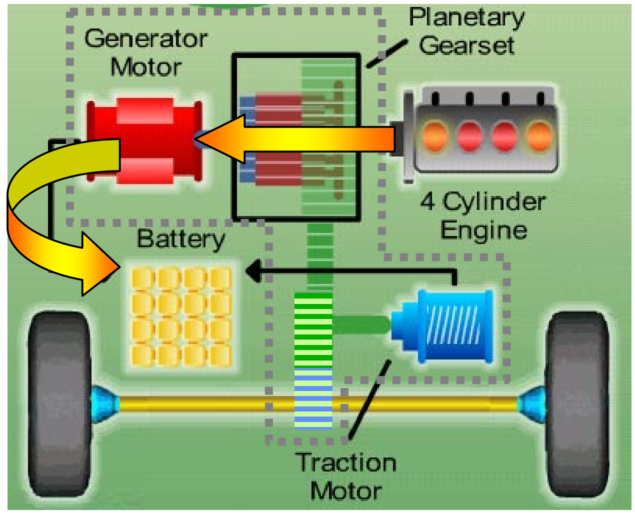
- Ni Metal Hydride
- 39 kW power rating (new)
- Nominal 330V DC operation
- 5.5 Amp-hrs capacity

Nickel-metal hydride batteries (NiMH) have a much longer life cycle than lead acid batteries. In addition to electric vehicles and HEVs, they are often used in consumer electronics, computers and medical equipment.

Propulsion Modes

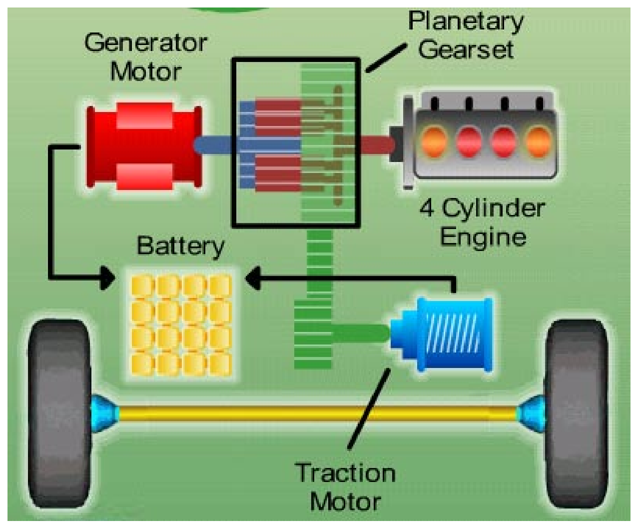
Series Mode

- Used only when vehicle is not moving and the engine is running
- Engine may be running for battery charging, cabin or battery temperature control, or catalyst warm-up.



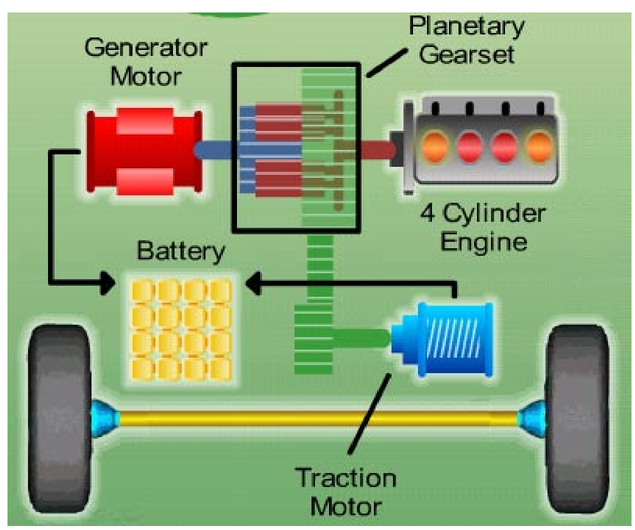
Positive Split Mode

- Engine is ON and driving the generator motor to produce electricity
- Power from the engine is split between the direct path to the road and the path through the generator motor
- Generator power can flow to the battery or to the traction motor
- The traction motor can operate as a motor or a generator to make up the difference between the engine power and the desired power
- This is the preferred mode whenever the battery needs to be charged or when at moderate loads and low vehicle speeds

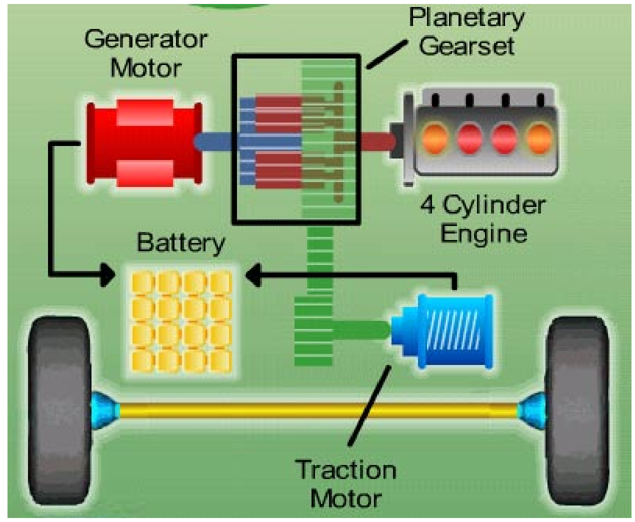


Negative Split Mode

- The engine is on and the generator motor consumes electrical energy to reduce engine speed
- The traction motor can operate as a motor or a generator to make up the difference between the engine power and the desired power
- Typical highway mode
- Occurs when the engine needs to be on, the system can not be operated in parallel mode and the battery is charged near its upper limit



Electric Mode



- The vehicle is propelled by stored electrical energy only
- The engine is turned off
- The tractive torque supplied from the traction motor
- Preferred mode whenever the desired power is low enough such that it can be produced more efficiently by electrical system than engine
- Preferred mode in reverse because the engine can not deliver reverse torque
- Separate electric pump maintains power assisted steering

City & Highway Traffic Scenarios

Stopped

- The engine will be off unless it needs to be on for reasons other than tractive power (Max A/C, vacuum, catalyst temp, heat, purge, low SOC)

Launching

- At low speed or low power demand, the launch mode will be electric, unless the engine needs to be on for other reasons.
- At moderate speed or high desired power, the engine will come on.

Entering highway or Passing

- At high acceleration demand, the engine power will be boosted with battery power through the traction motor to provide quick V-6 like response.

Cruising

- At light load, the system may operate in parallel, positive split or negative split mode depending on the battery charge.
- At heavy load (due to high speeds, weight, towing or grade), the system will be limited to engine only performance (no battery support).
- Limited regenerative braking will be used.

Exiting highway

- Provides an opportunity for regenerative braking.

Braking

- At high speed, the engine torque is ramped down, the traction motor regenerates to a limit and the foundation brakes are applied as necessary (at the traction motor or battery regen limits).
- At moderate and low speed, the engine will be turned off.

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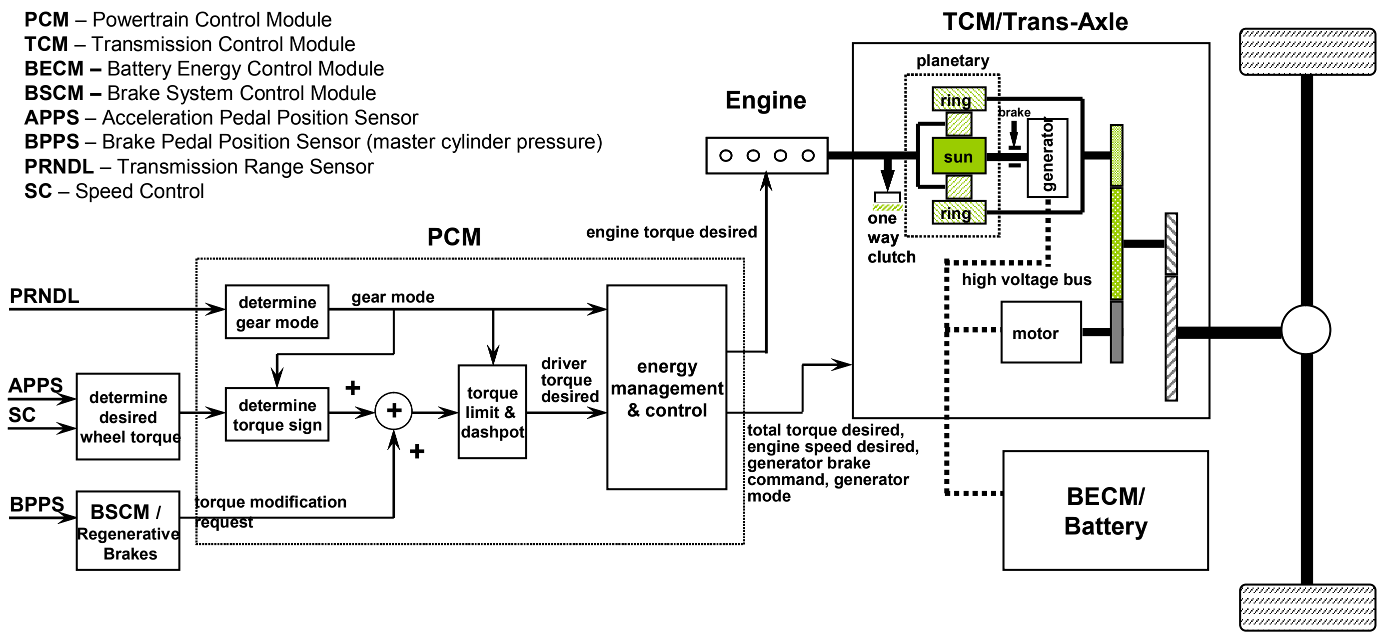
Escape HEV Powertrain Control System



The Hybrid Electric Vehicle Control System uses four modules to control hybrid electric powertrain functions:

The Powertrain Control Module control overall vehicle system functions as well as engine operation.

The Transmission Control Module controls the transaxle as well as generator and motor functions.

The Battery Energy Control Module controls the high voltage battery pack.

The Brake System Control Module controls the regenerative braking functions.

All these modules use CAN communication for all diagnostic functions and normal-mode communications.

The Powertrain Control Module (PCM) is a stand-alone OBD-II control module and meets all J1979 requirements. These include generic PIDs, freeze frame storage, pending and confirmed DTC retrieval and clearing, Mode 06 test data, Mode 08 evap system test and Mode 09 VIN, CALID and CVN. The OBD-II monitors for the engine are similar to the monitors used by a conventional gasoline vehicle. The basic difference between a conventional gasoline engine and the hybrid engine is that the engine often shuts down while in electric mode. This sometimes requires active intervention by the diagnostic executive to ensure that all OBD-II monitor can complete.

The Transmission Control Module (TCM) is a stand-alone OBD-II control module and meets all J1979 requirements. These include generic PIDs, freeze frame storage, pending and confirmed DTC retrieval and clearing, and Mode 09 CALID and CVN. Some of the OBD-II monitors for transmission are similar to the monitors used by a conventional transmission; however, many of the monitors are unique to the hybrid generator and motor sensors and controls. The TCM is housed within the transmission case and is not serviceable with the exception of reflashing memory.

The Battery Energy Control Module (BECM) is not a stand-alone OBD-II control module. The battery module sends fault information to the PCM. The PCM stores and reports freeze frame and DTCs for the BECM. The BECM is housed within the battery pack and is not serviceable with the exception of reflashing memory. As a result, the BECM supports J1979 Mode 09 CALID and CVN.

The Brake System Control Module (BSCM) is not an OBD-II control module because there are no regenerative braking faults that affect emissions.

Catalyst Efficiency Monitor

The Catalyst Efficiency Monitor uses an oxygen sensor before and after the catalyst to infer the hydrocarbon efficiency based on oxygen storage capacity of the ceria and precious metals in the washcoat. Under normal, closed-loop fuel conditions, high efficiency catalysts have significant oxygen storage. This makes the switching frequency of the rear HO2S very slow and reduces the amplitude of those switches as compared to the switching frequency and amplitude of the front HO2S. As catalyst efficiency deteriorates due to thermal and/or chemical deterioration, its ability to store oxygen declines. The post-catalyst HO2S signal begins to switch more rapidly with increasing amplitude, approaching the switching frequency and amplitude of the pre-catalyst HO2S. The predominant failure mode for high mileage catalysts is chemical deterioration (phosphorus deposition on the front brick of the catalyst), not thermal deterioration.

Index Ratio Method

In order to assess catalyst oxygen storage, the catalyst monitor counts front HO2S switches during part-throttle, closed-loop fuel conditions after the engine is warmed-up and inferred catalyst temperature is within limits. Front switches are accumulated in up to three different air mass regions or cells. While catalyst monitoring entry conditions are being met, the front and rear HO2S signal lengths are continually being calculated. When the required number of front switches has accumulated in each cell (air mass region), the total signal length of the rear HO2S is divided by the total signal length of front HO2S to compute a catalyst index ratio. An index ratio near 0.0 indicates high oxygen storage capacity, hence high HC efficiency. An index ratio near 1.0 indicates low oxygen storage capacity, hence low HC efficiency. If the actual index ratio exceeds the threshold index ratio, the catalyst is considered failed.

General Catalyst Monitor Operation

If the catalyst monitor does not complete during a particular driving cycle, the already-accumulated switch/signal-length data is retained in Keep Alive Memory and is used during the next driving cycle to allow the catalyst monitor a better opportunity to complete, even under short or transient driving conditions.

Rear HO2S sensors can be located in various ways to monitor different kinds of exhaust systems. In-line engines and many V-engines are monitored by individual bank. A rear HO2S sensor is used along with the front, fuel-control HO2S sensor for each bank. Two sensors are used on an in-line engine; four sensors are used on a V-engine.

Most vehicles that are part of the “LEV” catalyst monitor phase-in will monitor less than 100% of the catalyst volume – often the first catalyst brick of the catalyst system. Partial volume monitoring is done on LEV and ULEV vehicles in order to meet the 1.75 * emission-standard. The rationale for this practice is that the catalysts nearest the engine deteriorate first, allowing the catalyst monitor to be more sensitive and illuminate the MIL properly at lower emission standards.

Many applications that utilize partial-volume monitoring place the rear HO2S sensor after the first light-off catalyst can or, after the second catalyst can in a three-can per bank system. (A few applications placed the HO2S in the middle of the catalyst can, between the first and second bricks.)

All vehicles employ an Exponentially Weighted Moving Average (EWMA) algorithm to improve the robustness of the FTP catalyst monitor. During normal customer driving, a malfunction will illuminate the MIL, on average, in 3 to 6 driving cycles. If KAM is reset (battery disconnected), a malfunction will illuminate the MIL in 2 driving cycles. See the section on EWMA for additional information.

CATALYST MONITOR OPERATION:	
DTCs	P0420 Bank 1
Monitor execution	once per driving cycle
Monitor Sequence	HO2S response test complete and no DTCs (P0133/P0153) prior to calculating switch ratio, no SAIR pump stuck on DTCs (P0412/P1414), no evap leak check DTCs (P0442/P0456), no EGR stuck open DTCs (P0402)
Sensors OK	ECT, IAT, TP, VSS, CKP
Monitoring Duration	Approximately 900 seconds during appropriate FTP conditions

TYPICAL INDEX RATIO CATALYST MONITOR ENTRY CONDITIONS:		
Entry condition	Minimum	Maximum
Time since engine start-up (70 °F start)	5 seconds	
Engine Coolant Temp	150 °F	230 °F
Intake Air Temp	20 °F	180 °F
Time since entering closed loop fuel	30 sec	
Inferred Rear HO2S sensor Temperature	1000 °F	
EGR flow (Note: an EGR fault disables EGR)	0%	8%
Throttle Position	Part Throttle	Part Throttle
Rate of Change of Throttle Position		0.244 volts / 0.050 sec
Vehicle Speed	20 mph	80 mph
Fuel Level	15%	
First Air Mass Cell	0.8 lb/min	2.3 lb/min
Engine RPM for first air mass cell	1,300 rpm	1,800 rpm
Engine Load for first air mass cell	28%	44%
Monitored catalyst mid-bed temp. (inferred) for first air mass cell	800 °F	1,600 °F
Number of front O2 switches required for first air mass cell	70	

TYPICAL MALFUNCTION THRESHOLDS:
Rear-to-front O2 sensor switch/index-ratio > 0.80 (bank monitor)

J1979 CATALYST MONITOR MODE $06 DATA			
Monitor ID	Test ID	Description for CAN	
$21	$80	Bank 1 index-ratio and max. limit	unitless

** NOTE: In this document, a monitor or sensor is considered OK if there are no DTCs stored for that component or system at the time the monitor is running.

