Chapter 8

Strategies—Responding to Operating Conditions

Contents

TABLES

8

INTRODUCTION

In this chapter I bring it all together. I'll describe how the sensors, control module and actuators operate during each of the nine engine strategies I outlined in Chapter 2. I'll discuss the systems that control the three basics of engine control, fuel, spark timing, and intake air, concentrating on the active sensors.

Rather than confuse by describing all the engines in all strategies, I'll discuss typical strategies of an SFI (MAF-SFI) 6-cylinder engine.

I'll look at the fuel injection, spark timing and throttle-by-pass-air for each of the strategies. While most recent Ford engines operate with reduced emission controls (compared to the early '80s), I'll discuss emission-control considerations in general, and you can apply them to the specific engines depending on the specific emission controls. And I'll discuss some MECS differences. The Nissan 3.0L engine in the 1993 Mercury Villager is a completely different engine from the Ford 3.0L, and its strategies differ somewhat from EEC.

1. WARM CRUISE—STRATEGY #1

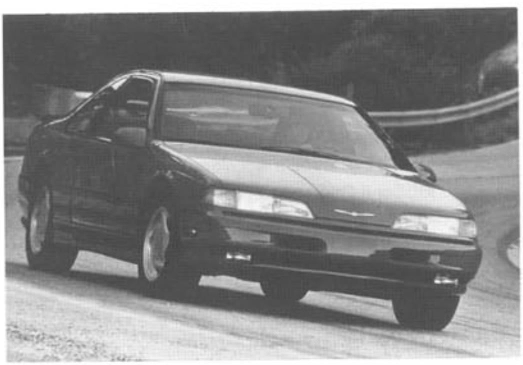

Fig. 1-1. Warm cruise is simplest of engine control strategies.

In some ways, Warm Cruise is the simplest of strategies because conditions are relatively stable, and because the engine operates without some of the special control actions applied to a cold engine. The engine operates more time in Warm Cruise than in any other strategy. As I described in Chapter 2, Warm Cruise strategy is designed for moderate power, maximum fuel economy, and minimum emissions. Level cruise generally draws 15–30 horsepower, a fraction of maximum engine output.

1.1 Active Sensors

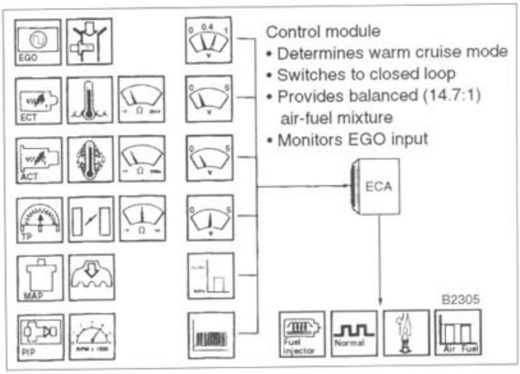

Fig. 1-2. In Warm Cruise, some sensors are active, sending operating signals. Other sensors, such as EVP are advising control module of conditions that might determine change of strategy.

All the sensors are operating, but some have no control effect on engine operations. So, for each strategy, I'll concentrate on the active sensors. Examples: Selection of Warm Cruise Strategy is based on:

- PIP is active, signalling engine rpm. For each two revolutions of the crankshaft, each sequential injector opens and closes once. At 2,000 rpm, each injector fires 16 times per second. For six injectors, a total of 96 pulses per second (Note: PIP and MAF indicate engine load)
- TPS is active, signalling throttle position. TPS signals Part Throttle, less than Wide Open Throttle (WOT), and more than Closed Throttle
- Engine coolant temperature (ECT) is normal so the control module is not active—does not add to the fuel-injection base pulse
- Delta Pressure Feedback EEGR Sensor (DPFE) signals indicate EGR pressures related to EGR flow. (Note: EGR sensors vary with different engines.)

1.2 Fuel Control

All those input signals match the values stored in the memories for Warm Cruise Strategy so the control module oper-

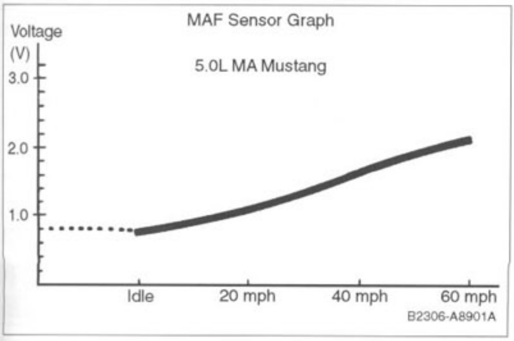

Fig. 1-3. MAF signals Mass Air Flow.

ates in a closed-loop mode. Each fuel injector receives a pulse signal of about 7–10 ms (milliseconds). The base injector pulse signal is calculated from the amount of air flow into the cylinders for a burning at the ideal (stoichiometric) ratio of 14.7:1.

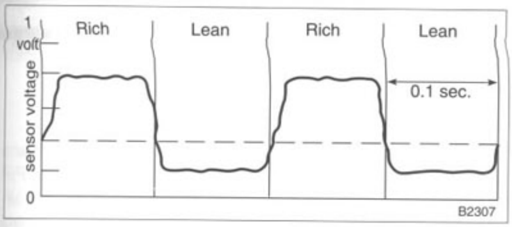

Fig. 1-4. Oxygen sensors (HEGO) signal exhaust gas oxygen.

Table a. Typical SFI Engine Warm Cruise Operation at 60 mph		
Warm Cruise 60 mph	**Per minute**	**Per second**
Air burned	3 lb (1.4kg)	0.05 lb (.02kg)
Fuel burned—6 inj.	0.2 lb (0.1kg)	0.003 lb (.0015kg)
Six injectors	6,000 pulses	100 pulses
Each injector	1,000 pulses	16 pulses
Each injection	0.00003 lb (0.000015kg, 0.015 grams)!	

We're talking a fraction of a drop per SFI injection pulse! In comparison, MFI injectors may fire four times as often as SFI, and deliver 1/4 as much fuel per pulse for the same rpm/load conditions.

The amount of fuel injected is continuously fine-tuned by signals from the oxygen sensors. The signals advise the control module of the oxygen content of the exhaust. Remember:

- When the sensor observes oxygen in the exhaust, it generates low voltage (between 0.1–0.4v.). That indicates lean mixture. The control module adds fuel by slightly increasing injection pulse time
- When the sensor observes little or no oxygen in the exhaust, it generates higher voltage (between 0.6–0.9v.). That indicates rich mixture. The control module slightly decreases injection pulse time

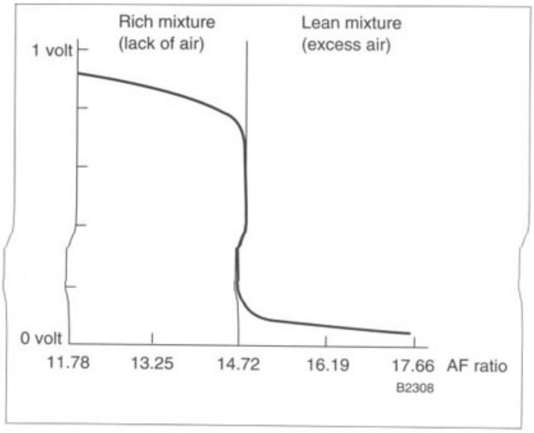

Fig. 1-5. Oxygen sensor output varies sharply on either side of ideal ratio.