Misfire Monitor

The HEV uses the Low Data Rate misfire monitor. The LDR system is capable of meeting “full-range” misfire monitoring requirements on 4-cylinder engines. The software allows for detection of any misfires that occur 6 engine revolutions after initially cranking the engine. This meets the new OBD-II requirement to identify misfires within 2 engine revolutions after exceeding the warm drive, idle rpm.

Low Data Rate System

The LDR Misfire Monitor uses a low-data-rate crankshaft position signal, (i.e. one position reference signal at 10 deg BTDC for each cylinder event). The PCM calculates crankshaft rotational velocity for each cylinder from this crankshaft position signal. The acceleration for each cylinder can then be calculated using successive velocity values. The changes in overall engine rpm are removed by subtracting the median engine acceleration over a complete engine cycle. The resulting deviant cylinder acceleration values are used in evaluating misfire in the “General Misfire Algorithm Processing” section below.

“Profile correction” software is used to “learn” and correct for mechanical inaccuracies in crankshaft tooth spacing under de-fueled engine conditions (requires extended engine shutdown either at key off, or on multiple engine shutdown events during normal vehicle operation, after Keep Alive Memory has been reset). These learned corrections improve the high-rpm capability of the monitor for most engines. The misfire monitor is not active until a profile has been learned.

Generic Misfire Algorithm Processing

The acceleration that a piston undergoes during a normal firing event is directly related to the amount of torque that cylinder produces. The calculated piston/cylinder acceleration value(s) are compared to a misfire threshold that is continuously adjusted based on inferred engine torque. Deviant accelerations exceeding the threshold are conditionally labeled as misfires.

The calculated deviant acceleration value(s) are also evaluated for noise. Normally, misfire results in a non-symmetrical loss of cylinder acceleration. Mechanical noise, such as rough roads or high rpm/light load conditions, will produce symmetrical acceleration variations. Cylinder events that indicate excessive deviant accelerations of this type are considered noise. Noise-free deviant acceleration exceeding a given threshold is labeled a misfire.

The number of misfires are counted over a continuous 200 revolution and 1000 revolution period. (The revolution counters are not reset if the misfire monitor is temporarily disabled such as for negative torque mode, etc.) At the end of the evaluation period, the total misfire rate and the misfire rate for each individual cylinder is computed. The misfire rate evaluated every 200 revolution period (Type A) and compared to a threshold value obtained from an engine speed/load table. This misfire threshold is designed to prevent damage to the catalyst due to sustained excessive temperature (1600°F for Pt/Pd/Rh conventional washcoat, 1650°F for Pt/Pd/Rh advanced washcoat and 1800°F for Pd-only high tech washcoat). If the misfire threshold is exceeded and the catalyst temperature model calculates a catalyst mid-bed temperature that exceeds the catalyst damage threshold, the MIL blinks at a 1 Hz rate while the misfire is present. If the misfire occurs again on a subsequent driving cycle, the MIL is illuminated. If a single cylinder is indicated to be consistently misfiring in excess of the catalyst damage criteria, the fuel injector to that cylinder may be shut off for a period of time to prevent catalyst damage. Up to two cylinders may be disabled at the same time. This fuel shut-off feature is used on all engines starting in the 2005 MY. Next, the misfire rate is evaluated every 1000 rev period and compared to a single (Type B) threshold value to indicate an emission-threshold malfunction, which can be either a single 1000 rev exceedence from startup or four subsequent 1000 rev exceedences on a drive cycle after start-up. Some vehicles will set a P0316 DTC if the Type B malfunction threshold is exceeded during the first 1,000 revs after engine startup. This DTC is normally stored in addition to the normal P03xx DTC that indicates the misfiring cylinder(s). If misfire is detected but cannot be attributed to a specific cylinder, a P0300 is stored. This may occur on some vehicles at higher engine speeds, for example, above 3,500 rpm.

Profile Correction

"Profile correction" software is used to "learn" and correct for mechanical inaccuracies in the crankshaft position wheel tooth spacing. Since the sum of all the angles between crankshaft teeth must equal 360^{o}, a correction factor can be calculated for each misfire sample interval that makes all the angles between individual teeth equal. To prevent any fueling or combustion differences from affecting the correction factors, learning is done during extended engine shutdown.

In order to minimize learning time for profile correction factors, the correction factors are learned after an engine shutdown has been commanded and fuel has been discontinued while the generator spins the engine. In order to protect the battery, and assure vehicle starting, the following conditions must be met to extend the shutdown: battery temperature and charge state must be within limits (i.e. the battery must be able to spin the engine). This condition occurs either when the key is turned off, or when normal operating conditions dictate an engine shutdown (typically one key off induced shutdown, but may be multiple shutdown events during normal operation). During this extended shutdown, the engine is spun at approximately 1100 rpm, while delta time intervals are captured for computation of the correction factors. Average profile correction factors are calculated for each of the 4 combustion intervals over approximately 15 engine cycles. This procedure occurs once per KAM reset during the life of the vehicle. In order to assure the accuracy of these corrections, a tolerance is placed on the incoming values such that an individual correction factor must be repeatable within the tolerance during learning; this is to reduce the possibility of learning corrections on rough road conditions which could limit misfire detection capability.

Since inaccuracies in the wheel tooth spacing can produce a false indication of misfire, the misfire monitor is not active until the corrections are learned. In the event of battery disconnection or loss of Keep Alive Memory the correction factors are lost and must be relearned. The software may be unable to learn a profile if the instantaneous profile calculations vary by more than a specified tolerance from the mean values. In this case a P0315 DTC is set.

Misfire Monitor Operation:	
DTCs	P0300 to P0304 (general and specific cylinder misfire) P0315 (unable to learn profile) P0316 (misfire during first 1,000 revs after start-up)
Monitor execution	Continuous, misfire rate calculated every 200 or 1000 revs
Monitor Sequence	None
Sensors OK	CKP, CMP, no EGR stuck open DTCs (P0402)
Monitoring Duration	Entire driving cycle (see disablement conditions below)

Typical misfire monitor entry conditions:		
Entry condition	Minimum	Maximum
Time since engine start-up	0 seconds	0 seconds
Engine Coolant Temperature	20 ^{o}F	250 ^{o}F
RPM Range (Full-Range Misfire certified, with 2 rev delay)	2 revs after exceeding 150 rpm below “drive” idle rpm	redline on tach or fuel cutoff
Profile correction factors learned in KAM	Yes	
Fuel tank level	15%	

Typical misfire temporary disablement conditions:
Temporary disablement conditions:
Closed throttle decel (negative torque, engine being driven)
Fuel shut-off due to vehicle-speed limiting or engine-rpm limiting mode
High rate of change of torque (heavy throttle tip-in or tip out)

Typical misfire monitor malfunction thresholds:
Type A (catalyst damaging misfire rate): misfire rate is an rpm/load table ranging from 20% at idle to 5% at high rpm and loads
Type B (emission threshold rate): 1.7%

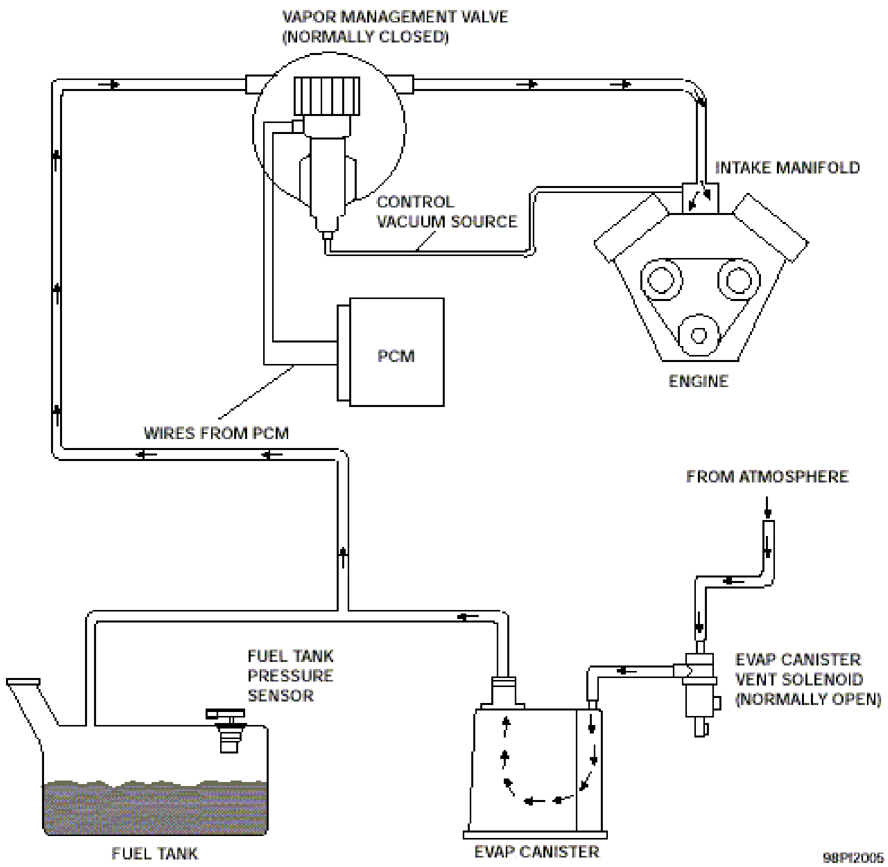
J1979 Misfire Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
A1	$80	Total engine misfire and catalyst damage misfire rate (updated every 200 revolutions)	percent
A1	$81	Total engine misfire and emission threshold misfire rate (updated every 1,000 revolutions)	percent
A1	$82	Highest catalyst-damage misfire and catalyst damage threshold misfire rate (updated when DTC set or clears)	percent
A1	$83	Highest emission-threshold misfire and emission threshold misfire rate (updated when DTC set or clears)	percent
A1	$84	Inferred catalyst mid-bed temperature	^{o}C
A2 – AD	$0B	EWMA misfire counts for last 10 driving cycles	events
A2 – AD	$0C	Misfire counts for last/current driving cycle	events
A2 – AD	$80	Cylinder X misfire rate and catalyst damage misfire rate (updated every 200 revolutions)	percent
A2 – AD	$81	Cylinder X misfire rate and emission threshold misfire rate (updated every 1,000 revolutions)	percent

Profile Correction Operation	
DTCs	P0315 - unable to learn profile
Monitor Execution	once per KAM reset.
Monitor Sequence:	Profile must be learned before misfire monitor is active.
Sensors OK:	CKP, CMP, no AICE communication errors, CKP/CMP in synch
Monitoring Duration;	10 cumulative seconds in conditions

Typical profile learning entry conditions:		
Entry condition	Minimum	Maximum
Engine in decel-fuel cutout mode for 4 engine cycles		
Brakes applied	N/A	N/A
Engine RPM	800 rpm	1750 rpm
Change in RPM		600 rpm/background loop
Vehicle Speed	0 mph	30 mph
Learning tolerance		1.5%
Battery temperature	-15 degrees C	
Battery Voltage	216 V	
Battery power discharge limit	12 Kw	

EVAP System Monitor - 0.020" dia. vacuum leak check

Some vehicles that meet enhanced evaporative requirements utilize a vacuum-based evaporative system integrity check that checks for 0.020" dia leaks. The evap system integrity check uses a Fuel Tank Pressure Transducer (FTPT), a Canister Vent Solenoid (CVS) and Fuel Level Input (FLI) along with the Vapor Management Valve (VMV) or Electric Vapor Management Valve (EVMV) to find 0.020" diameter, 0.040" diameter, or larger evap system leaks.



The evap system integrity test is done under two different sets of conditions - first a cruise test is performed to detect 0.040" dia leaks and screen for 0.020" leaks. If a 0.020" dia leak is suspected during the cruise test, an idle test is performed to verify the leak under more restrictive, but reliable, cold-start-idle conditions.

The cruise test is done under conditions that minimize vapor generation and fuel tank pressure changes due to fuel slosh since these could result in false MIL illumination. The check is run after a 6 hour cold engine soak (engine-off timer), during steady highway speeds at ambient air temperatures (inferred by IAT) between 40 and 100 ^{o}F.

A check for refueling events is done at engine start. A refuel flag is set in KAM if the fuel level at start-up is at least 20% greater than fuel fill at engine-off. It stays set until the evap monitor completes Phase 0 of the test as described below. The refueling flag is used to prohibit the 0.020" idle test until the gross leak check is done during cruise conditions. This is done to prevent potential idle concerns resulting from the high fuel vapor concentrations present with a fuel cap off/gross leak condition. Note that on some vehicles, a refueling check may also be done continuously, with the engine running to detect refueling events that occur when the driver does not turn off the vehicle while refueling (in-flight refueling).

The cruise test is done in four phases.

Phase 0 - initial vacuum pulldown

First, the Canister Vent Solenoid is closed to seal the entire evap system, then the VMV or EVMV is opened to pull a 8” H_2O vacuum.

If the initial vacuum could not be achieved, a large system leak is indicated (P0455). This could be caused by a fuel cap that was not installed properly, a large hole, an overfilled fuel tank, disconnected/kinked vapor lines, a Canister Vent Solenoid that is stuck open, a VMV that is stuck closed, or a disconnected/blocked vapor line between the VMV and the FTPT.

If the initial vacuum could not be achieved after a refueling event, a gross leak, fuel cap off (P0457) is indicated and the recorded minimum fuel tank pressure during pulldown is stored in KAM. A “Check Fuel Cap” light may also be illuminated.

If the initial vacuum is excessive, a vacuum malfunction is indicated (P1450). This could be caused by blocked vapor lines between the FTPT and the Canister Vent Solenoid, or a stuck open VMV. If a P0455, P0457, P1443, or P1450 code is generated, the evap test does not continue with subsequent phases of the small leak check, phases 1-4. These codes also prevent the idle portion of the 0.020” dia leak check from executing.

Note: Not all vehicles will have the P0457 test or the Check Fuel Cap light implemented. These vehicles will continue to generate only a P0455. After the customer properly secures the fuel cap, the P0457, Check Fuel Cap and/or MIL will be cleared as soon as normal purging vacuum exceeds the P0457 vacuum level stored in KAM.

Phase 1 - Vacuum stabilization

If the target vacuum is achieved, the VMV is closed and vacuum is allowed to stabilize for a fixed time. If the pressure in the tank immediately rises, the stabilization time is bypassed and Phase2 of the test is entered.

Some software has incorporated a "leaking" VMV test, which will also set a P1450 (excessive vacuum) DTC. This test is intended to identify a VMV that does not seal properly, but is not fully stuck open. If more than 1 " H_2O of additional vacuum is developed in Phase 1, the evap monitor will bypass Phase 2 and go directly to Phase 3 and open the canister vent solenoid to release the vacuum. Then, it will proceed to Phase 4, close the canister vent solenoid and measure the vacuum that develops. If the vacuum exceeds approximately 4 " H_2O, a P1450 DTC will be set.

Phase 2 - Vacuum hold and decay

Next, the vacuum is held for a calibrated time. Two test times are calculated based on the Fuel Level Input and ambient air temperature. The first (shorter) time is used to detect 0.040” dia leaks, the second (longer) time is used to detect 0.020” dia leaks. The initial vacuum is recorded upon entering Phase 2. At the end of the 0.040” dia test time, the vacuum level is recorded. The starting and ending vacuum levels are checked to determine if the change in vacuum exceeds the 0.040” dia vacuum bleed up criteria. If the 0.040” dia vacuum bleed-up criteria is exceeded on three successive monitoring attempts, a 0.040” dia leak is likely and a final vapor generation check is done to verify the leak (phases 3 and 4).

If the 0.040” dia bleed-up criteria is not exceeded, the test is allowed to continue until the 0.020” dia leak test time expires. The starting and ending vacuum levels are checked to determine if the change in vacuum exceed the 0.020” dia vacuum bleed-up criteria. If the 0.020” dia vacuum bleed-up is exceed on a single monitoring attempt, a 0.020” dia leak is likely and a final vapor generation check is done to verify the leak (phases 3 and 4).

If the vacuum bleed-up criteria is not exceeded, the leak test (either 0.040” or 0.020” dia is considered a pass. For both the 0.040” and 0.020” dia leak check, Fuel Level Input and Intake Air Temperature is used to adjust the vacuum bleed-up criteria for the appropriate fuel tank vapor volume and temperature. Steady state conditions must be maintained throughout this bleed up portion of the test. The monitor will abort if there is an excessive change in load, fuel tank pressure or fuel level input since these are all indicators of impending or actual fuel slosh. If the monitor aborts, it will attempt to run again (up to 20 or more times) until the maximum time-after-start is reached.

Phase 3 - Vacuum release

The vapor generation check is initiated by opening the Canister Vent Solenoid for a fixed period of time and releasing any vacuum. The VMV remains closed.

If FTIV (Fuel Tank Isolation Valve) is installed, Phase 3 is used for FTIV functionality check test. If vehicle passed 0.02" leak test in phase 2, it goes into phase 3 for FTIV test. VMV and CVS are remained closed and FTIV is closed during this phase. If the vacuum bleed-up criteria is not exceeded, the FTIV stuck open test is considered a pass

Phase 4 - Vapor generation

In this phase, the sealed system is monitored to determine if tank pressure remains low or if it is rising due to excessive vapor generation The initial tank pressure is recorded. The pressure is monitored for a change from the initial pressure, and for absolute pressure. If the pressure rise due to vapor generation is below the threshold limit for absolute pressure and for the change in pressure, and a 0.040" dia leak was indicated in phase 2, a P0442 DTC is stored. If the pressure rise due to vapor generation is below the threshold limit for absolute pressure and for the change in pressure, and a 0.020" dia leak was indicated in phase 2, a 0.020" idle check flag is set to run the 0.020" leak check during idle conditions.

Idle Check

The long test times required to detect a 0.020" dia leak in combination with typical road grades can lead to false 0.020" leak indications while the vehicle is in motion. The Idle Check repeats Phases 0, 1, and 2 with the vehicle stationary to screen out leak indications caused by changes in altitude. The 0.020" idle check is done under cold-start conditions to ensure that the fuel is cool and cannot pick up much heat from the engine, fuel rail, or fuel pump. This minimizes vapor generation. The 0.020" idle check is, therefore, conducted only during the first 10 minutes after engine start.

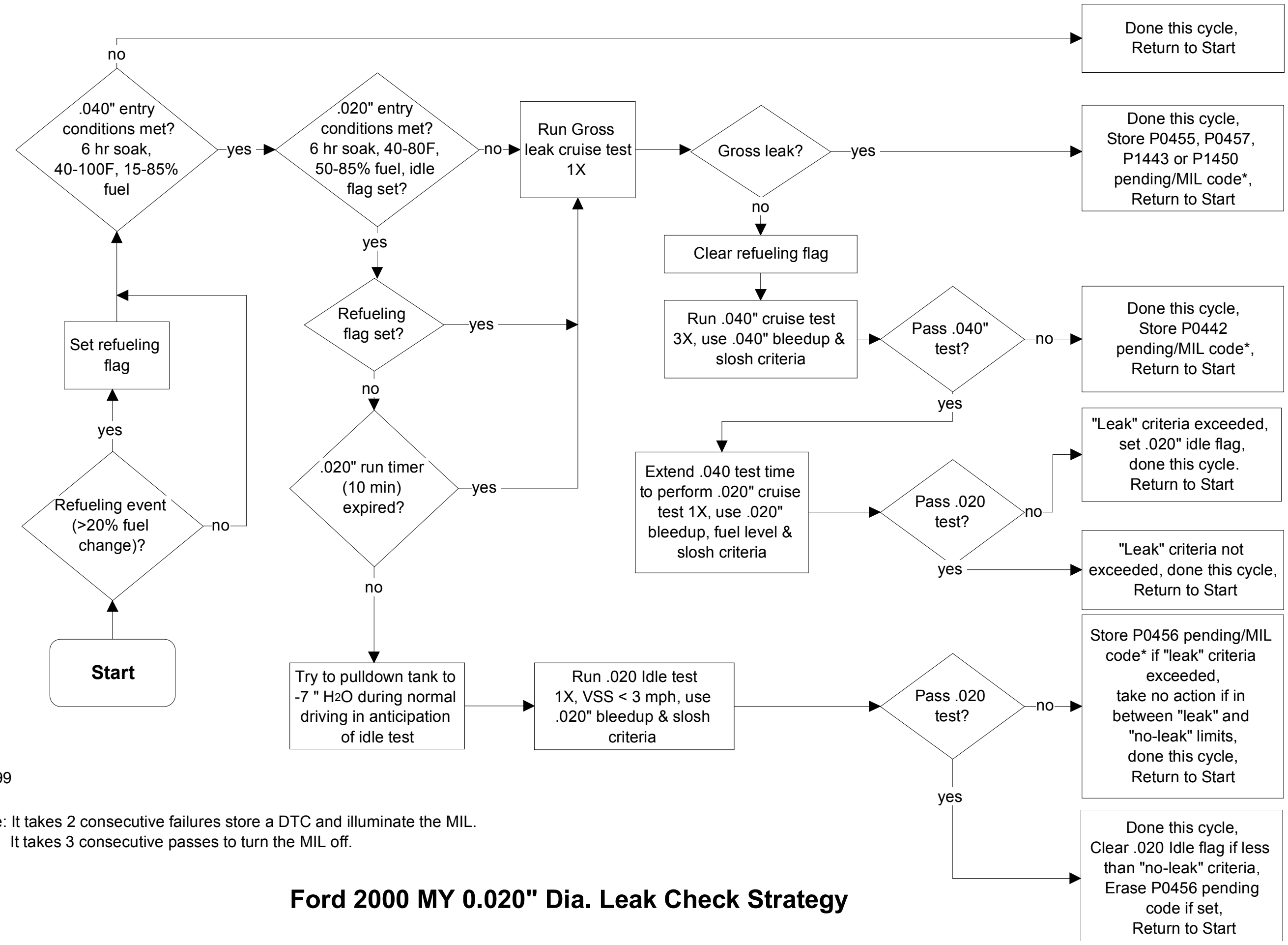
The 0.020" dia leak test entry conditions, test times and thresholds are used. Unique criteria for excessive changes in load, fuel tank pressure and fuel level are used to indicate fuel slosh. The test is aborted if vehicle speed exceeds a calibrated threshold, approx. 10 mph. The initial vacuum pull-down (phase 0) can start with the vehicle in motion in order to minimize the required time at idle to complete the test. If the vacuum bleed-up is greater than the 0.020" dia max. criteria during a single monitoring event, a P0456 DTC is stored. If the vacuum bleed-up is less than the 0.020" dia min. criteria, the pending P0456 DTC may be cleared. If the vacuum bleed-up is in between, no leak assessment is made. A flowchart of the entire 0.020" test sequence is provided below, on a subsequent page.

Ford's 0.020" evaporative system monitor is designed to run during extended, cold-start idle conditions where the fuel is cool and not likely to generate excessive vapors. These conditions will typically occur at traffic lights or immediately after start-up, (e.g. idle in the driveway).

As indicated previously, the 0.020" idle test uses two sets of malfunction thresholds to screen out test results in the area where "leak" and "no-leak" distributions overlap. Loss of vacuum greater than the 0.020" malfunction criteria is designated as a failure. No/low vacuum loss below the pass criteria is designated a pass. Vacuum loss that is greater than the pass criteria but less that the failure criteria is indeterminate and does not count as a pass or a fail.

Test results in this overlap area can stem from high volatility fuel at high ambient temperatures. These situations are not expected to be encountered routinely by customers. Therefore, this strategy will only temporarily hamper monitor performance, while effectively preventing false MIL illumination.

A more detailed description of the functional characteristics of the Evaporative Monitor is provided in the representative calibration submissions to the agency. Additional calibration information is contained on file by Ford Motor Company and may be obtained via agency request.



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* Note: It takes 2 consecutive failures store a DTC and illuminate the MIL.
It takes 3 consecutive passes to turn the MIL off.

Ford 2000 MY 0.020" Dia. Leak Check Strategy

0.020" EVAP Monitor Operation:	
DTCs	P0455 (gross leak), P1450, (excessive vacuum), P0457 (gross leak, cap off), P0442 (0.040" leak), P0456 (0.020" leak)
Monitor execution	once per driving cycle for 0.040" dia leak once per driving cycle, no refueling event for 0.020" dia leak
Monitor Sequence	HO2S monitor for front sensors completed and OK
Sensors/Components OK	MAF, IAT, VSS, ECT, CKP, TP, FTP, VMV, CVS
Monitoring Duration	360 seconds for 0.040" (see disablement conditions below) 60 seconds for 0.020" (see disablement conditions below)

Typical 0.020" EVAP monitor entry conditions, Phases 0 through 4:		
Entry condition	Minimum	Maximum
Engine off (soak) time	6 hours	
Time since engine start-up for 0.040"	330 seconds	2700 seconds
Time since engine start-up for 0.020" idle test	30 seconds	600 seconds
Refueling event (for 0.020" idle test only)	none	
Intake Air Temp for 0.040"	40 ^{o}F	110 ^{o}F
Intake Air Temp for 0.020"	40 ^{o}F	90 ^{o}F
Vehicle Speed for cruise test, 0.040 and 0.020"	40 mph	80 mph
Vehicle Speed for idle test, 0.020"		4 mph
Fuel Fill Level for 0.040"	15%	85%
Fuel Fill Level for 0.020"	15%	85%
BARO (<8,000 ft altitude)	22.0 " Hg	
Engine Load	20%	54%
Purge Flow	0.04 lbm/min	
Fuel Tank Pressure Range	- 17.82 H_2O	16.06 H_2O

Typical 0.020" EVAP abort (fuel slosh) conditions for Phase 2:
Change in load: > 40% for 0.040"
Change in load: > 40% for 0.020"
Change in tank pressure: > 4 " H_2O for 0.040"
Change in tank pressure: > 0.15 " H_2O for 0.020"
Change in fuel fill level: > 18% for 0.040"
Change in fuel fill level: > 18% for 0.020"
Number of aborts: > 30

Typical 0.020 EVAP monitor malfunction thresholds:
P1450 (Excessive vacuum): < -8.0 in H_2O over a 20 second evaluation time or > -4. in H_2O vapor generation. P0455 (Gross leak): > -8.0 in H_2O over a 20 second evaluation time. P0457 (Gross leak, cap off): > -8.0 in H_2O over a 30 second evaluation time after a refueling event. P0442 (0.040" leak): > 4.0 in H_2O bleed-up over a 20 sec. evaluation time at 75% fuel fill. (Note: bleed-up and evaluation times vary as a function of fuel fill level and ambient temperature). P0456 (0.020" leak): > 1.8 in H_2O bleed-up over a 20 sec. evaluation time at 75% fuel fill. (Note: bleed-up and evaluation times vary as a function of fuel fill level and ambient temperature) P0442 vapor generation limit: < 1.8 in H_2O over a 60 second evaluation time.

J1979 Evaporative System Mode $06 Data			
Monitor ID	Test ID	Description for CAN	Units
$3A	$80	Phase 0 Initial tank vacuum and minimum vacuum limit (data for P1450 – excessive vacuum)	Pascals
$3A	$81	Phase 4 Vapor generation minimum change in pressure and minimum vacuum limit (data for P1450, VMV stuck open)	Pascals
$3A	$82	Phase 0 Initial tank vacuum and gross leak maximum vacuum limit (data for P0455/P0457 – gross leak/cap off)	Pascals
$3B	$80	Phase 2 0.040" cruise leak check vacuum bleed-up and maximum vacuum limit (data for P0442 – 0.040" leak)	Pascals
$3C	$80	Phase 2 0.020" idle leak check vacuum bleed-up and maximum vacuum limit (data for P0456 – 0.020" leak)	Pascals
Note: Default values (0.0 in H_20) will be displayed for all the above TIDs if the evap monitor has never completed. Each TID is associated with a particular DTC. The TID for the appropriate DTC will be updated based on the current or last driving cycle, default values will be displayed for any phases that have not completed.			

EVAP System Monitor Component Checks

Additional malfunctions that are be identified as part of the evaporative system integrity check are as follows:

The Vapor Management Valve or Electric Vapor Management Valve (EVMV) (purge solenoid) output circuit is checked for opens and shorts (P0443)

Note that a stuck closed VMV generates a P0455, a leaking or stuck open VMV generates a P1450.

Vapor Management Valve Check Operation:	
DTCs	P0443 – Vapor Management Valve Circuit
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to obtain smart driver status

Typical Vapor Management Valve check malfunction thresholds:
P0443 (Vapor Management Valve Circuit): open/shorted at 0 or 100% duty cycle

The Canister Vent Solenoid output circuit is checked for opens and shorts (P0446), a stuck closed CVS generates a P1450, a leaking or stuck open CVS generates a P0455.

Canister Vent Solenoid Check Operation:	
DTCs	P0446 – Canister Vent Solenoid Circuit
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to obtain smart driver status

Typical Canister Vent Solenoid check malfunction thresholds:
P0446 (Canister Vent Solenoid Circuit): open/shorted

The Fuel Tank Pressure Sensor input circuit is checked for out of range values (P0452 short, P0453 open), noisy readings (P0454 noisy).

Note that carryover 2004 MY software and 2003 MY and earlier software will set P0451 for the noisy sensor test.

Note that an open power input circuit or stuck check valve generates a P1450.

Fuel Tank Pressure Sensor Transfer Function		
FTP volts = [Vref * (0.14167 * Tank Pressure) + 2.6250] / 5.00		
Volts	A/D Counts in PCM	Fuel Tank Pressure, Inches H_2O
0.100	20	-17.82
0.500	102	-15.0
1.208	247	-10.0
2.265	464	0
3.475.	712	6.0
4.750	973	15.0
4.90	1004	16.06

Fuel Tank Pressure Sensor Check Operation:	
DTCs	P0452 – Fuel Tank Pressure Sensor Circuit Low P0453 – Fuel Tank Pressure Sensor Circuit High P0454 – Fuel Tank Pressure Sensor Intermittent/Erratic (noisy)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds for electrical malfunctions, 16.7 minutes for noisy sensor test

Typical Fuel Tank Pressure Sensor check malfunction thresholds:
P0452 (Fuel Tank Pressure Sensor Circuit Low): < -17.82 in H_2O P0453 (Fuel Tank Pressure Sensor Circuit High): > 16.06 in H_2O P0454 (Fuel Tank Pressure Sensor Circuit Noisy): > 8 in H_2O change between samples, sampled every 10 seconds, more than 100 fault occurrences

The Fuel Level Input is checked for out of range values (opens/ shorts). The FLI input can be hardwired to the PCM or be obtained from the serial data link, typically from the instrument cluster. If the FLI signal is open or shorted, a P0460 is set. Some software will be able to discriminate between an open and short and set the appropriate DCT (P0462 circuit low and P0463 circuit high).

Finally, the Fuel Level Input is checked for noisy readings. If the FLI input changes from an in-range to out-of-range value repeatedly, a P0461 DTC is set.

Fuel Level Input Check Operation:	
DTCs	P0460 – Fuel Level Input Circuit P0461 – Fuel Level Input Circuit Noisy P0462 – Fuel Level Input Circuit Low P0463 – Fuel Level Input Circuit High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	30 seconds for electrical malfunctions, Fuel Level Stuck test (P0460) can take up to 120 miles to complete

Typical Fuel Level Input check malfunction thresholds:
P0460 or P0462 (Fuel Level Input Circuit Low): < 5 ohms
P0460 or P0463 (Fuel Level Input Circuit High): > 200 ohms
P0461 (Fuel Level Input Noisy): > 100 circuit low or circuit high exceedences, sampled every 0.100 seconds

The FLI signal is also checked to determine if it is stuck. The PCM calculates the amount of fuel being consumed by accumulating fuel pulse width. (Fuel consumed and fuel gauge reading range are both stored in KAM and reset after a refueling event or DTC storage.) If the there is an insufficient corresponding change in fuel tank level, a P0460 DTC is set.