By cycling back and forth between slightly rich and slightly lean, the computer controls the air-fuel ratio very close to 14.7:1, minimizing the output of emissions. Typical cruise cycles are 10–20 times per second.

SFI allows control of injection pulse times of each individual cylinder. Under some engine conditions, the control unit program calculates the individual cylinder air-fuel ratio by reading the oxygen sensor, knowing the time required for the exhaust gas from that cylinder to reach the sensor at that rpm. In V-type engines, two oxygen sensors are used, one for each bank. Metering is improved in what Ford Electronics engineers call "Stereo Hego".

1.3 Emission Control

EGR

All of these three sensors must signal in the proper range before the control module turns on EGR:

- ECT is neither too cool nor too hot
- TPS is part throttle
- PIP is between minimum rpm and maximum rpm

EGR affects Warm Cruise fuel injection. The formation of NO_x is controlled by the EGR Vacuum Regulator (EVR) solenoid. The EGR valve is opened the proper amount to recirculate exhaust gas into the intake manifold, minimizing the output of NO_x.

The Delta Pressure Feedback (DPFE) sensor sends feedback signals to the control module, verifying that the EGR valve is open the proper amount for these engine operating conditions. Calculations in the control module subtract the EGR flow (as unburnable) from the fresh air intake and reduce the fuel injection pulses accordingly.

Canister Purge

Canister purge during Warm Cruise affects fuel injection. Fuel vapors stored in the canister are being purged—drawn through the open Canister Purge valve (CANP) into the intake manifold to be burned in the engine. The look-up tables for fuel injection consider this flow during Warm Cruise. Fuel-injection pulse times are slightly shorter than they would be without canister purge. This delivers the ideal air-fuel mixture.

Secondary Air—Thermactor

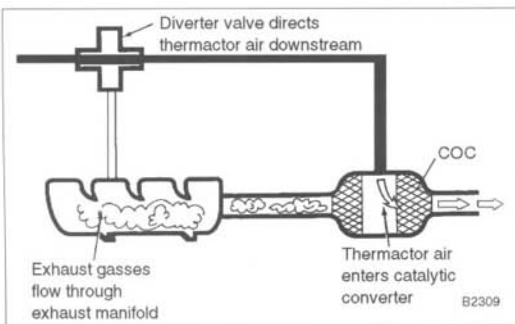

Fig. 1-6. Warm Cruise thermactor air flow.

On Thermactor-equipped engines (4.9L and larger) in Warm Cruise strategy, the control module closes the Thermactor Air Diverter (TAD), and opens the Thermactor Air Bypass (TAB). During Warm Cruise, the Thermactor system delivers secondary air to the Conventional Oxidation Converter (COC) to assist in oxidizing the HC and CO.

1.4 Spark Timing

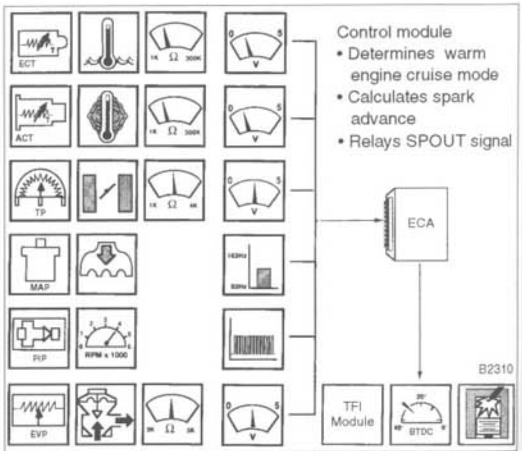

Fig. 1-7. Warm Cruise timing control.

Spark timing is determined by the look-up tables for Warm Cruise. Remember that, at a base timing of 10° BTDC, the PIP signal comes to the TFI 10° BTDC. In Warm Cruise, the air-fuel ratio allows for relatively slower burning, so the control module SPOUT signal advances timing to about 30° BTDC. This advance increases fuel economy; it also increases HC and NO_x engine-out emissions, but the tradeoffs favor the advance.

Effect of Exhaust Gas Recirculation

EGR flow during Warm Cruise affects Spark Timing because the EGR slows the burning of the air-fuel mixture. Using the DPFE signal, the control module changes the SPOUT signal to advance the spark timing by a few degrees to ignite the fuel earlier, allowing for the effect of the EGR.

1.5 Throttle Air Bypass (ISC)

From its original name of Idle Speed Control (ISC-BPA), the Throttle Air Bypass would seem to be operative only at idle. But no. The Warm Cruise bypass signals are 100% duty cycle to drive the bypass full open. Full open bypass flow prepares for deceleration. It's ready to close slowly like a dashpot to reduce emissions. When fully closed, it provides engine braking, and, at low engine speeds, it opens to prevent engine stalling.

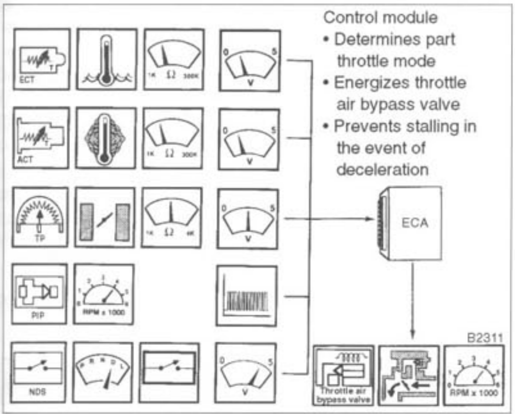

Fig. 1-8. Warm Cruise idle air bypass control.

You can see that even in the relatively stable conditions of Warm Cruise, the control module must keep track of several foreground operations with considerable interaction. In between, the control module must keep track of several background conditions, such as adaptive fuel corrections.

1.6 Mazda Engine Control Systems (MECS)

MEC systems generally operate quite similarly to those of EEC systems. Their strategies are generally simpler. I'll describe the principle differences.

MECS Warm Cruise

In Warm Cruise, the engine operates closed loop, with fuel control, EGR, and canister purge similar to EEC. Below 5000 rpm, on 1.8L engines, the High-Speed Intake Air (HSIA) valves are closed. For most engines, Electronic Spark Advance (ESA) spark timing is by control module. Exceptions: 1.6L and 2.2L non-turbo engines modify advance by centrifugal weights and vacuum diaphragm. With Automatic Transaxles, at vehicle speeds above about 40 mph, the control module signals the 4EAT module to lock up the torque converter.

For most MECS-I cruising, each bank of two injectors fires once every other revolution. In effect, the manifold receives injected fuel once per revolution. When Warm Cruise exceeds 4500 rpm, control switches over to one pulse per cycle (every two crankshaft revolutions). With half the number of pulses, pulse time is doubled to deliver the same amount of fuel per revolution.

Output device \ Engine condition		Cranking (cold engine)	Warming (during idle)	Medium load: Cold	Medium load: Warm	Acceleration	Heavy load	Deceleration	Idle	IG: on (engine not running)	Remark
Injector	Fuel injection amount	Rich			Normal	Rich		Fuel cut*	Normal	No injection	* Engine speed: above 1,500 rpm
Fuel pump relay		On								Off	
Igniter		Fixed at BTDC 6°	Advanced: depends on engine condition								
Solenoid valve	Purge control	Off			On (purge)			Off			
Solenoid valve	EGR	Off			On*			Off			* Engine speed: 1,300–4,500 rpm
Solenoid valve	PRC	Off (vacuum to pressure regulator)							On*	Off	* During hot start only
BAC valve	IACV	On (closed loop duty)		On (fixed duty)					On (closed loop duty)	Off	
BAC valve	Air valve	Open			Closed					—	
A/C relay		Off (a/c cut)	On			Off (a/c cut)	On			Off	

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Fig. 1-9. MECS outputs also vary according to Strategy (engine condition).