Different malfunction criteria are applied based on the range in which the fuel level sensor is stuck.

In the range between 15% and 94%, a 30% difference between fuel consumed and fuel is used

In the range below 15%, a 39% difference between fuel consumed and fuel is used

In the range above 94%, a 47% difference between fuel consumed and fuel is used

Fuel Level Input Stuck Check Operation:	
DTCs	P0460 – Fuel Level Input Circuit Stuck
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	Between 15 and 94%, monitoring can take from100 to 120 miles to complete

Typical Fuel Level Input Stuck check malfunction thresholds:
P0460 (Fuel Level Input Stuck): Fuel level stuck at greater than 94%: > 47% difference in calculated fuel tank capacity consumed versus change in fuel level input reading Fuel level stuck at less than 15%: > 39% difference in calculated fuel tank capacity consumed versus change in fuel level input reading Fuel level stuck between 15% and 94%: > 30% difference in calculated fuel tank capacity consumed versus change in fuel level input reading

Fuel Tank Isolation Valve:	
DTCs	P2418 – FTIV Circuit Check P2450 – FTIV Stuck Open
Monitor execution	once per driving cycle
Monitor Sequence	Runs during phase 3 of evap monitor, after passing 0.02" leak test
Sensors OK	MAF, IAT, VSS, ECT, CKP, TP, FTP, VMV, CVS
Monitoring Duration	5 seconds

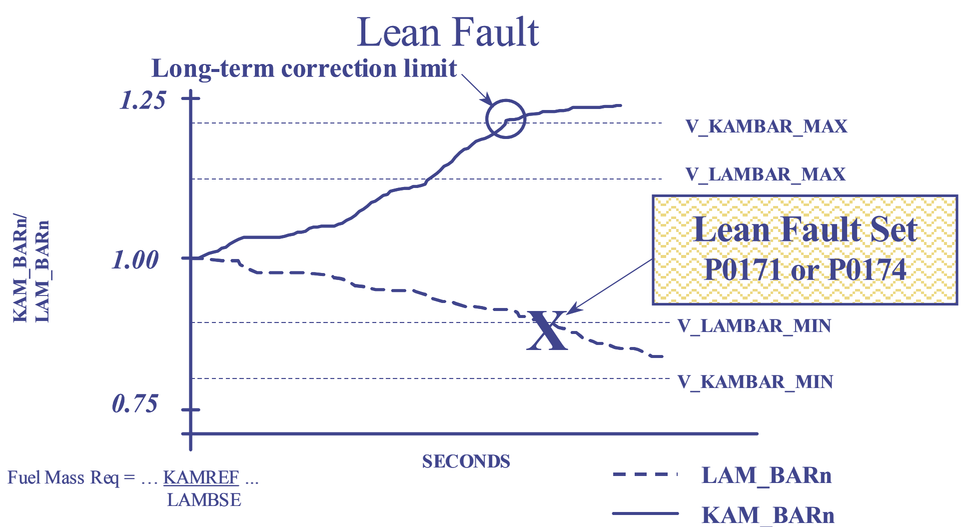
Typical Fuel Tank Isolation Valve check malfunction thresholds:
P2418 (Fuel Tank Isolation Valve Circuit): open/shorted P2450 (Fuel Tank Isolation Valve Circuit Stuck Open): fuel tank vacuum changes > - 2 in H_20 in 5 seconds during phase 3 after 0.020" leak test passes in phase 2

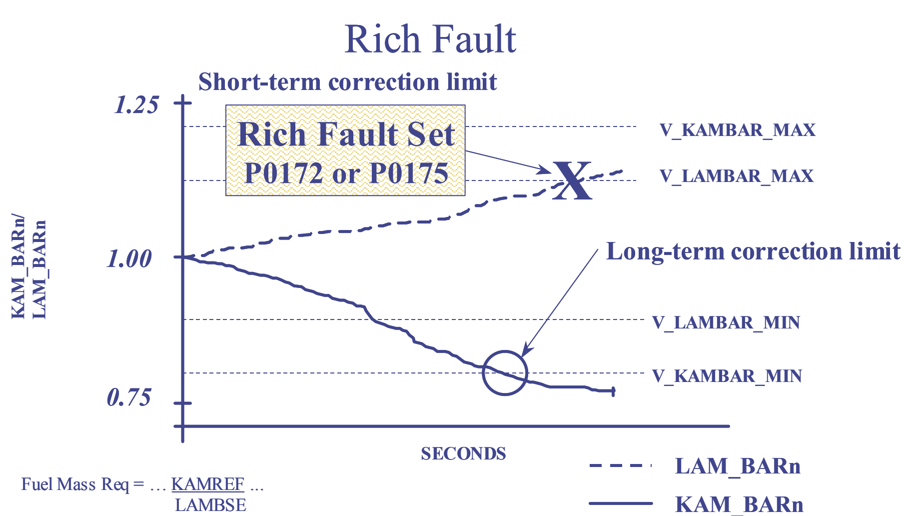
Fuel System Monitor

As fuel system components age or otherwise change over the life of the vehicle, the adaptive fuel strategy learns deviations from stoichiometry while running in closed loop fuel. These learned corrections are stored in Keep Alive Memory as long term fuel trim corrections. They may be stored into an 8x10 rpm/load table or they may be stored as a function of air mass. As components continue to change beyond normal limits or if a malfunction occurs, the long-term fuel trim values will reach a calibratable rich or lean limit where the adaptive fuel strategy is no longer allowed to compensate for additional fuel system changes. Long term fuel trim corrections at their limits, in conjunction with a calibratable deviation in short term fuel trim, indicate a rich or lean fuel system malfunction.

Note that in the PCM, both long and short-term fuel trim are multipliers in the fuel pulse width equation. Scan tools normally display fuel trim as percent adders. If there were no correction required, a scan tool would display 0% even though the PCM was actually using a multiplier of 1.0 in the fuel pulse width equation.

$$\text{Fuel Mass} = \frac{\text{Air Mass * Long-term Fuel Trim}}{\text{Short-term Fuel Trim * 14.64}}$$





Fuel Monitor Operation:	
DTCs	P0171 Bank 1 Lean P0172 Bank 1 Rich
Monitor execution	continuous while in closed loop fuel
Monitor Sequence	none
Sensors OK	Fuel Rail Pressure (if available)
Monitoring Duration	2 seconds to register malfunction

Typical fuel monitor entry conditions:		
Entry condition	Minimum	Maximum
RPM Range	1000	4000
Air Mass Range	0.4 lb/min	
Purge Dutycycle	0%	0%

Typical fuel monitor malfunction thresholds:
Long Term Fuel Trim correction cell currently being utilized in conjunction with Short Term Fuel Trim: Lean malfunction: LONGFT > 28%, SHRTFT > 2% Rich malfunction: LONGFT < 28%, SHRTFT < -1%

HO2S Monitor

Front HO2S Signal

The time between HO2S switches is monitored after vehicle startup when closed loop fuel has been requested, and during closed loop fuel conditions. Excessive time between switches with short term fuel trim at its limits (up to +/- 50%), or no switches since startup indicate a malfunction. Since "lack of switching" malfunctions can be caused by HO2S sensor malfunctions or by shifts in the fuel system, DTCs are stored that provide additional information for the "lack of switching" malfunction. Different DTCs indicate whether the sensor was always indicates lean/disconnected (P2195), or always indicates rich (P2196).

2005 MY vehicles will monitor the HO2S signal for high voltage, in excess of 1.1 volts and store a unique DTC. (P0132, P0152). An over voltage condition is caused by a HO2S heater or battery power short to the HO2S signal line.

HO2S "Lack of Switching" Operation:	
DTCs	P2195 - Lack of switching, sensor indicates lean, Bank 1 P2196 - Lack of switching, sensor indicates rich, Bank 1 P0132 Over voltage, Bank 1
Monitor execution	continuous, from startup and while in closed loop fuel
Monitor Sequence	None
Sensors OK	TP, MAF, ECT, IAT, FTP
Monitoring Duration	25 to 60 seconds to register a malfunction

Typical HO2S "Lack of Switching" entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop Requested		
Short Term Fuel Trim	At limits (up to +/- 45 %)	
Time within entry conditions	10 seconds	
Fuel Tank Pressure		10 in H_2O
Fuel Level	15%	
Inferred O2 sensor temperature (for overvoltage test only)	400 ^oF	

Typical HO2S "Lack of Switching" malfunction thresholds:
< 8 switches since startup for > 60 seconds in test conditions or > 60 seconds since last switch while closed loop fuel > 1.1 volts for 25 seconds for over voltage test

The HO2S is also tested functionally. The response rate is evaluated by entering a special 1.5 Hz. square wave, fuel control routine. This routine drives the air/fuel ratio around stoichiometry at a calibratable frequency and magnitude, producing predictable oxygen sensor signal amplitude. A slow sensor will show reduced amplitude. Oxygen sensor signal amplitude below a minimum threshold indicates a slow sensor malfunction. (P0133 Bank 1). If the calibrated frequency was not obtained while running the test because of excessive purge vapors, etc., the test will be run again until the correct frequency is obtained.

HO2S Response Rate Operation:	
DTCs	P0133 (slow response Bank 1)
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	ECT, IAT, MAF, VSS, CKP, TP, CMP, no misfire DTCs, FRP
Monitoring Duration	4 seconds

Typical HO2S response rate entry conditions:		
Entry condition	Minimum	Maximum
Short Term Fuel Trim Range	90%	110%
Engine Coolant Temp	150 ^{o}F	240 ^{o}F
Intake Air Temp		140 ^{o}F
Engine Load	18%	57%
Vehicle Speed	20 mph	45 mph
Engine RPM	1000 rpm	2300 rpm
Time since entering closed loop fuel	3 seconds	

Typical HO2Sresponse rate malfunction thresholds:
Voltage amplitude: < 0.5 volts

J1979 Front HO2S Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
$01	$80	HO2S11 voltage amplitude and voltage threshold	Volts
$01	$01	H02S11 sensor switch-point voltage	Volts

Rear HO2S Signal

A functional test of the rear HO2S sensors is done during normal vehicle operation. The peak rich and lean voltages are continuously monitored. Voltages that exceed the calibratable rich and lean thresholds indicate a functional sensor. If the voltages have not exceeded the thresholds after a long period of vehicle operation, the air/fuel ratio may be forced rich or lean in an attempt to get the rear sensor to switch. This situation normally occurs only with a green catalyst (< 500 miles). If the sensor does not exceed the rich and lean peak thresholds, a malfunction is indicated.

2005 MY vehicles will monitor the rear HO2S signal for high voltage, in excess of 1.1 volts and store a unique DTC. (P0138). An over voltage condition is caused by a HO2S heater or battery power short to the HO2S signal line.

Rear HO2S Check Operation:	
DTCs Sensor 2	P2270 HO2S12 Signal Stuck Lean P2271 HO2S12 Signal Stuck Rich P0138 HO2S12 Over voltage
Monitor execution	once per driving cycle for activity test, continuous for over voltage test
Monitor Sequence	none
Sensors OK	
Monitoring Duration	continuous until monitor completed

Typical Rear HO2S check entry conditions:		
Entry condition	Minimum	Maximum
Inferred exhaust temperature range	220 ^{o}F	1400 ^{o}F
Rear HO2S heater-on time	90 seconds	
Throttle position	Part throttle	
Engine RPM (forced excursion only)	1000 rpm	2000 rpm

Typical Rear HO2S check malfunction thresholds:
Does not exceed rich and lean threshold envelope: Rich < 0.48 volts Lean > 0.42 volts

J1979 Rear HO2S Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
$02	$01	HO2S12 sensor switch-point voltage	volts

HO2S Heaters, front and rear

The HO2S heaters are monitored for proper voltage and current. A HO2S heater voltage fault is determined by turning the heater on and off and looking for corresponding voltage change in the heater output driver circuit in the PCM.

A separate current-monitoring circuit monitors heater current once per driving cycle. The heater current is actually sampled three times. If the current value for two of the three samples falls below a calibratable threshold, the heater is assumed to be degraded or malfunctioning. (Multiple samples are taken for protection against noise on the heater current circuit.)

HO2S Heater Monitor Operation:	
DTCs	Sensor 1 - P0135 Bank 1 Sensor 2 - P0141 Bank 1
Monitor execution	once per driving cycle for heater current, continuous for voltage monitoring
Monitor Sequence	heater voltage check is done prior to heater current check
Sensors OK	
Monitoring Duration	< 5 seconds

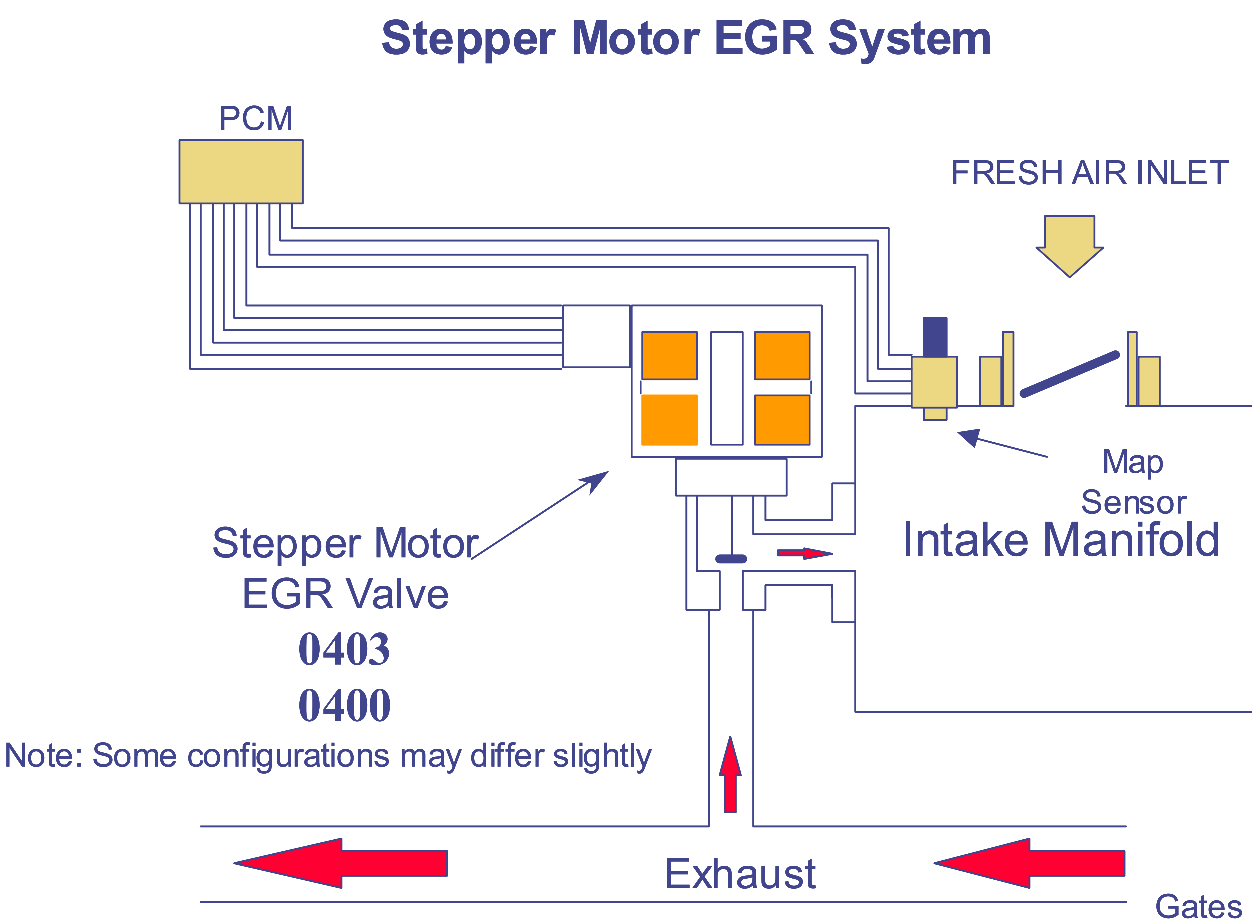
Typical HO2S heater monitor entry conditions:		
Entry condition	Minimum	Maximum
Inferred exhaust temperature range	250 °F	1400 °F
HO2S heater-on time	30 seconds	

Typical HO2S heater check malfunction thresholds:
Smart driver status indicated malfunction Heater current outside limits: < 0.465 amps or > 3 amps, (NTK Fast Light Off)

J1979 HO2S Heater Mode $06 Data			
Monitor ID	Test ID	Description for CAN	Units
$01	$81	HO2S11 Heater Current	Amps
$02	$81	HO2S12 Heater Current	Amps

Stepper Motor EGR System Monitor – Non-intrusive Monitor

The Electric Stepper Motor EGR System uses an electric stepper motor to directly actuate an EGR valve rather than using engine vacuum and a diaphragm on the EGR valve. The EGR valve is controlled by commanding from 0 to 52 discreet increments or "steps" to get the EGR valve from a fully closed to fully open position. The position of the EGR valve determines the EGR flow. Control of the EGR valve is achieved by a non-feedback, open loop control strategy. Because there is no EGR valve position feedback, monitoring for proper EGR flow requires the addition of a MAP sensor.



The Non-Intrusive Stepper Motor EGR Monitor consists of an electrical and functional test that checks the stepper motor and the EGR system for proper flow.

The stepper motor electrical test is a continuous check of the four electric stepper motor coils and circuits to the PCM. A malfunction is indicated if an open circuit, short to power, or short to ground has occurred in one or more of the stepper motor coils for a calibrated period of time. If a malfunction has been detected, the EGR system will be disabled, and additional monitoring will be suspended for the remainder of the driving cycle, until the next engine start-up.

EGR Stepper Monitor Electrical Check Operation:	
DTCs	P0403
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	4 seconds to register a malfunction

Stepper motor electrical check entry conditions:
Battery voltage > 11.0 volts

Typical EGR electrical check malfunction thresholds:
"Smart" Coil Output Driver status indicates open or short to ground, or short to power

EGR flow is monitored using an analog Manifold Absolute Pressure Sensor (MAP). If a malfunction has been detected in the MAP sensor, the EGR monitor will not perform the EGR flow test.

The MAP sensor is checked for opens, shorts, or out-of-range values by monitoring the analog-to-digital (A/D) input voltage.

MAP Sensor Check Operation	
DTCs	P0107 (low voltage), P0108 (high voltage)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

MAP electrical check entry conditions:
Battery voltage > 11.0 volts

Typical MAP sensor check malfunction thresholds:
Voltage < 0.024 volts or voltage > 4.96 volts

The MAP sensor is also checked for rational values. The value of inferred MAP is checked against the actual value of MAP at idle and non-idle engine operating conditions.

MAP Sensor Rationality Check Operation	
DTCs	P0106
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	10 seconds to register a malfunction

Typical MAP Rationality check entry conditions:		
Entry Conditions	Minimum	Maximum
Change in load		5%
Engine rpm	500 rpm	1800 rpm

Typical MAP Rationality check malfunction thresholds:
Difference between inferred MAP and actual MAP > 8 in Hg

The MAP sensor is also checked for intermittent MAP faults.

MAP Sensor Intermittent Check Operation	
DTCs	P0109 (non-MIL)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	2 seconds to register a malfunction

Typical MAP Intermittent check malfunction thresholds:
Voltage < 0.024 volts or voltage > 4.96 volts

After the vehicle has warmed up and normal EGR rates are being commanded by the PCM, the EGR flow test is performed. The flow test is performed once per drive-cycle after the remaining entry conditions required to initiate the test are satisfied.

The EGR flow test is done by observing the behavior of two different values of MAP - the analog MAP sensor reading, and inferred MAP, (MAP calculated from the Mass Air Flow Sensor, throttle position, rpm, BARO, etc.). The calculation of inferred MAP is not compensated for EGR flow and, therefore, does not account for the effects of EGR flow whereas measured MAP does respond to the effects of EGR flow. The amount of EGR flow can therefore be calculated by looking at the difference between measured MAP and inferred MAP.

Measured MAP can be thought of as consisting of three contributors: fresh air drawn into the intake manifold, EGR flow, and a noise/variability term. The following equation describes this:

Pmap = **P**maf + **P**egr + **P**noise

Where: **P**map = pressure in manifold measured by the MAP sensor

Pmaf = fresh air pressure without EGR flow, inferred from the MAF sensor, also known as inferred MAP

Pegr = EGR flow pressure due to EGR flow

Pnoise = any discrepancy between measured MAP and inferred MAP, without EGR

Pmaf (inferred MAP) is determined by the amount of fresh air drawn into manifold as measured by the Mass Air Flow (MAF) sensor. Inferred MAP is determined during the engine mapping process with no EGR, as a function of rpm and load

Pegr , the pressure due to EGR contribution can be modeled in the following equation:

Pegr = K * (Actual EGR / Desired EGR) * Desired EGR

Where: K = converts EGR pressure to a percent EGR flow rate

By rearranging the equation:

Actual EGR / Desired EGR = **P**egr / (K * Desired EGR)

The ratio of actual to desired EGR will eventually be calculated by the EGR monitor and will reflect how accurately EGR is being delivered to the engine.

Some differences will always exist between measured MAP and inferred MAP due to hardware variations. Within steady engine operating conditions without EGR, it is reasonable to model any differences between inferred and measured MAP as an offset and slope that is a function of load. The offset and slope are learned at various loads. This correction can be represented as:

MAP correction = **P**noise = M * LOAD + B

Where: B = offset between measured MAP and inferred MAP

M = slope which accounts for the difference between measured MAP and inferred MAP as a function of load

The terms B and M are learned and compensate for differences between measured MAP and inferred MAP.

Rearranging and substituting in the equations above results in the following system model:

Actual EGR / Desired EGR = (measured MAP – inferred MAP – MAP correction) / (K * Desired EGR)

The Actual EGR / Desired EGR is called the "degradation index". A value near one indicates the system is functioning properly whereas a value near zero reflects severe flow degradation.

When the entry conditions for the flow test have been satisfied, a calibrated number of samples of the difference between measured MAP and inferred MAP are taken at low, medium and high load regions, with and without EGR, to learn the MAP correction terms and then calculate the degradation index. When the number of samples in each load region is complete, a degradation index value from zero to one is computed. A value near one indicates the system is functioning properly whereas a value near zero reflects EGR severe flow degradation.

The degradation index is compared to a calibrated threshold to determine if a low flow malfunction has occurred.

Once the EGR monitor has been completed, the counter for the number of samples in each load region is reset to zero. If an EGR flow malfunction has occurred, the P0400 DTC flow malfunction is registered.

Note: BARO is inferred at engine startup using the KOEO MAP sensor reading. It is updated during high, part-throttle, engine operation.

This monitor employs an Exponentially Weighted Moving Average (EWMA) algorithm to improve the robustness threshold of the degradation index. During normal customer driving, a malfunction will illuminate the MIL, on average, in 3 to 6 driving cycles. If KAM is reset (battery disconnected), a malfunction will illuminate the MIL in 2 driving cycles. See the section on EWMA for additional information.

EGR Flow Check Operation:	
DTCs	P0400
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	CPS, ECT, IAT, MAF, MAP (P0106/7/8), TP, BARO not available yet
Monitoring Duration	200 seconds (600 data samples)

Typical EGR flow check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM	1050 rpm	3700 rpm
Inferred Ambient Air Temperature	32 ^{o}F	200 ^{o}F
Engine Coolant Temperature	140 ^{o}F	240 ^{o}F
Engine RPM Steady (change/0.100 sec)		100 rpm
MAP Steady (change/0.100 sec)		0.2 in Hg
Engine Load Steady (change/0.100 sec)		2 %
BARO	22.5 "Hg	
Samples for slope calculation (a sample/0.1sec)	600 samples	

Typical EGR flow check malfunction thresholds:
< 0.25 degradation index

J1979 Mode $06 Data			
Monitor ID	Test ID	Description for CAN	Units
$33	$82	Degradation index and min. threshold	none

I/M Readiness Indication

If the inferred ambient temperature is less than 20 ^{o}F, greater than 130 ^{o}F, or the altitude is greater than 8,000 feet (BARO < 22.5 "Hg), the EGR flow test cannot be reliably done. In these conditions, the EGR flow test is suspended and a timer starts to accumulate the time in these conditions. If the vehicle leaves these extreme conditions, the timer starts decrementing, and, if conditions permit, will attempt to complete the EGR flow monitor. If the timer reaches 800 seconds, the EGR flow test is disabled for the remainder of the current driving cycle and the EGR Monitor I/M Readiness bit will be set to a “ready” condition after one such driving cycle. Two such consecutive driving cycles are required for the EGR Monitor I/M Readiness bit to be set to a "ready" condition.

PCV System Monitor

Ford plans to comply with the PCV monitoring requirements by modifying the current PCV system design. The PCV valve will be installed into the rocker cover using a quarter-turn cam-lock design to prevent accidental disconnection. High retention force molded plastic lines will be used from the PCV valve to the intake manifold. The diameter of the lines and the intake manifold entry fitting will be increased so that inadvertent disconnection of the lines after a vehicle is serviced will cause either an immediate engine stall or will not allow the engine to be restarted. Some vehicles will incorporate such designs beginning in the 2001 MY. In the event that the vehicle does not stall if the line between the intake manifold and PCV valve is inadvertently disconnected, the vehicle will have a large vacuum leak that will cause the vehicle to run lean at idle. This will illuminate the MIL after two consecutive driving cycles and will store one or more of the following codes: Lack of O2 sensor switches, Bank1 (P1131 or P2195), Lack of O2 sensor switches Bank 2 (P1151 or P2197), Fuel System Lean, Bank1 (P0171),, Fuel System Lean, Bank 2 (P0174), MAP/BARO Range/Performance (P0106)

Thermostat Monitor

Ford plans to comply with the thermostat-monitoring requirement by using a slightly-modified version of the current “Insufficient temperature for closed-loop” test (P0125 or P0128). If the engine is being operated in a manner that is generating sufficient heat, the engine coolant temperature (ECT) or cylinder head temperature (CHT) should warm up in a predictable manner. A timer is incremented while the engine is at moderate load and vehicle speed is above a calibrated limit. The target/minimum timer value is based on ambient air temperature at start-up. If the timer exceeds the target time and ECT/CHT has not warmed up to the target temperature, a malfunction is indicated. The test runs if the start-up IAT temperature is below the target temperature. A 2-hour engine-off soak time is required to erase a pending or confirmed DTC. This feature prevents false-passes where engine coolant temperature rises after the engine is turned off during a short engine-off soak. The target temperature is calibrated to the thermostat regulating temperature minus 20 ^{o}F. For a typical 195 ^{o}F thermostat, the warm-up temperature would be calibrated to 175 ^{o}F. This test is being phased in starting in the 2000 MY. A vehicle, which is not part of the thermostat monitor phase-in, utilizes a 140 ^{o}F warm-up temperature.

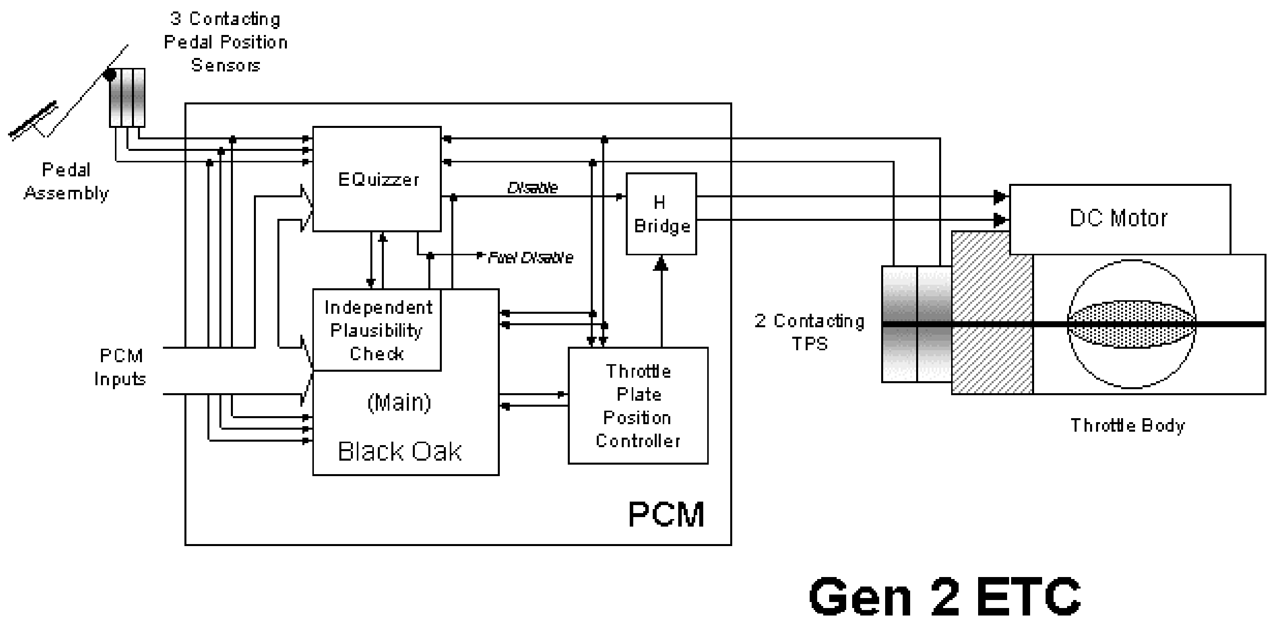
Insufficient Temperature for Closed Loop Check Operation:	
DTCs	P0128
Monitor execution	Once per driving cycle
Monitor Sequence	None
Monitoring Duration	300 to 800 seconds within test entry conditions, based on ambient temperature

Typical P0128 check entry conditions:		
Entry Condition	Minimum	Maximum
Vehicle speed	15 mph	
Intake Air Temp at Start-up	20 ^{o}F	Target ECT temp.
Engine Load	30%	
Engine off (soak) time to clear pending/confirmed DTC	2 hours	

Typical P0125/P0128 check malfunction thresholds:
Time period expired without reaching 160 ^{o}F target ECT temperature. Time period is 300 to 800 seconds based on ambient temperature at start-up.

Electronic Throttle Control

The Gen 2 Electronic Throttle Control system uses a strategy that delivers output shaft torque, based on driver demand, utilizing an electronically controlled throttle body. Gen 2 ETC strategy was developed mainly to improve fuel economy. This is possible by decoupling throttle angle (produces engine torque) from pedal position (driver demand). This allows the powertrain control strategy to optimize fuel control and transmission shift schedules while delivering the requested wheel torque. Gen 2 ETC is being used on the Lincoln LS and Ford Thunderbird, new Explorer/Mountaineer, and the new light-duty F-series.



Because safety is a major concern with ETC systems, a complex safety monitor strategy (hardware and software) was developed. The monitor system is distributed across two processors: the main powertrain control processor and a monitoring processor called an Enhanced-Quizzer (E-Quizzer) processor.

The primary monitoring function is performed by the Independent Plausibility Check (IPC) software, which resides on the main processor. It is responsible for determining the driver-demanded torque and comparing it to an estimate of the actual torque delivered. If the generated torque exceeds driver demand by specified amount, the IPC takes appropriate mitigating action.

Since the IPC and main controls share the same processor, they are subject to a number of potential, common-failure modes. Therefore, the E-Quizzer processor was added to redundantly monitor selected PCM inputs and to act as an intelligent watchdog and monitor the performance of the IPC and the main processor. If it determines that the IPC function is impaired in any way, it takes appropriate Failure Mode and Effects Management (FMEM) actions.