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MECS-II differences:

- 2.0L 4-cylinder & 2.5L V-6—Sequential injection fires each injector on that cylinder exhaust-stroke, just before the intake valve opens. If malfunction of CID signal or control module, control switches to simultaneous injection (MPI)—all cylinders, once every two revolutions. On the '93 2.5L V-6 the MECS-II Variable Resonance Induction System (VRIS) valves close below 3250 rpm, and also above 6250 rpm. VRIS #1 is open from 3250 to 6250 rpm, VRIS #2 is open from 4250 to 6250 rpm. See Fig. 2-2.

1.7 Warm Cruise Summary

- Fuel injection controlled to match engine rpm and load
- Spark timing controlled to match engine rpm and load
- Closed loop (oxygen sensor signal)
- Throttle-Bypass Air is full open
- Emission controls: EGR, secondary air (large engines only), Canister Purge

2. ENGINE CRANK—STRATEGY # 2

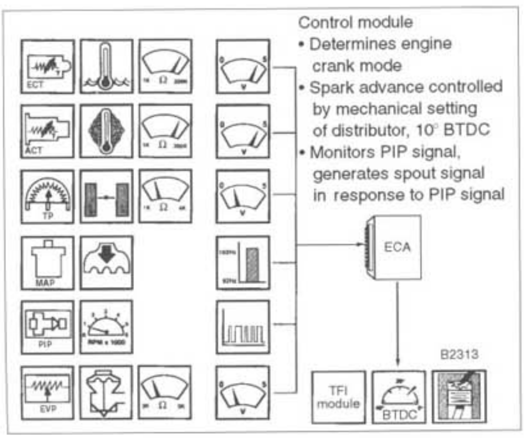

Fig. 2-1. Engine Crank strategy. Note irregular PIP signals.

The normal condition for Engine Crank is a cold engine. Remember, I'm talking about engine cold, and that could be as cold to you as 20-below zero or as warm to you as +100°F *(In Celsius, minus 30° to +35°C). It's still engine-cold.* The sensors advise the control module to operate under Engine Crank strategy.

Turning the key to ON causes the fuel pump to run for one second to pressurize the system. To reduce load on the starter, the control module shuts off the Air Conditioning compressor clutch during cranking, cold or hot.

Sensor input signals

- PIP is slow and irregular
- MAF is low and irregular
- ECT is low
- ACT is low
- TPS is low, for closed throttle
- Oxygen sensor signals are near zero

All those signals match the Engine Crank values stored in the memory. The system operates open loop. No controls are energized for emission control.

2.1 Fuel Control

Pulse times are based solely on temperatures. From its Engine Crank look-up tables, the control module finds the base injection pulse times for rich mixtures. Then the control module adds to the pulse times, adding more:

- When the ECT signal indicates lower coolant temperature
- When the ACT signal indicates colder intake air

No fuel is delivered until the engine starts to turn. Injection timing is synchronized with the PIP signal, 10° BTDC.

SFI injectors are fired sequentially, once during each two crankshaft revolutions. MFI injectors are double fired in gangs, twice every crankshaft revolution (that's once for each PIP signal). Ford gasoline systems do not use the Cold Start Injector common to Bosch systems and to some General Motors systems. You'll find a Bosch-type cold-start injector in EEC Flexible Fuel Vehicles to improve starting with methanol mixtures of fuel.

The control module also starts the timer. After 20 seconds, if the engine has not fired, the control unit reduces injector pulse times to prevent flooding.

Engine control shuts off EGR during Engine Crank. Control bypasses Thermactor air to prevent exhaust manifold explosions from the rich mixture. This also improves engine start by relieving the starter loading by the air pump.

If you flood the engine, you can clear the cylinders by cranking with the accelerator pressed to the floor. This Wide Open Throttle TPS signal cuts off fuel *injection so the incoming air can* sweep out some of the raw fuel and dilute the rest enough to fire.

2.2 Spark Timing

Spark timing during Engine Crank is set by the distributor. Distributor mechanical setting is the base timing of 10° BTDC. The control module receives the PIP signal and generates the SPOUT signal without modifying PIP. On some EDIS engines, the spark signal is delayed for about one-half second. This insures oil flow to the bearings before the starting loads. Delay also insures full crankshaft revolution of the VRS for better timing signals. MECS fixed spark timing during Crank is 6° BTDC. MECS-II fixed timing is 7° BTDC.

Push-Start Timing

New provisions for Push-Start change the spark output signals. When the control module sees low-rpm PIP signals (Ignition ON) but no START signal, it provides spark timing for push starts.

Compared to Computer-Controlled Dwell (CCD), Push-Start Waveforms show a longer dwell and a corresponding shorter SPOUT signal. See Chapter 6 for more information.

2.3 Throttle Air ByPass (ISC)

The Throttle Air Bypass is full open during Engine Crank, operating with 100% duty cycle. With the throttle plate closed ("No Touch" starting), the bypass supplies the air to start the engine.

2.4 Cold/Warm Differences

Warm Engine Crank strategy is the same Cold Engine, but the ECT and ACT signals cause the control module to signal shorter fuel-injection pulses.

2.5 MECS Engine Crank

Bypass air is full open with the cold thermowax element. The valve begins to open with warm coolant temperatures: 40–50° C (105–125°F), except the 1.6L in the Capri—60°C (140°F). Control shuts off the Air Conditioning compressor clutch during cranking. It stays off during the first 5 seconds after start. Establishing the initial idle is more important than cooling the passengers, at least for 5 seconds.

MECS-II

On the 2.0L 4-cylinder, for Engine Crank there are simultaneous injections, two per crankshaft revolution (four per cycle), each injector. See Fig. 2-2. On the 2.5L V-6, there are sequential injections, the same as during engine running.

2.6 Engine Crank Summary

- Fuel-injection pulse times from look-up tables, corrected for ECT and ACT. MAF signals ignored
- Spark timing directly from PIP, 10°BTDC. No SPOUT
- Throttle-Bypass Air full open, bypassing closed throttle
- Open Loop
- No emission controls operating

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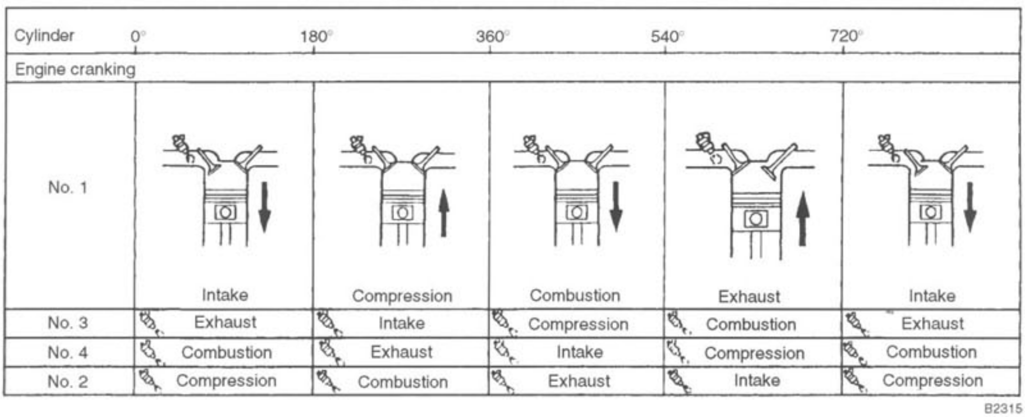

Fig. 2-2. MECS 2.0L Engine Crank strategy: simultaneous injection, twice per crankshaft revolution.