ETC System Failure Mode and Effects Management:	
Effect	Failure Mode
No Effect on Driveability	A loss of redundancy or loss of a non-critical input could result in a fault that does not affect driveability. The ETC light will turn on, but the throttle control and torque control systems will function normally.
RPM Guard w/ Pedal Follower	In this mode, torque control is disabled due to the loss of a critical sensor or PCM fault. The throttle is controlled in pedal-follower mode as a function of the pedal position sensor input only. A maximum allowed RPM is determined based on pedal position (RPM Guard.) If the actual RPM exceeds this limit, spark and fuel are used to bring the RPM below the limit. The ETC light and the MIL are turned on in this mode and a P2106 is set. EGR, VCT, and IMRC outputs are set to default values.
RPM Guard w/ Default Throttle	In this mode, the throttle plate control is disabled due to the loss of Throttle Position, the Throttle Plate Position Controller, or other major Electronic Throttle Body fault. A default command is sent to the TPPC, or the H-bridge is disabled. Depending on the fault detected, the throttle plate is controlled or springs to the default (limp home) position. A maximum allowed RPM is determined based on pedal position (RPM Guard.) If the actual RPM exceeds this limit, spark and fuel are used to bring the RPM below the limit. The ETC light and the MIL are turned on in this mode and a P2110 is set. EGR, VCT, and IMRC outputs are set to default values.
RPM Guard w/ Forced High Idle	This mode is caused by the loss of 2 or 3 pedal position sensor inputs due to sensor, wiring, or PCM faults. The system is unable to determine driver demand, and the throttle is controlled to a fixed high idle airflow. There is no response to the driver input. The maximum allowed RPM is a fixed value (RPM Guard.) If the actual RPM exceeds this limit, spark and fuel are used to bring the RPM below the limit. The ETC light and the MIL are turned on in this mode and a P2104 is set. EGR, VCT, and IMRC outputs are set to default values.
Shutdown	If a significant processor fault is detected, the monitor will force vehicle shutdown by disabling all fuel injectors. The ETC light and the MIL may be turned on in this mode and a P2105 is set. Note: Vehicle shutdown does not increase emissions; therefore the MIL is not required to be illuminated for this fault.
	Note: ETC illuminates or displays a message on the message center immediately, MIL illuminates after 2 driving cycles

Electronic Throttle Monitor

Electronic Throttle Monitor Operation:	
DTCs	P0606 - PCM processor failure (MIL, ETC light) P2110 – ETC FMEM – forced limited rpm; two TPs failed; TPPC detected fault (MIL, ETC light) P2104 – ETC FMEM – forced idle, two or three pedal sensors failed (MIL, ETC light) P2105 – ETC FMEM – forced engine shutdown; EQuizzer detected fault (MIL, ETC light) U0300 – ETC software version mismatch, IPC, EQuizzer or TPPC (non-MIL, ETC light)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

Accelerator and Throttle Position Sensor Inputs

Accelerator Pedal Position Sensor Check Operation:	
DTCs	P2122, P2123 – APP D circuit continuity (ETC light, non-MIL) P2121 – APP D range/performance (ETC light, non-MIL) P2127, P2128 – APP E circuit continuity (ETC light, non-MIL) P2126 – APP E range/performance (ETC light, non-MIL) P2132, P2133 – APP F circuit continuity (ETC light, non-MIL) P2131 – APP F range/performance (ETC light, non-MIL)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

APP sensor check malfunction thresholds:
Circuit continuity - Voltage < 0.25 volts or voltage > 4.75 volts Range/performance – sensor disagreement between processors (PCM and EQuizzer)

Throttle Position Sensor Check Operation:	
DTCs	P0122, P0123 – TP A circuit continuity (MIL, ETC light) P0121 – TP A range/performance (non-MIL) P2135 – TP A / TP B correlation (ETC light, non-MIL) P0222, P0223 – TP B circuit continuity (MIL, ETC light) P0221 – TP B range/performance (non-MIL)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

TP sensor check malfunction thresholds:
Circuit continuity - Voltage < 0.25 volts or voltage > 4.75 volts Correlation and range/performance – sensor disagreement between processors (PCM and EQuizzer), TP inconsistent with TPPC throttle plate position

Throttle Plate Position Controller (TPPC) Outputs

The purpose of the TPPC is to control the throttle position to the desired throttle angle. It is a separate chip embedded in the PCM. The desired angle is communicated from the main CPU via a 312.5 Hz duty cycle signal. The TPPC interprets the duty cycle signal as follows:

0% <= DC < 5% - Out of range, limp home default position.

5% <= DC < 6% - Commanded default position, closed.

6% <= DC < 7% - Commanded default position. Used for key-on, engine off.

7% <= DC < 10% - Closed against hard-stop. Used to learn zero throttle angle position (hard-stop) after key-up

10% <= DC <=92% - Normal operation, between 0 degrees (hard-stop) and 82%, 10% duty cycle = 0 degrees throttle angle, 92% duty cycle = 82 degrees throttle angle.

92% < DC <= 96% - Wide Open Throttle, 82 to 86 degrees throttle angle.

96% < DC <= 100% - Out of Range, limp home default position

The desired angle is relative to the hard-stop angle. The hard-stop angle is learned during each key-up process before the main CPU requests the throttle plate to be closed against the hard-stop. The output of the TPPC is a voltage request to the H-driver (also in PCM). The H driver is capable of positive or negative voltage to the Electronic Throttle Body Motor.

Throttle Plate Controller Check Operation:	
DTCs	P2107 – processor test (MIL) P2111 – throttle actuator system stuck open (MIL) P2112 – throttle actuator system stuck closed (MIL) P2100 – throttle actuator circuit open, short to power, short to ground (MIL) P2101 – throttle actuator range/performance test (MIL) P2072 – throttle body ice blockage (non-MIL) Note: For all the above DTCs, in addition to the MIL, the ETC light will be on for the fault that caused the FMEM action.
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	< 5 seconds to register a malfunction

Comprehensive Component Monitor - Engine

Engine Inputs

Analog inputs such as Intake Air Temperature (P0112, P0113), Cylinder Head Temperature (P1289. P1290), Mass Air Flow (P0102, P0103) and Throttle Position (P0122, P0123, P1120), Fuel Temperature (P0182, P0183), Engine Oil Temperature (P0197, P0198), Fuel Rail Pressure (p0192, P0193) are checked for opens, shorts, or rationality by monitoring the analog -to-digital (A/D) input voltage.

The ECT rationality test checks to make sure that ECT is not stuck high in a range that causes other OBD to be disabled. If after a long (6 hour) soak, ECT is very high (> 230 ^{o}F) and is also much higher than IAT at start, it is assumed that ECT is stuck high.

ECT Sensor Rationality Check Operation:	
DTCs	P0116 (ECT stuck high)
Monitor execution	Once per driving cycle
Monitor Sequence	None
Sensors OK	ECT, CHT, IAT
Monitoring Duration	100 seconds to register a malfunction

Typical ECT Sensor Rationality check entry conditions:		
Entry Condition	Minimum	Maximum
Engine-off time (soak time)	360 min	
Difference between ECT and IAT		50 deg
Engine Coolant Temperature	230 ^{o}F	

Typical ECT Sensor Rationality check malfunction thresholds:
Catalyst, Misfire, Fuel System or HO2S Monitors have not run this drive cycle

The CHT sensor measures cylinder head metal temperature as opposed to engine coolant temperature. At lower temperatures, CHT temperature is equivalent to ECT temperature. At higher temperatures, ECT reaches a maximum temperature (dictated by coolant composition and pressure) whereas CHT continues to indicate cylinder head metal temperature. If there is a loss of coolant or air in the cooling system, the CHT sensor will still provides an accurate measure of cylinder head metal temperature. If a vehicle uses a CHT sensor, the PCM software calculates both CHT and ECT values for use by the PCM control and OBD systems.

Cylinder Head Temperature Sensor Check Operation:	
DTCs	P1289 (high input), P1290 (low input), P1299 (fail-safe cooling activated)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical CHT sensor check malfunction thresholds:
Voltage < 0.244 volts or voltage > 4.96 volts
For P1299, MIL illuminates immediately if CHT > 270 $^{o.}$ Fuel shut-off is activated to reduce engine and coolant temperature

Intake Air Temperature Sensor Check Operation:	
DTCs	P0112 (low input), P0113 (high input)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical IAT sensor check malfunction thresholds:
Voltage < 0.244 volts or voltage > 4.96 volts

ECT, IAT, EOT Temperature Sensor Transfer Function		
Volts	**A/D counts in PCM**	**Temperature, degrees F**
4.89	1001	-40
4.86	994	-31
4.81	983	-22
4.74	970	-13
4.66	954	-4
4.56	934	5
4.45	910	14
4.30	880	23
4.14	846	32
3.95	807	41
3.73	764	50
3.50	717	59
3.26	666	68
3.00	614	77
2.74	561	86
2.48	508	95
2.23	456	104
1.99	407	113
1.77	361	122
1.56	319	131
1.37	280	140
1.20	246	149
1.05	215	158
0.92	188	167
0.80	165	176
0.70	144	185
0.61	126	194
0.54	110	203
0.47	96	212
0.41	85	221
0.36	74	230
0.32	65	239
0.28	57	248
0.25	51	257
0.22	45	266
0.19	40	275
0.17	35	284
0.15	31	293
0.14	28	302

Fuel Rail Pressure Sensor Check Operation:	
DTCs	P0192 (low input), P0193 (high input)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	8 seconds to register a malfunction

Typical FRP sensor check malfunction thresholds:
Voltage < 0.049 volts or voltage > 4.88 volts

The FRP range/performance test checks to make sure that fuel rail pressure can be properly controlled by the electronic returnless fuel system. The FPS sensor is also checked for in-range failures that can be caused by loss of Vref to the sensor. Note that the FRP is referenced to manifold vacuum (via a hose) while the fuel rail pressure sensor is not referenced to manifold vacuum. It uses gage pressure. As a result, a mechanical gage in the fuel rail will display a different pressure than the FPR PID on a scan tool. The scan tool PID will read higher because of manifold vacuum.

FRP Range/Performance Check Operation:	
DTCs	P0191 (FRP range/performance), P1090 (stuck in range)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	FRP
Monitoring Duration	8 seconds to register a malfunction

Typical FRP Sensor Range/Performance check entry conditions:		
Entry Condition	Minimum	Maximum
Demand pressure reasonable	35 psig	60 psig
Fuel level	15%	

Typical FRP Range/Performance check malfunction thresholds:
Fuel pressure error (demand – actual pressure) > 40 psig

Typical FRP Sensor Stuck check entry conditions:		
Entry Condition	Minimum	Maximum
FRP sensor input	0 psig	46 psig
FRP input not moving		1 psig / sec

Typical FRP Stuck check malfunction thresholds:
Fuel pressure error (demand – actual pressure) > 5 psig

Throttle Position Sensor Check Operation:	
DTCs	P0122 (low input), P0123 (high input), P1120 (closed throttle too low)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical TP sensor check malfunction thresholds:
Voltage < 0.20 volts or voltage > 4.80 volts or voltage < 0.488

MAF Sensor Check Operation:	
DTCs	P0102 (low input), P0103 (high input)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical MAF sensor check malfunction thresholds:
Voltage < 0.244 volts and engine running or voltage > 4.785 volts engine rpm < 4,000 rpm

The MAF and TP sensors are cross-checked to determine whether the sensor readings are rational and appropriate for the current operating conditions. (P0068)

MAF/TP Rationality Check Operation:	
DTCs	P0068
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds within test entry conditions

Typical MAF/TP rationality check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM	1025 rpm	minimum of 3800 rpm
Engine Coolant Temp	40 ^{o}F	

Typical MAF/TP rationality check malfunction thresholds:
Load > 55% and TP < 0.288 volts or Load < 20% and TP > 1.953 volts

Miscellaneous

Loss of Keep Alive Memory (KAM) power (a separate wire feeding the PCM) results is a P1633 DTC and immediate MIL illumination on most applications.

Vehicles that require tire/axle information to be programmed into the Vehicle ID block (VID) will store a P1639 if the VID block is not programmed or corrupted.

The PCM "engine off" or "soak" timer is tested to ensure that it is functional. The value of engine coolant temperature decays after the engine is turned off. This decay is modeled as a function of ECT, IAT and soak time. If, during a cold start, (difference between ECT and IAT is low), the actual ECT at start is much lower than the predicted ECT at start, it means that the soak timer is not functioning and a P0606 DTC is stored. (If the timer fails, it will read zero seconds and the model will predict that ECT will be the same temperature as when the engine was last turned off.)

Ignition

Power PC Ignition

New "Power PC" processors no longer use an EDIS chip for ignition signal processing. The signals are now directly processed by the PCM using a special interface chip called a Time Processing Unit or TPU. The 36-tooth crankshaft and camshaft position signals come directly into the TPU. The signals to fire the ignition coil drivers also come from the TPU.

The PowerPC ignition system is checked by monitoring three ignition signals during normal vehicle operation:

> CKP, the signal from the crankshaft 36-1-tooth wheel. The missing tooth is used to locate the cylinder pair associated with cylinder # 1 The TPU also generates the Profile Ignition Pickup (PIP) signal, a 50% duty cycle, square wave signal that has a rising edge at 10 deg BTDC.
>
> Camshaft IDentification (CMP, commonly known at CID), a signal derived from the camshaft to identify the #1 cylinder
>
> NOMI, a signal that indicates that the primary side of the coil has achieved the nominal current required for proper firing of the spark plug. This signal is received as a digital signal from the coil drivers to the TPU. The coil drivers determine if the current flow to the ignition coil reaches the required current (typically 5.5 Amps for COP, 3.0 to 4.0 Amps for DIS) within a specified time period (typically > 200 microseconds for both COP and DIS).

First, several relationships are checked on the 36-1 tooth CKP signal. The TPU looks for the proper number of teeth (35 or 39) after the missing tooth is recognized; time between teeth too low (< 30 rpm or > 9,000 rpm); or the missing tooth was not where it was expected to be. If an error occurs, the TPU shuts off fuel and the ignition coils and attempts to resynchronize itself. It takes on revolution to verify the missing tooth, and another revolution to verify cylinder #1 using the CMP input. Note that if a P0320 DTC is set on a vehicle with Electronic Throttle Control, (ETC), the ETC software will also set a P2106.

If the proper ratio of CMP events to PIP events is not being maintained (for example, 1 CMP edge for every 8 PIP edges for an 8-cylinder engine), it indicates a missing or noisy CMP signal (P0340). On applications with Variable Cam Timing (VCT), the CMP wheel has five teeth to provide the VCT system with more accurate camshaft control. The TPU checks the CMP signal for an intermittent signal. If an intermittent is detected, the VCT system is disabled and a P0344 (CMP Intermittent Bank 1) or P0349 (CMP intermittent Bank 2) is set.

Finally, the relationship between NOMI events and PIP events is evaluated. If there is not an NOMI signal for every PIP edge (commanded spark event), the PCM will look for a pattern of failed NOMI events to determine which ignition coil has failed.

CKP Ignition System Check Operation:	
DTCs	P0320 (CKP)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	< 5 seconds

Typical CKP ignition check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM for CKP	200 rpm	

Typical CKP ignition check malfunction thresholds:
EDIS: For PIP: Time between PIP edges: > 350 milliseconds
Ratio of current PIP period to last two periods: < 0.75, > 1.75
PowerPC: Incorrect number of teeth after the missing tooth is recognized,
Time between teeth too low (< 30 rpm or > 9,000 rpm)
Missing tooth was not where it was expected to be.

CMP Ignition System Check Operation:	
DTCs	P0340 (CMP)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	< 5 seconds

Typical CMP ignition check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM for CMP	200 rpm	

Typical CMP ignition check malfunction thresholds:
EDIS: Ratio of PIP events to CMP events: 4:1, 6:1, 8:1 or 10:1 based on engine cyl.
PowerPC: Ratio of PIP events to CMP events: 4:1, 6:1, 8:1 or 10:1 based on engine cyl

Coil Primary Ignition System Check Operation:	
DTCs	P0351 – P0354 (Coil primary)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	< 5 seconds

Typical Coil primary ignition check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM for coil primary	200 rpm	Minimum of 3200 rpm
Positive engine torque	Positive torque	

Typical Coil primary ignition check malfunction thresholds:
Ratio of PIP events to IDM or NOMI events 1:1

Engine Outputs

The PCM will monitor the "smart" driver fault status bit that indicates either an open circuit, short to power or short to ground.

Injector Check Operation:	
DTCs	P0201 through P0204 (opens/shorts)
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	10 seconds

Typical injector circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	
Engine Coolant Temp		240 ^{o}F
Intake Air Temp		150 ^{o}F

Electronic Returnless Fuel Systems (ERFS) utilize a Fuel Pump Driver Module (FPDM) to control fuel pressure. The PCM uses a Fuel Rail Pressure Sensor (FRP) for feedback. The PCM outputs a duty cycle to the FPDM to maintain the desired fuel rail pressure. During normal operation, the PCM will output a FP duty cycle from 5% to 51%. The FPDM will run the fuel pump at twice this duty cycle, e.g. if the PCM outputs a 42% duty cycle, the FPDM will run the fuel pump at 84%. If the PCM outputs a 75% duty cycle, the FPDM will turn off the fuel pump.