3. Cold Start/Warm-Up—Strategy # 3

Fig. 3-1. Engine Cold/Warm-Up strategy depends on engine temperature.

The control module changes over from Engine Crank Strategy to Cold Start/Warm-Up when it observes the signs of engine running:

- PIP input indicates a steady rpm signal, higher than cranking
- MAF signals become regular, indicating low load
- TPS remains low, closed throttle

3.1 Fuel Control

Cold Start/Warm-Up strategy changes fuel-control look-up tables to reduce basic injection pulse time by half. To this, pulse time is added because the ECT signals cold engine, but that gradually reduces as the engine warms up. Air-temperature input signals add fuel-injection pulse time as needed, depending on the temperature of the intake manifold. Warm-up Strategy looks for a balance in enrichment:

- On one hand, a richer mixture means better combustion in cold cylinders, improving cold idle and reducing the chances of a cold stall. Further, extra fuel delivered to the catalytic converter burns sooner and heats up the converter for earlier action
- On the other hand, a leaner mixture means the engine will more likely pass its qualification emission test. Many engines fail during the first minute, the cold warm-up period

3.2 Emission Control

Emission control is important during Cold Start/Warm-Up. It must be handled by the fuel control for the air-fuel mixture in the combustion chamber because none of the emission systems can be engaged immediately after cold start.

During warm starting, on engines with Thermactor, when ECT signals warmer than 12°C (55°F), the control module signals the bypass valve (TAB) to close. This sends the secondary air through the diverter valve (TAD) upstream to the exhaust manifold. The control module timer limits upstream delivery to about 3 minutes.

Remember, diverting the secondary air upstream to the exhaust manifold burns "leftover" HC and CO gasses from the rich air-fuel mixtures of warm ups, providing three results:

1. Less warm-up pollution—with the addition of air containing oxygen, HC and CO from the air-fuel mixtures tend to be burned or oxidized into H_2O and CO_2.
2. The hot exhaust gasses resulting from the burning air-fuel mixtures in the exhaust manifold help to heat the catalytic converter. HEGOs are warming electrically.
3. The Thermactor air (mostly oxygen) increases the oxygen content of the exhaust gasses flowing past the oxygen sensor. Because it is sensing extra oxygen, it signals low voltage, inaccurately indicating lean mixture. The control module ignores any oxygen sensor readings while the Thermactor is diverted to upstream.

3.3 Spark Timing

Cold Start/Warm-Up strategy changes Spark-timing look-up tables to advance base spark timing according to PIP and MAF inputs. The base timing is advanced further depending on the cold-engine ECT signals. The control-module timer causes further advance after a calibrated time. Spark-timing advance increases combustion chamber temperatures, warming the catalytic converter.

Cold Start/Warm-Up timing is also changed according to the engine load, depending on the transaxle status. Cranking can only be done in Neutral or Park, indicated by the NDS switch (or the indications of neutral or clutch disengaged in manual transaxles). After start, shifting the Transaxle into Drive or Reverse signals the control module to adjust the spark timing for adequate power and a smooth idle.

3.4 Throttle Air Bypass (ISC)

As the engine warms up, the Throttle-Air Bypass closes more for a normal idle rpm. The control module signals a reduced duty cycle to the Bypass Air for a smaller opening, so-called fast idle. For colder ECT and air-temperature signals, idle rpm is higher. Without the fast-idle cam of carburetors, you do not need to kick it off the cam. Notice too that Warm-up cold-idle rpm is much lower with fuel injection than with carburetors.

Transaxle-load status helps to determine throttle bypass-air to control rpm. *Neutral load allows the bypass to close, maintaining* the desired lower Warm-up rpm. Shifting to any drive mode causes the bypass to open, carrying the load of the transaxle. To reduce creep, Drive rpm is lower than Neutral or Park.

Idle rpm receives several feed-forward signals related to electrical loads affecting the alternator drag, or power-steering pump drag:

- Heated rear window (backlight to Ford), or heated windshield (special option on some luxury Fords). The control module increases bypass air to anticipate the drop in idle rpm caused by the increased alternator load. Higher idle rpm also increases alternator rpm for greater output rate to carry the electrical load
- Air conditioner. Receiving a signal from the A/C compressor clutch, the control module signals to increase bypass air to anticipate the load of the compressor
- Power steering. Turning the steering wheel while still at standstill puts the greatest load on the power-steering system. If the pump pressures rise above 400–600 psi (2700–4100 kPa), the control module signals to increase bypass air to anticipate the power-steering pump load, preventing engine stalling
- Headlamps ON increases alternator load. (Daytime Running Lamps in Canada)
- Heater blower on position 3 or 4

Idle rpm is controlled in a closed-loop mode. The computer compares the PIP signal to each different target idle rpm from the control module computations and modifies output signals to maintain the target idle rpm.

3.5 MECS Cold Start/Warm-Up

Fuel and spark timing are similar to EEC systems except for the 1.6L engines and the 2.2L non-turbo engines, with vacuum-controlled advance retard. Spark timing operates independently of the control module, using port vacuum.

Bypass air is increased through two passages: 1) direct temperature control through the thermowax pellet of the Air Valve, and 2) through the control module actuator signals to the Idle-Speed Control Solenoid. As the engine warms past 40–50°C (100–120°F) (Capri 1.6L and Probe 2.0L and 2.5L slightly warmer), the wax pellet expands and closes that passage. The other passage, the ECA-controlled bypass, operates at all temperatures.

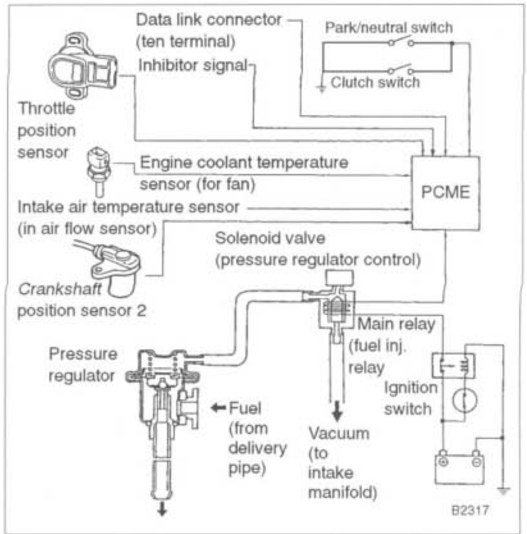

Fig. 3-2. MECS increases fuel pressure after hot start by venting pressure regulator to atmosphere instead of to intake manifold. Venting determined by high coolant temperature or high intake air temperature.

To prevent fuel boiling in the injectors or fuel rail after a hot start, MECS solenoid valve vents the fuel pressure regulator. When the fuel-pressure regulator is open to the atmosphere, it raises the fuel pressure to about 41 psi (280 kPa). After about 2 minutes, or if the engine is loaded by driveaway, the solenoid closes the vent, resuming normal relative fuel pressure of 33 psi (230 kPa).

MECS-II delays Air-conditioning power for 3–4 seconds after start to prevent stalling.

3.6 Cold Start/Warm-Up Summary

- Fuel injection controlled by PIP and MAF, corrected for ECT and intake-air temperature. Emission controls delayed, EGR, Canister Purge; Secondary air as ECT signals warm-up
- Spark timing controlled by PIP and MAF, corrected for ECT and air temperature, also for transaxle status; advanced by timer
- Open Loop based on seconds since start, ignoring first signals from HEGO
- Throttle Air Bypass operates closed loop, opening and closing the passage to maintain target rpm—higher for cold temperatures, modified by feed-forward signals from various loads on alternator and power-steering pump

COLD START/WARM-UP— STRATEGY # 3

4. COLD DRIVEAWAY—STRATEGY # 4

Cold Driveaway probably happens within one minute. The active sensors are:

- PIP signals increase in rpm
- MAF signals increase in air flow
- TPS signals increase in amount of throttle opening, and rate of throttle opening
- ECT and ACT signal cold temperatures

4.1 Fuel Control

Cold Driveaway uses fuel-injection look-up tables for the changing PIP (rpm) and MAF (load). To these base pulse times, the control module adds pulse time for the TPS signals of amount and rate of throttle opening. Control further adds pulse time according to the ECT signals of the cool engine. ACT signals also add pulse time as needed. As ECT and intake-air temperature rise, the cold enrichments gradually reduce.

During Cold Driveaway, based on ECT signals greater than 77°C (170°F), or on elapsed time greater than 3 minutes, the control module opens the diverter (TAD) valve. If the secondary air were not diverted from the exhaust manifold, continued burning of excess fuel would overheat the manifold. The open Diverter Valve sends the secondary air downstream of the exhaust manifold and the oxygen sensor. The oxygen in the air helps to burn the HC and CO in the oxidation section of the catalytic converter (OC), reducing tailpipe emissions.

For engines with EGR, during Cold Driveaway, the control module signals keep the EGR valve closed. Exhaust gas would interfere with the engine operation. At the low engine temperatures, little NO_x is forming in the combustion chambers.

During Cold Driveaway, control shuts off Canister Purge (CANP) to prevent interfering with the air-fuel ratio during warm up.

4.2 Spark Timing

Cold Driveaway uses Part-Throttle spark-timing look-up tables for the changing PIP (rpm) and MAF (load). Base spark timing increases with increases in the PIP signal rpm. With a cool ECT signal, spark timing is advanced from base timing.

4.3 Throttle Air Bypass (ISC)

Cold Driveaway continues the increased duty-cycle signal that keeps the air bypass partly open. While the bypass air is reduced with further warm up, the control-module signal continues to keep some bypass air flowing. If the throttle is suddenly closed, the bypass air prevents engine stall.

4.4 Cold Driveaway Summary

- Fuel injection cuts back as engine warms. EGR and Canister Purge still shut off. Secondary air to catalytic converter
- Spark timing advances with rpm and retards as engine warms
- Throttle Air Bypass partly open, reducing with warm-up.

5. WARM DRIVEAWAY—STRATEGY # 5

The important Warm Driveaway sensors are:

- PIP signals increasing engine rpm
- MAF signals increasing mass air flow
- ECT and ACT signal engine temperatures approaching warm
- TPS signals cause mixture enrichment as throttle is opened (as accelerator pump). Enrichment increases with lower ECT and ACT, and with increases in MAP (load)
- DPFE signals indicate EGR backpressures as exhaust gas begins to circulate, about one minute after starting
- From operating Open Loop, the oxygen sensor warms enough to begin sending good (fluctuating) signals so the control module can begin Closed Loop operation.

5.1 Fuel Control

Warm Driveaway fuel control is based on the base fuel-injection pulse times from the PIP and MAF signals. Extra fuel is provided for acceleration. ECT is warm enough that no added fuel pulse times are needed, but ACT may signal cold air in the intake system, requiring extra fuel pulse time to be added.

- DPFE signals indicate EGR backpressures as exhaust gas begins to recirculate, and PFE signals indicate EGR pressure drop
- Early in this warm up in Open Loop (as quickly as 10 seconds), the heated oxygen sensor warms enough so its signals begin fluctuating. As permitted by the timer, the control module signals closed-loop operation

The Canister Purge valve remains closed until ECT signals indicate that the engine is fully warmed up, ready to receive fuel vapors into the incoming air-fuel mixture.

5.2 Spark Timing/EGR Flow

Warm Driveaway base spark timing is taken from a part-throttle look-up table. Timing may be advanced if the control module is receiving low ECT signals. As the engine warms, the control unit cuts back the temperature-based timing advance.

As EGR begins to flow, the control module adds advance to the base timing:

- The EGR-diluted air-fuel mixture takes longer to burn, so the spark timing must be advanced
- The EGR-diluted air-fuel mixture is less likely to detonate so the spark timing can be advanced

Advanced timing tends to burn the mixture more completely, reducing HC and CO. Spark timing is proportional to EGR flow rate—the more flow, the more advance.

Spark-timing/Automatic Transmissions

Spark timing is retarded during some shifts of later model automatic transmissions such as E4OD, AXODE, and 4EAT to provide smoother shifts. The strategy reduces the torque for about 50 milliseconds during the shift.

- When the A/T control unit is ready to shift, it signals the engine control unit. Under certain load conditions, if the engine control unit is warm, it signals the A/T control unit, something like, "OK shift"
- During the shift, the control module retards the timing briefly (20–30 ms), then resumes normal timing
- If the engine is cold, the control module may signal that it is not going to retard timing. "Shift, but under continued torque conditions"
- The A/T increases hydraulic pressure during the shift to handle continuing torque

Later models combine control of engine and automatic transmission (transaxle) into a single EEC-IV or MECS control unit.

5.3 Throttle Air Bypass (ISC)

Quite similar to Cold Driveaway.

5.4 MECS Part Throttle Acceleration

When you press the accelerator, the TPS signals throttle position and rate of movement on 2.2L and 1.8.L with automatic transaxle (ATX), also on 1993 and later 2.0L and 2.5L. But on the other MECS engines, control calculates acceleration when it senses larger-than-normal air flow signals from the VAF for the current crankshaft speed.

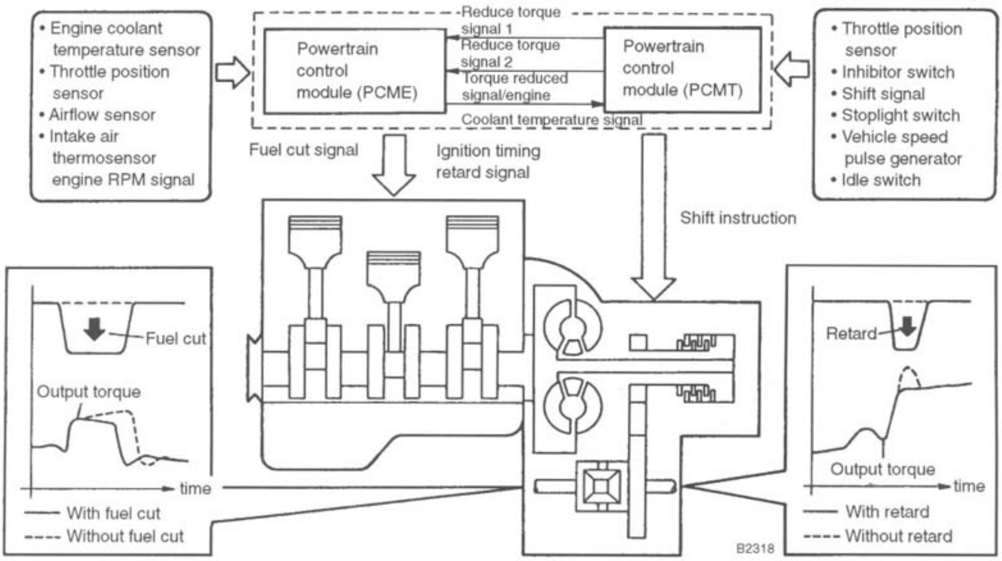

Fig. 5-1. Engine control module (PCME) and Transaxle Control Module (PCMT) trade signals for torque reduction—fuel cut during some upshifts, spark timing retard during most downshifts.