The FPDM returns a duty cycled diagnostic signal back to the PCM on the Fuel Pump Monitor (FPM) circuit to indicate if there are any faults in the FPDM.

If the FPDM does not out any diagnostic signal, (0 or 100% duty cycle), the PCM sets a P1233 DTC. This DTC is set if the FPDM loses power. This can also occur if the Inertia Fuel Switch is tripped.

If the FPDM outputs a 25% duty cycle, it means that the fuel pump control duty cycle is out of range. This may occurs if the FPDM does not receive a valid control duty cycle signal from the PCM. The FPDM will default to 100% duty cycle on the fuel pump control output. The PCM sets a P1235 DTC.

If the FPDM outputs a 75% duty cycle, it means that the FPDM has detected an open or short on the fuel pump control circuit. The PCM sets a P1237 DTC.

If the FPDM outputs a 50% duty cycle, the FPDM is functioning normally.

Fuel Pump Driver Module Check Operation:	
DTCs	P1233 – FPDM disabled of offline P1235 – Fuel pump control out of range P1237 – Fuel pump secondary circuit
Monitor execution	Continuous, voltage > 11.0 volts
Monitor Sequence	None
Monitoring Duration	3 seconds

There are several different styles of hardware used to control airflow within the engine air intake system. In general, the devices are defined based on whether they control in-cylinder motion (charge motion) or manifold dynamics (tuning).

Systems designed to control charge motion are defined to be Intake Manifold Runner Controls. IMRC systems generally have to modify spark when the systems are active because altering the charge motion affects the burn rate within the cylinder.

Systems designed to control intake manifold dynamics or tuning are defined to be Intake Manifold Tuning Valves. IMTV systems generally do not require any changes to spark or air/fuel ratio because these systems only alter the amount of airflow entering the engine.

Intake Manifold Runner Control Systems

The Intake Manifold Swirl Control Valve used on the 2.3L engine consists of a manifold mounted vacuum actuator and a PCM controlled electric solenoid. The linkage from the actuator attaches to the manifold butterfly plate lever. The IMSCV actuator and manifold are composite/plastic with a single intake air passage for each cylinder. The passage has a butterfly valve plate that blocks 60% of the opening when actuated, leaving the top of the passage open to generate turbulence. The housing uses a return spring to hold the butterfly valve plates open. The vacuum actuator houses an internal monitor switch circuit to provide feedback to the PCM indicating butterfly valve plate position.

Below approximately 3000 rpm, the vacuum solenoid will be energized. This will allow manifold vacuum to be applied and the butterfly valve plates to remain closed. Above approximately 3000 rpm, the vacuum solenoid will be de-energized. This will allow vacuum to vent from the actuator and the butterfly valve plates to open.

IMRC System Check Operation:	
DTCs	P2008 - IMRC output electrical check P2004 – IMRC stuck open, vacuum operated, Bank 1 P2006 – IMRC stuck closed, vacuum operated, Bank 1
Monitor execution	Continuous, after ECT > 40 deg F
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds after commanded position changes

Typical IMRC functional check malfunction thresholds
IMRC plates do not match commanded position (functional) IMRC switches open/shorted (electrical)

The engine is monitored for excessive torque generation at idle. If excessive torque is being produced, injectors are turned off in order to reduce torque. If the frequency of injector cut-off is higher than the EWMA threshold, a P2279 DTC is set.

Intake Air System Leak Check Operation:	
DTCs	P2279 Intake Air System Leak
Monitor execution	Continuous during Idle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	< 16 seconds

Typical Intake Air System Leak test entry conditions:		
Entry Condition	Minimum	Maximum
Engine Speed		Idle
Vehicle Speed		2 MPH
High Voltage Battery Temperature	0 degree F	
Inferred Ambient Temperature	20 degree F	

Typical Intake Air System Leak test malfunction thresholds:
Injectors cut off for > 0.7 frequency (EWMA)

Comprehensive Component Monitor – Battery Energy Control Module

BECM Inputs/Outputs

BECM has many inputs/outputs used to control the high voltage battery; however, none of the components are serviceable. The battery itself consists of 250 battery cells. A group of 5 cells is called a battery module; thus, there are 50 battery modules in the vehicle battery pack. The battery pack is physically split into two half-packs, a 24 module half-pack and a 26 module half-pack. Each half-pack is monitored by a microprocessor that senses voltage in each battery pack, temperature in eight placers, and monitors the half-pack for current or voltage leakage.

The BECM sends the ECM fault information over the CAN network if any of the BECM input or output components are faulty. The ECM immediately set a P0A1F DTC if a fault request was received from BECM.

Battery Energy Control Module (BECM) Check Operation:	
DTCs	P0A1F (Battery Energy Control Module)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 – 10 seconds

Battery Energy Control Module (BECM) fault check malfunction thresholds:

(1) The difference between the maximum battery voltage and the minimum battery voltage between any battery module is greater than 1.4 volts for 1 second.

(2) Both current sensors fail:
For Current Sensor #1, the current offset (calculated at power up) is > 6.5 A, or the magnitude of the current is greater than 280A for 1 second (detects shorts and opens).
For Current Sensor #2, communications are lost for 5 seconds or the magnitude of the current is greater than 350A for 5 seconds.

(3) The BECM is unable to access EEPROM data at power up.

(4) One of the two Voltage/Temperature Sensor microprocessor units reports a temperature, voltage, or leakage fault, or can not communicate with the BECM microprocessor for ten seconds.

(5) The vehicle battery pack voltage is reported as either < 5.0 or > 470.0 V for ten seconds and a battery module voltage fault exists.

(6) Both voltage reference wires for any battery half-pack (there are redundant wires) are detected as faulted for 10 seconds, or the half-pack voltage is out of range for ten seconds.

(7) Eight or more of the sixteen battery temperature sensors in the vehicle battery pack are faulted.

Comprehensive Component Monitor - Transmission

Transmission External Inputs

There are four external, hardwired inputs into the transmission.

Rapid Discharge **(RDC)** signals come from the Battery Module (TBCM), and cause the Transmission to perform a rapid discharge.

High Voltage (HV) Interlock (HVIL) is a circuit that causes a vehicle shutdown if opened.

Motor Shut Down (MSDN) and **Generator Shut Down (GSDN)** are signals from the PCM, which cause the transmission to shutdown either the Motor or the Generator.

Clean Tach Out (CTO) is a signal from the PCM, which is used to determine Engine Speed.

Rapid Discharge

The Rapid Discharge (RDC) signals are two hardwires coming from the TBCM to the transmission. The voltage on these signals should always be high (Charge) during normal operation. If one of the wires goes low (Discharge), the transmission will set a DTC (P1A0A) but not perform any action. If both of the wires go low, the transmission will set the DTC, and perform a Rapid Discharge.

Rapid Shutdown Signal Check Operation:	
DTCs	P1A0A (Rapid Shutdown Circuit request or fault)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	10 - 200 msec

Rapid Shutdown Circuit fault check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	100 msec	none

Rapid Shutdown Circuit fault check malfunction thresholds:
Voltage of Rapid Discharge Signal1 is not equal to Signal 2 for 200 msec

Rapid Shutdown Request check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
12V Battery voltage	7.5 V	17.0 V

Rapid Shutdown Request check malfunction thresholds:
Both Rapid Discharge Signals = Discharge, and HV Interlock Circuit = Charge, for > 10 msec

High Voltage Interlock

The HV Interlock (HVIL) is a circuit that goes through the Transmission, the DC/DC converter, and the Battery. If this circuit is detected to be open by the transmission, the vehicle will be shutdown.

High Voltage Interlock Open Check Operation:	
DTCs	P0A0A (High Voltage Interlock Open)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	10 - 200 msec

High Voltage Interlock Open check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	100 msec	none
12V Battery voltage	7.5 V	17.0 V

High Voltage Interlock Open check malfunction thresholds:
(1) and (2) and (3) for > 10 msec OR (1) and (4) and (5) for > 200 msec (1) HV Interlock = discharge (2) Rapid Discharge Signal 1 = discharge (3) Rapid Discharge Signal 2 = discharge (4) Rapid Discharge Signal 1 = charge (5) Rapid Discharge Signal 2 = charge

MSDN/GSDN (Motor Shutdown/Generator Shutdown)

The MSDN and GSDN are hardwires going from the PCM to the transmission. A signal can be sent from the PCM to command the transmission to shutdown the motor or the generator.

MSDN/GSDN Signal Check Operation:	
DTCs	P1A03 and P1A04 (Motor and Generator shutdown Signal Command or Signal circuit failure)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	CAN status not "Bus-off"
Monitoring Duration	520 – 528msec

Motor/Generator Shutdown Signal Command check entry conditions:		
CAN TimeOut($575)	Normal	

Motor/Generator Shutdown Signal Command check malfunction thresholds:
MSDN/GSDN Signal = Shutdown OR EQ Motor/Generator Inverter Shutdown CAN signal = Shutdown for > 528 msec

Motor/Generator Shutdown Signal Circuit Failure check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	200 msec	none
12V Battery voltage	7.5 V	17.0 V
CAN TimeOut($575)	Normal	

Motor/Generator Shutdown Signal Circuit Failure check malfunction thresholds:
MSDN/GSDN Signal = Shutdown and EQ Motor/Generator Inverter Shutdown CAN signal = Not Shutdown for > 520 msec

CTO (Clean Tach Out)

The CTO signal is sent from the PCM to the transmission. The signal is sent at 10 degrees before Top Dead Center (TDC) for each cylinder. This translates into the transmission seeing this signal every 180 degrees of engine rotation. This signal is used to calculate Engine Speed.

CTO Signal Check Operation:	
DTCs	P0727 and P0726 (CTO Circuit failure and out-of-range)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	Motor/Generator Serial Communication Status OK Motor/Generator Resolver sensor OK Motor/Generator R/D Converter OK Motor/Generator Rotor Position OK
Monitoring Duration	280 – 290 msec

CTO Input Circuit Failure and Out- of- Range check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	125 msec	none
12V Battery voltage	7.5 V	17.0 V
Motor enable signal to18V power supply	Supply	
Generator enable signal to18V power supply	Supply	
Engine Speed	600 rpm	None
CTO Signal Circuit Open/Short Status	Normal	

CTO Input Circuit Failure check malfunction thresholds:
CTO Signal = Hi for > 280 msec OR CTO Signal = Low for > 280 msec

<table>
<tr><th>CTO Input Circuit Out-of-Range check malfunction thresholds:</th></tr>
<tr><td>Engine Speed from CTO > 10000 rpm OR
| TCM Engine Speed – PCM Engine Speed | > 1000 rpm for > 290 msec</td></tr>
</table>

*Resolver sensor and R/D Converter are used to detect the magnetic motor/generator pole position
Motor/Generator speed is calculated using magnetic pole position.
The TCM calculates Engine speed from Motor/Generator speed.

Transmission Temperature Inputs

Motor/Generator Coil Temperature Sensors
These temperature sensors are located on the coil windings of the stators of the motor and the generator.

Motor/Generator Coil Temperature Sensor check Operation:	
DTCs	P0A2A (Motor Coil Sensor failure) P0A2F (Motor Coil Sensor over temp) P0A36 (Generator Coil Sensor failure) P0A3B (Generator Coil Sensor over temp)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	TCM A/D Converter OK
Monitoring Duration	240 - 2400 msec

Motor/Generator Coil Temp check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	0 msec	none
12V Battery voltage	7.5 V	17.0 V

Motor/Generator Coil Temp Over Temp check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	50 msec	none
12V Battery voltage	7.5 V	17.0 V
Motor/Generator Serial Comm. Status	Normal	

Motor/Generator Coil Temp Shorted Low check malfunction thresholds:
Motor/Generator Coil Temp > 220 deg C for > 240 msec

Motor/Generator Coil Temp Sensor Shorted High check malfunction thresholds:
Motor Coil Temp Transmission Fluid Temperature >= 10 deg C AND Generator Coil Temp >= 10 deg C AND Motor Coil Temp <= -20 deg C for > 240 msec **Generator Coil Temp** Transmission Fluid Temperature >= 10 deg C AND Motor Coil Temp >= 10 deg C AND Generator Coil Temp <= -20 deg C for > 240 msec

Motor/Generator Coil Temp Sensor In-range failure check malfunction thresholds:
Motor Coil Temp
Transmission Fluid Temperature - Generator Coil Temp < 30 deg C AND Transmission Fluid Temperature - Motor Coil Temp > 30 deg C for > 2400 msec
Generator Coil Temp
Transmission Fluid Temperature - Motor Coil Temp < 30 deg C AND Transmission Fluid Temperature - Generator Coil Temp > 30 deg C for > 2400 msec

Motor/Generator Coil Temp Over Temp check malfunction thresholds:
Motor/Generator Coil Temp over Temp
Motor/Generator Coil Temp > 180 deg C detected by Motor Control Unit /Generator Control Unit
3 times in 1 drive cycle

Transmission Fluid (Oil) Temperature Sensor

The Transmission Fluid Temperature sensor measures the temperature of the transmission fluid.

Trans Fluid Temperature check Operation:	
DTCs	P0710 (Transmission fluid temp sensor failure)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	TCM A/D Converter OK
Monitoring Duration	240 – 2400 msec

Trans Fluid Temp Circuit check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	0 msec	none
12V Battery voltage	7.5 V	17.0 V

Trans Fluid Temp Shorted Low check malfunction thresholds:
Transmission Fluid Temperature > 150 deg C for > 240 msec

Trans Fluid Temp Sensor Shorted High check malfunction thresholds:
Transmission Fluid Temperature <= -20 deg C AND Motor and Generator Coil Temp >= 10 deg C for > 240 msec

Trans Fluid Temp Sensor In-range failure check malfunction thresholds:
Transmission Fluid Temperature – Motor Coil Temp > 30 deg C AND Transmission Fluid Temperature – Generator Coil Temp > 30 deg C for > 2400 msec

Motor/Generator Inverter Temperature Sensors

These temperature sensors are located on the Motor and Generator Inverters.