Torque Reduction

The 2.5L V-6 Engine Control Unit receives signals from the A/T Control Unit to provide smoother shifting, and to reduce load on the automatic transaxle shifting mechanism.

- Upshifting-1>2, and 2>3—when the transaxle is ready to shift, it signals the control module. If the coolant is warm, > 60°C (140°F), the control module sends "reduce torque signal #1" to cut fuel injection for about 50 milliseconds: if TPS signals throttle more than half-open, cut 1/2 the cylinders and, If TPS signals more than 3/4 open, cut all cylinders
- Downshifting (except OD>3)—when the transaxle is ready to downshift, it signals the control module. If warm, the control module sends "reduce torque signal #2" to retard timing for about 50 milliseconds

The 4-cylinder 2.0L Engine Control Unit also controls Automatic Transaxle similarly but in a single control unit for torque reduction during upshifts and downshifts.

5.5 Warm Driveaway Summary

- Fuel injection switches to Closed Loop in about one minute
- Spark timing considers rpm, temperature, EGR flow
- Secondary air to converter, Canister Purge off

6. Part-Throttle Acceleration—Strategy #6

Part-Throttle Acceleration considers that you want to increase car speed, but are still interested in good fuel economy and good emission control. To do this, engine control must remain closed loop, with emission controls operating. The most important sensor is the TPS, signalling less than Wide Open Throttle (WOT).

> If you are driving for economy, you may wonder how far to push the accelerator to increase speed. Some energy conservationists advise drivers to operate the accelerator as if an egg were on the accelerator pedal. During an earlier fuel crisis, BMW ran tests showing that the egg-on-the-accelerator concept did not save fuel. Indeed with fuel injection, accelerating briskly to the desired speed is more economical because the acceleration-enrichment time is shorter. I accelerate "briskly" at about 90%, "90kPa" on my manifold-pressure gauge. I want to avoid sending a Wide Open Throttle (WOT) signal to the computer because that changes all the rules of acceleration. I suspect the egg-on-the-accelerator bit is a leftover from carburetor days, avoiding that extra squirt from the accelerator pump that carburetors needed to prevent engine stumble.

6.1 Fuel Control

Part-Throttle Acceleration base injection pulse time is taken from the Part-Throttle look-up tables according to the PIP (rpm) and the MAF (load) signals. Pulse times are increased according to the TPS signal, indicating amount and rate of throttle opening. The rate signal, indicating how fast you depressed the accelerator, adds pulse time during the throttle movement, usually less than one second. Then control reduces enrichment to the proper pulse time for that throttle position.

Pulse time is also increased according to the ACT and ECT sensors, greater when the incoming air and/or the engine is colder. Control calculates the base pulse time and the additional fuel necessary to handle the increased air flow while maintaining the ideal air-fuel ratio. Oxygen sensor signals continue from the exhaust gas, and the system operates closed loop. Emission Control EGR, Thermactor, and Canister Purge continue as in Warm Cruise.

Acceleration that can cause a downshift of the automatic transmission may call for fuel cut or spark-timing retard to reduce torque loading during the shift. When the engine is warm, fuel may be cut from some injectors briefly—in milliseconds.

6.2 Spark Timing

Part-Throttle Acceleration spark timing continues from the Part-Throttle look-up tables, as in Warm Cruise, determined by rpm, load, and modified by ECT, and air temperature.

6.3 Throttle Air Bypass

Part-Throttle Acceleration Air Bypass continues as in Warm Cruise.

6.4 Intake Manifold Runner Control (IMRC)

During acceleration—part throttle or full throttle, as rpm increases above 3200—the control module opens the secondary throttle valves. This delivers air to the secondary intake valves, providing a smooth transition from low-speed low-load operation.

7. Full-Throttle Acceleration—Strategy # 7

Full-Throttle Acceleration is also defined as Wide Open Throttle (WOT). When the TPS signals WOT, that changes all the rules. You are indicating to the control system that you want full power. You are willing to sacrifice economy and emission control during that WOT acceleration.

7.1 Fuel Control

With the TPS signalling WOT, the control module shifts to Full-Throttle look-up tables. From those tables, the PIP and MAF signals to the control module determine a new set of base pulse times. Control provides extra enrichment during the throttle opening to handle the sudden rush of air. ECT and ACT add pulse times as necessary for lower temperatures.

The oxygen-sensor signals indicate rich mixture, but the control module ignores the oxygen sensor: "I know, I know, it's rich—and I want it that way!" Full-Throttle Acceleration causes the control module to shut off emission controls: Canister Purge valve closed; EGR valve closed; Thermactor Air diverted or dumped.

Wide-Open Throttle Air Conditioning (WAC) cuts out for 5–10 seconds after the WOT. In the Integrated Relay Control Module (IRCM), power is cut from the Air Conditioning Clutch for 10 seconds. The A/C compressor interruption is so short that you will probably never notice any change in air temperature. In some smaller engines, WOT control turns off the cooling fans for 10 seconds to reduce alternator drag. Again, the interruption will not be noticed.

7.2 RPM/Vehicle Speed Limitation

Some Ford engines with superchargers are easily capable of exceeding rpm limitations of the engine. To prevent engine destruction, rpm limitation operates from PIP signals to reduce fuel injection gradually to limit engine rpm.

The 3.8L SC engine in T'Bird/Cougars cuts back fuel injection if the coolant temperature or the oil temperature signals overheat when running above 100 mph for extended periods of time. If the engine rpm is too high for third gear, the T'Bird will illuminate the Shift Indicator Light and sound a chime. This warns the driver to upshift or slow down, otherwise, fuel will be cut back.

The SHO engine is rev-limited by the control module to 7300 rpm to prevent over-revving the accessories. If the pulley diameters are changed to under-drive accessories, engineers say the engine is safe to 8500 rpm.

7.3 Spark Timing

Full-Throttle Acceleration shifts spark timing to a different set of look-up tables that provide advanced spark timing for maximum power without regard to emission control. With a richer mixture that is less likely to detonate, spark timing increases, perhaps from 20° BTDC to 30°. The Knock Sensor (KS) monitors engine vibrations and retards spark if it detects detonation. KS operates closed loop, retarding to reduce knocking, and advancing slowly as knock signals disappear. See Figure 7-1.

Full-Throttle Acceleration often causes downshift of the automatic transmission. When engine conditions permit (warm), ignition timing is retarded for a fraction of a second, just long enough for the shift. This improves shift smoothness, and also increases life of the shift clutches.