Motor/Generator Inverter Temperature Check Operation:	
DTCs	P0A78 (Motor Inverter Temp Sensor failure) P0A3C (Motor Inverter Temp Sensor over temp) P0A7A (Generator Inverter Temp Sensor failure) P0A3E (Generator Inverter Temp Sensor over temp)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	Motor/Generator Serial Communication Status OK
Monitoring Duration	Continuous

Motor/Generator Inverter Temp Sensor Circuit Short check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	210 msec	none
12V Battery voltage	7.5 V	17.0 V

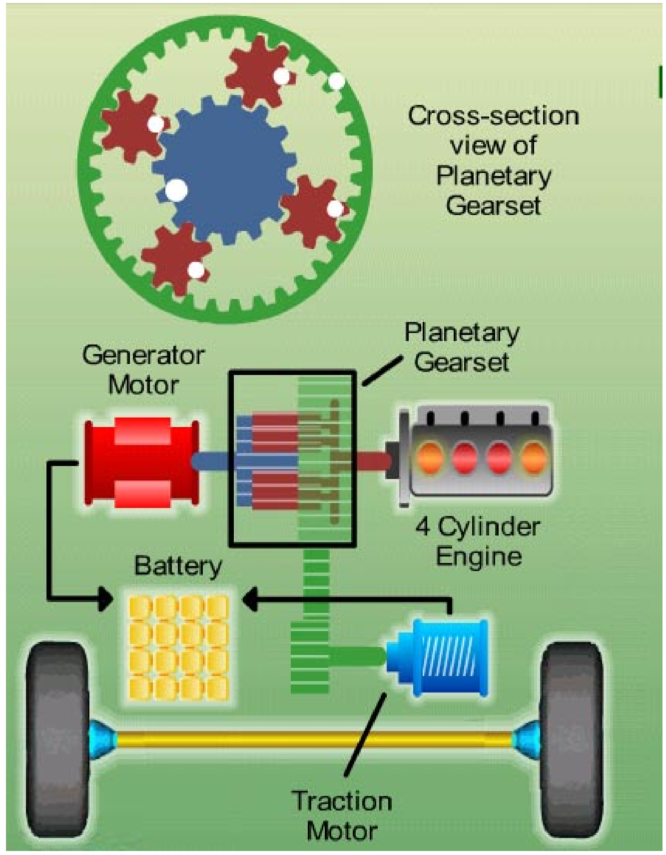
Motor/Generator Inverter Temp Sensor Short check malfunction thresholds:
(1) and (2) OR (3) and (4) OR (5) and (6) (1) Motor/Generator U phase inverter temp sensor fail flag via MCU/GCU = Error (2) Motor/Generator U phase junction temp >= 205 deg C (3) Motor/Generator V phase inverter temp sensor fail flag via MCU/GCU = Error (4) Motor/Generator V phase junction temp >= 205 deg C (5) Motor/Generator W phase inverter temp sensor fail flag via MCU/GCU = Error (6) Motor/Generator W phase junction temp >= 205 deg C 2 Times in 1 Drive Cycle

Motor/Generator Inverter Temp Sensor Open check malfunction thresholds:
(1) and (2) OR (3) and (4) OR (5) and (6) (1) Motor/Generator U phase inverter temp sensor fail flag via MCU/GCU = Error (2) Motor/Generator U phase junction temp <= -50 deg C (3) Motor/Generator V phase inverter temp sensor fail flag via MCU/GCU = Error (4) Motor/Generator V phase junction temp <= -50 deg C (5) Motor/Generator W phase inverter temp sensor fail flag via MCU/GCU = Error (6) Motor/Generator W phase junction temp <= -50 deg C 2 Times in 1 Drive Cycle

Motor/Generator Inverter Temp Over Temp check malfunction thresholds:
Motor/Generator Inverter Temperature >= 133 deg C
AND (Motor/Generator U phase inverter temp sensor fail flag via MCU/GCU = Normal
AND (Motor/Generator V phase inverter temp sensor fail flag via MCU/GCU = Normal
AND (Motor/Generator W phase inverter temp sensor fail flag via MCU/GCU = Normal
5 Times in 1 Drive Cycle

Aisin Powersplit Transaxle

Transmission Control System Architecture



The primary function of the Powersplit transaxle is to manage torque between the electric motors, engine, and driveline. The planetary gear set provides series, parallel and split paths for power distribution from the battery and engine. The torque ratio between the series path and the parallel path is fixed by the geometry of the planetary gear set. The power split between the series path and the parallel path is determined by the relative speeds (all series if vehicle speed is zero and engine is on; all parallel if generator is stopped; split otherwise)

The system behavior is similar to a CVT with the effective gear ratio between the engine and the wheels is determined by the split.

The transaxle is controlled by a standalone Transmission Control Module (TCM), The TCM communicates to the Engine Control Module (ECM), ABS Module, Traction Battery Control Module (TBCM), and Instrument Cluster using the high speed CAN communication link. The TCM incorporates a standalone OBD-II system. The TCM independently processes and stores fault codes, freeze frame, supports industry-standard PIDs as well as J1979 Mode 09 CALID and CVN. The TCM does not directly illuminate the MIL, but requests the ECM to do so. The TCM is located inside the transmission assembly. It is not serviceable with the exception of reprogramming.

Transmission Inputs

Angle Sensors

An angle sensor (resolver) is located on both the electric Motor and Generator and is used to detect the angular position of the rotor. The analog waveform generated by the resolver is converted into a digital signal by the Resolver to Digital (R/D) converter. The digital signal is used to calculate speed and angular acceleration which is used to control the electric Motor and Generator. The speed information is also used to calculate vehicle speed and is broadcasted to other modules over CAN. If a resolver open or short to power or ground is detected, or a failure with the R/D converter is detected, a P0A90 fault for the motor or a P0A92 fault for the generator will be stored.

Temperature Sensors

The Transmission Fluid Temperature Sensor (TFT) is monitored for open and short circuit faults and for in-range faults (P0710) where Trans Fluid, Motor Coil and Generator Coil temperatures do not correlate properly.

The Motor and Generator Coil Temperature Sensors are monitored for open and short circuit faults and for in-range faults where Trans Fluid, Motor Coil and Generator Coil temperatures do not correlate properly. (P0A2A – Motor Coil Sensor failure, P0A36 – Generator Coil Sensor failure). The Motor and Generator coils are also monitored for over-temperature (P0A2F, P0A3B).

The Motor and Generator Inverter Temperature Sensors are monitored for open and short circuit faults. (P0A78 – Motor Inverter Sensor failure, P0A7A – Generator Inverter Sensor failure). The Motor and Generator Inverters are also monitored for over-temperature (P0A3C, P0A3E).

Transmission Outputs

Inverter Control

Upon receiving the torque demanded by the driver from the ECM over CAN communication, the TCM calculates the required torque of the electric Motor and Generator to meet the demanded torque. The Motor/Generator Control Unit (MCU/GCU) will then control the Inverter over U, V, and W phase gate signals to regulate DC current into AC current that is fed into the stator.

The Motor and Generator gate signal lines are monitored for open circuits. A P0A78 fault for the Motor and a P0A7A fault for the Generator will be stored upon detection of a failure. The Inverter is also monitored for various faults such as over current, current sensor fault, current regulation fault, temperature sensor fault, etc. and will store a P0A78 fault for the Motor and a P0A7A fault for the Generator upon detection of a malfunction.

Transmission Control Module (TCM)

The TCM monitors itself by using various software monitoring functions. The flash ROM is checked using a checksum calculation. If the checksum is incorrect during initialization, a U2050 fault will be stored. The EEPROM is emulated in the flash ROM. If it is not possible to store information in the EEPROM emulation or if the verification fails, a P0613 fault is stored and the ECM is requested to illuminate the MIL immediately. If a RAM Read/Write error is detected during initialization, a P0613 fault code will be stored.

The Motor Control Unit (MCU) and Generator Control Unit (GCU) use similar types of RAM/ROM tests. If a fault is detected, a P0A1B fault is stored for the MCU, and a P0A1A fault is stored for the GCU.

CAN Communications error

The TCM receives information from the ECM via CAN. If the CAN link fails, the TCM no longer has torque or engine speed information available. The TCM will store a U0073 fault code if the CAN Bus is off. The TCM will store a U0100 or U0294 fault code if it doesn't receive any more CAN messages from the ECM.

The TCM receives wheel speed from the Antilock Brake System (ABS) module, A U0129 fault code will be stored if communication with the ABS module is lost. The TCM also receives information from the Traction Battery Control Module (TBCM) and a U0111 fault will be stored if the communication with the TBCM is lost.

Power Supply

If the power supply is outside of the specified 8 to 18 volt range, a fault will be stored (P0562, P0563).

PCM On Board Diagnostic Executive

The On-Board Diagnostic (OBD) Executive is a portion of the PCM strategy that manages the sequencing and execution of all diagnostic tests. It is the "traffic cop" of the diagnostic system. Each test/monitor can be viewed as an individual task, which may or may not be able to run concurrently with other tasks. The Diagnostic Executive enables/disables OBD monitors in order to accomplish the following:

- Sequence the OBD monitors such that when a test runs, each input that it relies upon has already been tested.
- Controls and co-ordinates the execution of the individual OBD system monitors: Catalyst, Misfire, EGR, O2, Fuel, AIR, EVAP and, Comprehensive Component Monitor (CCM).
- Stores freeze frame and "similar condition" data
- Manages storage and erasure of Diagnostic Trouble Codes as well as MIL illumination
- Controls and co-ordinates the execution of the On-Demand tests: Key On Engine Off (KOEO), Key On Engine Running (KOER), and the Output Test Mode (OTM).
- Performs transitions between various states of the diagnostic and powertrain control system to minimize the effects on vehicle operation.
- Interfaces with the diagnostic test tools to provide diagnostic information (I/M readiness, various J1979 test modes) and responds to special diagnostic requests (J1979 Mode 08 and 09).

The diagnostic also executive controls several overall, global OBD entry conditions.

- The Diagnostic Executive waits for 4 seconds after the PCM is powered before initiating any OBD monitoring. For the 2001 MY and beyond, this delay has been eliminated to meet the "zero startup delay" misfire monitoring requirements.
- The engine must be started to initiate a driving/monitoring cycle.
- The Diagnostic Executive suspends OBD monitoring when battery voltage falls below 11.0 volts.
- The Diagnostic Executive suspends monitoring of fuel-system related monitors (catalyst, misfire, evap, O2, AIR and fuel system) when fuel level falls below 15%

The diagnostic executive controls the setting and clearing of pending and confirmed DTCs.

- For the 2005 MY, pending DTCs will be displayed as long as the fault is present. Note that OBD-II regulations required a complete fault-free monitoring cycle to occur before erasing a pending DTC. In practice, this means that a pending DTC is erased on the next power-up after a fault-free monitoring cycle.
- For clearing comprehensive component monitoring (CCM) pending DTCs, the specific monitor must determine that no fault is present, and a 2-hour engine off soak has occurred prior to starting the vehicle. The 2-hour soak criteria for clearing CCM confirmed and pending DTCs has been utilized since the 2000 MY.

Exponentially Weighted Moving Average

Exponentially Weighted Moving Averaging is a well-documented statistical data processing technique that is used to reduce the variability on an incoming stream of data. Use of EWMA does not affect the mean of the data, however, it does affect the distribution of the data. Use of EWMA serves to “filter out” data points that exhibit excessive and unusual variability and could otherwise erroneously light the MIL.

The simplified mathematical equation for EWMA implemented in software is as follows:

New Average = [New data point * “filter constant”] + [(1 - “filter constant”) * Old Average]

This equation produces an exponential response to a step-change in the input data. The "Filter Constant" determines the time constant of the response. A large filter constant (i.e. 0.90) means that 90% of the new data point is averaged in with 10% of the old average. This produces a very fast response to a step change. Conversely, a small filter constant (i.e. 0.10) means that only 10% of the new data point is averaged in with 90% of the old average. This produces a slower response to a step change.

When EWMA is applied to a monitor, the new data point is the result from the latest monitor evaluation. A new average is calculated each time the monitor is evaluated and stored in Keep Alive Memory (KAM). This normally occurs each driving cycle. The MIL is illuminated and a DTC is stored based on the New Average store in KAM.

In order to facilitate repair verification and DDV demonstration, 2 different filter constants are used. A “fast filter constant” is used after KAM is cleared/DTCs are erased and a “normal filter constant” is used for normal customer driving. The “fast filter” is used for 2 driving cycles after KAM is cleared/DTCs are erased, and then the “normal filter” is used. The “fast filter” allows for easy repair verification and monitor demonstration in 2 driving cycles, while the normal filter is used to allow up to 6 driving cycles, on average, to properly identify a malfunction and illuminate the MIL.

In order to relate filter constants to driving cycles for MIL illumination, filter constants must be converted to time constants. The mathematical relationship is described below:

Time constant = [(1 / filter constant) - 1] * evaluation period

The evaluation period is a driving cycle. The time constant is the time it takes to achieve 68% of a step-change to an input. Two time constants achieve 95% of a step change input.

Catalyst Monitor and EGR Monitor EWMA

EWMA has been incorporated in the catalyst monitor and the non-intrusive stepper motor EGR monitor. There are 3 calibrateable parameters that determine the MIL illumination characteristics.

“Fast” filter constant, used for 2 driving cycles after DTCs are cleared or KAM is reset

“Normal” filter constant, used for all subsequent, “normal” customer driving

Number of driving cycles to use fast filter after KAM clear (normally set to 2 driving cycles)

Several examples for a typical catalyst monitor calibration are shown in the tables below. Specific calibration information can be obtained from the parameter listing provided for each strategy.

Monitor evaluation (“new data”)	EWMA Filter Calculation, “normal” filter constant set to 0.4 Malfunction threshold = .75	Weighted Average (“new average”)	Driving cycle number	Action/Comment
0.15	.15 * (0.4) + .15 * (1 - 0.4)	0.15		normal 100K system
1.0	1.0 * (0.4) + .15 * (1 - 0.4)	0.49	1	catastrophic failure
1.0	1.0 * (0.4) + .49 * (1 - 0.4)	0.69	2	
1.0	1.0 * (0.4) + .69 * (1 - 0.4)	0.82	3	exceeds threshold
1.0	1.0 * (0.4) + .82 * (1 - 0.4)	0.89	4	MIL on
0.15	.15 * (0.4) + .15 * (1 - 0.4)	0.15		normal 100K system
0.8	0.8 * (0.4) + .15 * (1 - 0.4)	0.41	1	1.5 * threshold failure
0.8	0.8 * (0.4) + .41 * (1 - 0.4)	0.57	2	
0.8	0.8 * (0.4) + .57 * (1 - 0.4)	0.66	3	
0.8	0.8 * (0.4) + .66 * (1 - 0.4)	0.72	4	
0.8	0.8 * (0.4) + .72 * (1 - 0.4)	0.75	5	exceeds threshold
0.8	0.8 * (0.4) + .75 * (1 - 0.4)	0.77	6	MIL on

Note: For the catalyst and EGR monitor, the "fast filter" is normally set to 1.0
For the catalyst monitor, the "fast filter" is normally used to 2 driving cycles, for the EGR monitor, "fast filter" is normally used for 1 driving cycle.

I/M Readiness Code

The readiness function is implemented based on the J1979 format. A battery disconnection or clearing codes using a scan tool results in the various I/M readiness bits being set to a “not-ready” condition. As each non-continuous monitor completes a full diagnostic check, the I/M readiness bit associated with that monitor is set to a “ready” condition. This may take one or two driving cycles based on whether malfunctions are detected or not. The readiness bits for comprehensive component monitoring, misfire and fuel system monitoring are considered complete once all the non-continuous monitors have been evaluated. Because the evaporative system monitor requires ambient conditions between 40 and 100 ^{o}F and BARO > 22.5 " Hg (< 8,000 ft.) to run, special logic can “bypass” the running the evap monitor for purposes of clearing the evap system I/M readiness bit due to the continued presence of these extreme conditions.

Evap bypass logic:

If the evaporative system monitor conditions are met with the exception of the 40 to 100 ^{o}F ambient temperatures or BARO range, a timer is incremented. The timer value is representative of conditions where the Evap monitor could have run (all entry conditions met except IAT and BARO) but did not run due to the presence of those extreme conditions. If the timer continuously exceeds 30 seconds during a driving cycle in which all continuous and non-continuous monitors were evaluated, the evaporative system monitor is then considered complete. If the above conditions are repeated during a second driving cycle, the I/M readiness bit for the evaporative system is set to a “ready” condition.

Power Take Off Mode

While PTO mode is engaged, the I/M readiness bits are set to a “not-ready” condition. When PTO mode is disengaged, the I/M readiness bits are restored to their previous states prior to PTO engagement. During PTO mode, only CCM circuit checks continue to be performed.

Catalyst Temperature Model

A catalyst temperature model is currently used for entry into the catalyst and oxygen sensor monitors. The catalyst temperature model uses various PCM parameters to infer exhaust/catalyst temperature. For the 1998 MY, the catalyst temperature model has been enhanced and incorporated into the Type A misfire monitoring logic. The model has been enhanced to include a misfire-induced exotherm prediction. This allows the model to predict catalyst temperature in the presence of misfire.

The catalyst damage misfire logic (Type A) for MIL illumination has been modified to require that both the catalyst damage misfire rate and the catalyst damage temperature is being exceeded prior to MIL illumination. This change is intended to prevent the detection of unserviceable, unrepeatable, burst misfire during cold engine start-up while ensuring that the MIL is properly illuminated for misfires that truly damage the catalyst.

Serial Data Link MIL Illumination

The instrument cluster on some vehicles uses the CAN data link to receive and display various types of information from the PCM. For example, the engine coolant temperature information displayed on the instrument cluster comes from the same ECT sensor used by the PCM for all its internal calculations.

These same vehicles use the CAN data link to illuminate the MIL rather than a circuit, hard-wired to the PCM. The PCM periodically sends the instrument cluster a message that tells it to turn on the MIL, turn off the MIL or blink the MIL. If the instrument cluster fails to receive a message within a 5-second timeout period, the instrument cluster itself illuminates the MIL. If communication is restored, the instrument cluster turns off the MIL after 5 seconds. Due to its limited capabilities, the instrument cluster does not generate or store Diagnostic Trouble Codes.