8

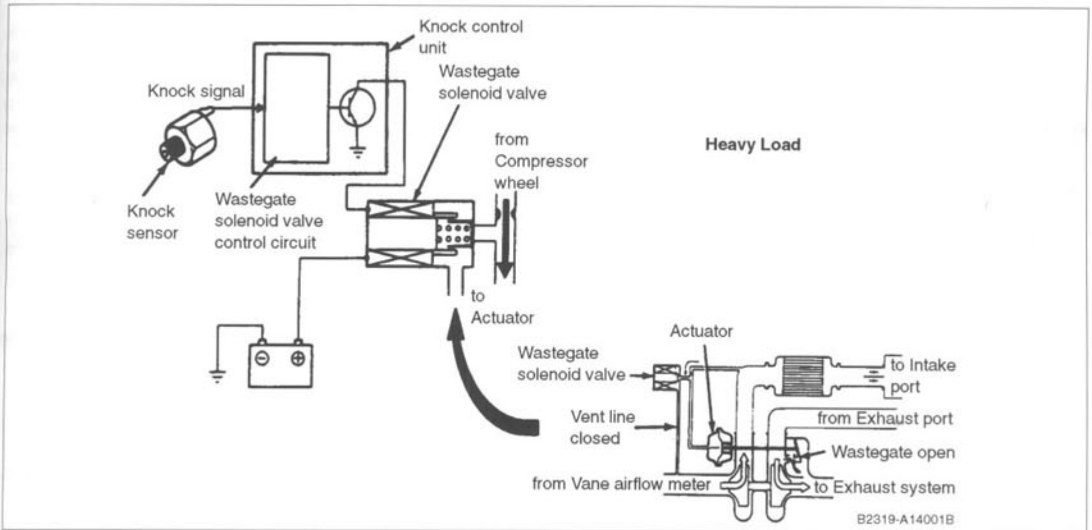

Fig. 7-1. Under heavy load, knock signals to Knock Control Unit (KCU) cause wastegate solenoid valve to open bypass, reducing turbo boost.

7.4 Throttle Air Bypass (ISC)

No change from the 100% duty cycle of Warm Cruise. Passing extra air around the wide-open throttle has the effect of fitting a larger throttle body. At the same time, if WOT is snapped shut without drive connection, (Neutral or clutch disengaged), the Throttle Air Bypass keeps the engine from stalling.

7.5 MECS Full-throttle Acceleration

The TPS signals WOT to the control module. Fuel enrichment begins and emission control (EGR and canister purge) cuts off. Turbo engines build boost, with knock protection:

- 2.2L computer-controlled spark retard and wastegate opening
- 1.6L computer-controlled spark retard, and mechanical control of wastegate opening

MECS-II Overspeed Protection

- 2.0L 4-cylinder cuts fuel supply over 6800 rpm, and over 5500 rpm if engine is cold—ECT below –15°C (5°F)
- 2.5L V-6 cuts fuel over 7500 rpm, and over 5500 rpm if engine is cold—ECT below –15°C (5°F)

7.6 Full-Throttle Acceleration Summary

- Fuel injection rich, Open Loop. Emission controls off (EGR, Secondary Air, Canister Purge), Speed limitation cuts fuel to limit overspeed
- Spark timing for max power. Knock signals retard timing and cut back boost, closed loop
- Throttle bypass wide open for added air/power

8. DECELERATION—STRATEGY # 8

Strangely enough, Deceleration closed-throttle operation presents some problems. The control module recognizes this operation by the signal from the Vehicle Speed Sensor (VSS) and by the closed-throttle signal from the Throttle Position Sensor (TPS). The strategy calls for reducing fuel flow (fuel is being wasted) while still controlling emissions that result from too-lean burning.

8.1 Fuel Control

Deceleration injector pulse times become shorter. When pulse times are less than 2 milliseconds and rpm is greater than 1500, control shuts off the injectors. In some engines, the oxygen sensor continues to switch voltages, calling for closed-loop operation to maintain ideal air-fuel ratio; in others, the mixture goes lean and the system operates open loop.

From shut-off, the control module resumes normal injection pulses:

- As engine speed decreases to 1200 rpm, sooner if ECT signals indicate cold engine
- As you step on the accelerator

Emission control does not function. Signals cut off EGR and Thermactor.

8.2 Spark Timing

Deceleration spark timing comes from a Closed-Throttle look-up table. With low air flow signals, there is little chance of detonation so spark timing is advanced.

8.3 Throttle Air Bypass (ISC)

Deceleration Throttle Air Bypass is complex, depending on PIP and VSS signals. Control-module signals drive the Bypass:

- Part-way closed when the TPS first signals closed throttle. The bypass acts as a throttle dashpot to prevent an over-rich mixture
- Full closed a few seconds later, to increase engine braking
- Partly open again as rpm approaches idle, to prevent engine stall

8.4 MECS Deceleration

MECS 1.3L, 1.6L and 1.8L engines use a mechanical dashpot to limit sudden throttle closing. The dashpot prevents stalling and excess emissions from too-rich operation. Full closing of the vane in the VAF normally cuts off the fuel-pump safety switch in the VAF, cutting off the fuel pump. MECS-I uses two different methods to prevent this fuel-pump shut off:

- In 2.2L turbo engines, the control module completes the circuit to the fuel pump relay during deceleration
- In 1.6L engines, a capacitor discharges current to the fuel-pump relay during deceleration, keeping the pump running

Deceleration fuel is cut off from the injectors above 2200 rpm.

MECS-II

The Throttle Bypass-Air prevents cut-off of air flow, eliminating the need for a dashpot.

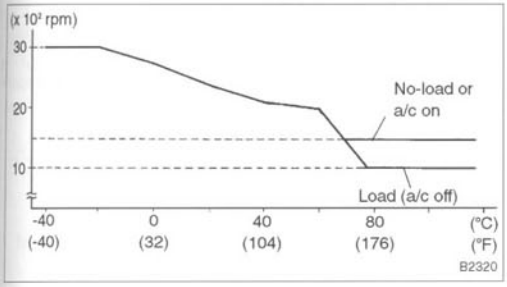

Fig. 8-1. Fuel cut-off ends as engine rpm drops, depending on ECT, AC, or engine load.

8.5 Deceleration Summary

- Fuel injection reduced, or cut off in most engines, resuming at lower rpm to prevent stalling
- Spark timing advanced
- Throttle Air Bypass closes partway as dashpot, then fully for engine braking, then open to prevent stalling

9. WARM IDLE—STRATEGY # 9

9.1 Fuel Control

The control module recognizes Warm Idle strategy when the TPS indicates closed throttle, VSS indicates zero vehicle speed, and ECT signals warm engine. The control module switches to Closed Throttle look-up tables. Injection pulses are short because the engine needs to deliver only enough power to keep itself running.

Usually, the oxygen sensor continues to deliver switching voltages, so the engine operates closed loop. If the control module sees no change in the switching voltage for 15 seconds, it goes to open loop. Then if it sees two exhaust-gas oxygen variations, the control module switches back to closed loop.

The control module shuts off the EGR. The Thermactor will continue to divert downstream, but if idle continues for several minutes, the Thermactor will bypass to avoid overheating the catalytic converter.

9.2 Spark Timing

Warm Idle allows the exhaust gasses to cool. If prolonged, Warm Idle increases emissions of HC and CO. Ford Warm Idle strategy increases the temperature of the exhaust gasses for better emission control. Spark timing is retarded gradually about 5° after 1 minute of Warm Idle. Spark retard is combined with increased Throttle Air Bypass.

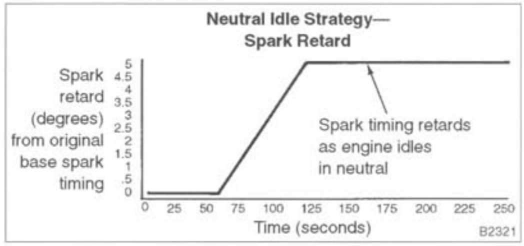

Fig. 9-1. After about 1 minute of warm idle, control module gradually retards spark about 5°.

9.3 Throttle Air Bypass (ISC)

Warm Idle Throttle Air Bypass increases gradually after 1 minute. This maintains idle rpm even with spark-timing retard. After 4 minutes, the throttle-air bypass opens slightly to increase engine speed about 80 rpm. But this rpm increase is limited unless the A/T is in Neutral or Park to prevent automatic-transmission creep.

Warm Idle can turn into hot idle, and the control module includes a strategy to reduce overheating:

- If coolant rises above 105°C (225°F), the control module signals the Throttle Air Bypass to increase Warm Idle engine speed about 100 rpm. It does this only if A/T is in Neutral or Park
- If the intake-air temperature is above 105°C (225°F), the control module signals the Throttle Air Bypass to increase Warm Idle engine speed about 25 rpm. It does this only if A/T is in Neutral or Park

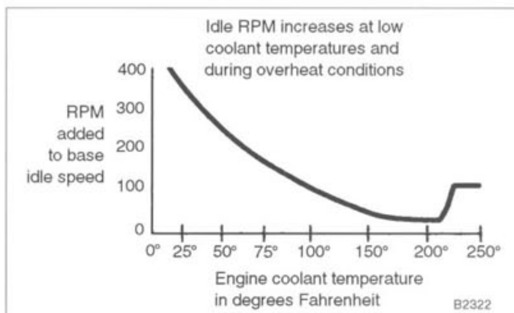

Fig. 9-2. High engine coolant temperatures (ECT—above 225°F) will cause control module to increase idle rpm about 100 rpm.

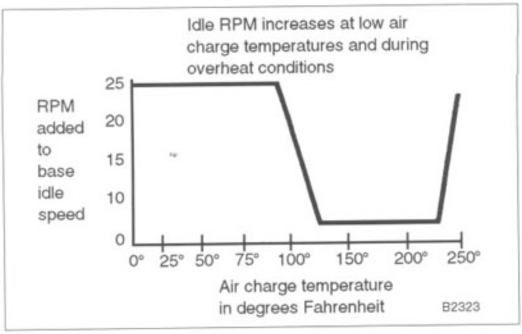

Fig. 9-3. In some engines, high intake air temperatures will cause control module to increase idle rpm about 25 rpm.

9.4 MECS Warm Idle

MECS engines do not operate on Warm Idle strategy as EEC engines. Control does not command advance in spark timing or rpm with high coolant temperatures or high air charge temperatures.

9.5 Warm Idle Summary

- Fuel injection, Closed Loop. Emission Controls off
- Spark timing gradually retards
- Throttle Bypass Air increases after time to reduce emissions or to reduce engine overheat

Table b. EEC-IV Control Strategies

Strategy Number	Fuel Control	Spark Timing	Bypass Air	Emission Control	Active Sensors
1. Warm Cruise	Closed loop, ideal	Advance, 30° BTDC	Full open (100% duty cycle)	EGR, canister purge, secondary air	PIP, MAF, HEGO, DPFE
2. Engine Crank	Open loop, rich	Fixed, 10° BTDC	Full open (100% duty cycle)	None (some secondary air)	PIP, ECT, ACT
3. Cold Start/Warm Up	Open loop, rich	Base, plus advance for load, rpm, time, ECT	Closed loop, feed forward signals, gradual close	Secondary air diverted	PIP, MAF, TPS, ECT, ACT, NDS
4. Cold Driveaway	Open loop, rich, gradually leaning	Base, plus advance for load, rpm, time	Full open (100% duty cycle)	Secondary air diverted	PIP, MAF, TPS, ECT, ACT, NDS
5. Warm Driveaway	Open loop, quick switch to closed loop	Base, plus advance for load, rpm, time, ECT, EGR flow	Full open (100% duty cycle	EGR, secondary air diverted, canister purge	PIP, MAF, TPS, ECT, ACT, NDS, DPFE
6. Part-throttle Acceleration	Closed loop, enrich for acceleration	Base, plus advance for load, rpm, time, ECT, EGR flow	Full open (100% duty cycle)	EGR, secondary air diverted, canister purge	PIP, MAF, TPS, ECT, ACT, DPFE
7. Full-throttle Acceleration	Open loop, rich, WOT look-up tables	Special advance look-up tables, KS	Full open (100% duty cycle)	None	PIP, MAF, TPS, ECT, ACT
8. Deceleration	Open loop, lean, some closed loop, some fuel cut	Advanced, special look-up tables	Dashpot, then engine braking, then open to avoid stall	Canister purge	PIP, TPS, ECT, VSS
9. Warm Idle	Closed loop unless no EGO switch	Gradual retard, after 1 minute of idle	Closed loop control, feed forward signals	Secondary air diverted, then switch to bypass	PIP, MAF, TPS, ECT, VSS, NDS

Table c. MECS-I Control Strategies

Strategy Number	Fuel Control	Spark Timing	Bypass Air	Emission Control	Active Sensors
1. Warm Cruise	Closed loop, ideal, 1.8L HISA valves close below 5000 rpm	Advance, 30° BTDC	Bypass closed, ISC valve open slightly	EGR, canister purge	CKP, VAF, HEGO
2. Engine Crank	Open loop, rich	Fixed, 6° BTDC (7° BTDC MECS-II)	Bypass full open, ISC open	None	CKP, ECT, ACT
3. Cold Start/Warm-Up	Open loop, rich	Base, plus advance for load, rpm, time, ECT	Bypass full open, ISC open, gradual close	None	CKP, VAF, TPS, ECT, ACT, NDS
4. Cold Driveaway	Open loop, rich, gradually leaning	Base, plus advance for load, rpm, time	Bypass full open, ISC open, gradual close	None	CKP, VAF, TPS, ECT, ACT, NDS
5. Warm Driveaway	Open loop, quick switch to closed loop	Base, plus advance for load, rpm, time, ECT, EGR flow	Bypass closed, ISC valve open slightly	EGR, canister purge	CKP, VAF, TPS, ECT, ACT, NDS
6. Part-throttle Acceleration	Closed loop, enrich for acceleration	Base, plus advance for load, rpm, time, ECT, EGR flow	Bypass closed, ISC valve open slightly	EGR, canister purge	CKP, VAF, TPS, ECT, ACT, DPFE
7. Full-throttle Acceleration	Open loop, rich, WOT look-up tables	Special advance look-up tables, KS	Bypass closed, ISC valve open slightly	None	CKP, VAF, TPS, ECT, ACT
8. Deceleration	Open loop, lean, some closed loop, some fuel cut	Advanced	Bypass closed, ISC valve open slightly	None	CKP, VAF, ECT, VSS
9. Warm Idle	Closed loop unless no EGO switch	Advanced according to rpm	Bypass closed, ISC valve open slightly, feed forward signals	None	CKP, VAF, TPS, ECT, VSS, NDS