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fitting; when current flows through the electrical connections, the solenoid lifts the armature from the valve seat. Fuel flows to the nozzle where it is swirled. That swirl action provides a fine vaporized mist that fills the manifold between the closed throttle and the intake valves.

The injector receives voltage whenever the key is in START position, but it only operates when it is grounded by the thermo-time switch. Think of this as a switch, not a resistor. It limits the open-time of the start injector to prevent flooding during cranking. See Fig. 2-36. Inside the housing is a bimetal switch arm surrounded by a heater winding. When the bimetal is cold, it closes the switch contact. The bimetal is a strip of two different metals bonded together; as it gets hot, it bends to open the contact.

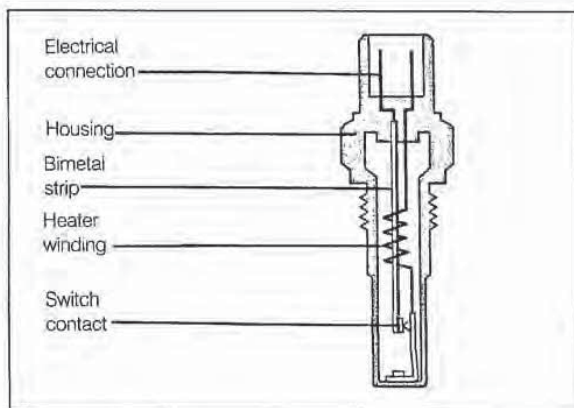


Fig. 2-36. Thermo-time switch bimetal opens start-injector circuit when coolant is warm, preventing flooding.

When you turn the key to START, that powers the start injector, and also powers the heater. If the engine is cold-cold, the closed switch grounds the circuit and the start injector delivers fuel. But as the heater winding warms the bimetal, it bends away and opens the grounding circuit, ending the start injection. Even at the coldest temperatures, the delivery time will be less than 10 seconds. Of course, delivery stops when you release the key from START. If the engine does not start for some reason, the already-heated bimetal will stay open, preventing excess fuel delivery. If the engine is warm-cold when you crank it, the bimetal is already bent to open the circuit as a result of coolant temperature. The result, no fuel delivery from the start injector.

Consider this auxiliary fuel injector in two terms: it must operate when the engine is cold, or the engine won't start. It must remain closed without spray or drip when the engine is warm, or the mixture will be rich. A leaking cold-start valve will cause hot-starting problems as fuel leaks into the manifold.

In the start control system, the control unit lengthens the injector pulses to the port injectors when the key is turned to START, based on the input from the engine temperature sensor. The colder the engine, the longer the pulses. To prevent flooding from repeated attempts to start, the control unit

includes a recovery-time factor. This determines how many seconds must elapse before $\frac{2}{3}$ of initial start-fuel quantity can be delivered.

In some cars, the start-control impulse is also influenced by the rpm during cranking, as shown in Fig. 2-37. The start-control impulse (t_2) is superimposed on the basic pulse-time (t_1). When the engine is cold-cold, cranking rpm is likely to be low. If so, the reduced-rpm signal causes the system to double the pulses, two per crankshaft revolution, and to add large compensation to the basic pulse-time. If the engine is warm, but cranking rpm is low, perhaps because of low battery voltage, less compensation is added, still 2 pulses per revolution. When the engine is warm, usually above 140°F (60°C), there is only 1 pulse per revolution.

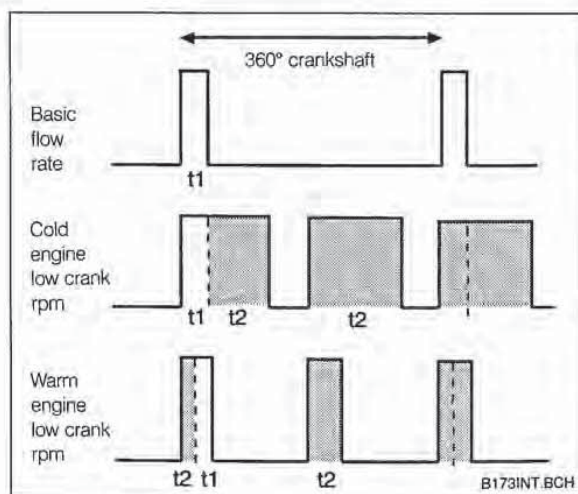


Fig. 2-37. On some systems, pulse time increases if engine is cold and turning slowly; pulse time decreases if engine is warm and turning slowly.

Auxiliary Air Valve. The auxiliary air valve helps the engine overcome the mechanical drag of a cold engine by adding additional air flow as shown in Fig. 2-38. It does this without racing the engine, as is common on engines with a fast-idle cam. Usually located on top of the cylinder head or valve cover, the auxiliary air valve can also be on the block because it is influenced by engine temperature. Look for it to bypass the throttle body with an auxiliary passage of air at barometric (atmospheric) pressure to the intake manifold at reduced manifold pressure. It is this pressure difference that causes the air flow when the valve is open.

The air bypassing the throttle through the auxiliary air valve is measured air; it has been measured by the air-flow sensor, so the required fuel is being delivered for injection. With the cold engine receiving extra air-fuel mixture, the extra friction resistance is overcome. Cold-idle rpm is increased, but will vary according to the engine manufacturer's calibration, as well as oil viscosity, engine condition and other variables. It is not rpm-controlled, as we'll see in later systems with idle-speed stabilization.

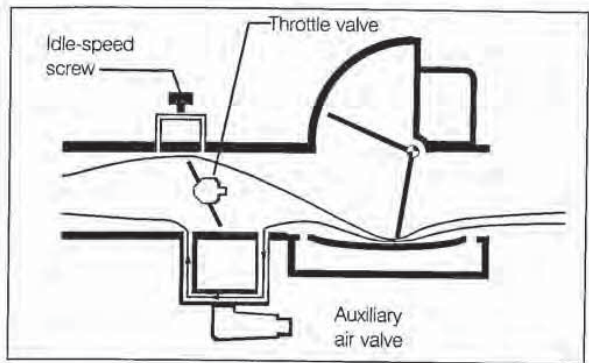


Fig. 2-38. Auxiliary air valve bypasses closed throttle when cold.

Two types of auxiliary air valves are used. Most are electrically heated, while a few early types are coolant heated. When the valve is cold, the blocking plate pivots to allow bypass air through the opening. When it is warm, the plate closes the opening.

Operation of the electrical type depends on the position of a bimetal arm, wrapped with an electric heating element, as shown in Fig. 2-39. When cold, the bimetal arm moves the blocking plate for maximum bypass air. When warm, the bimetal closes the opening. See Fig. 2-40. By shaping the hole in the plate, the designer can control the amount of bypass air for each engine temperature so idle rpms are close to the desired speeds.

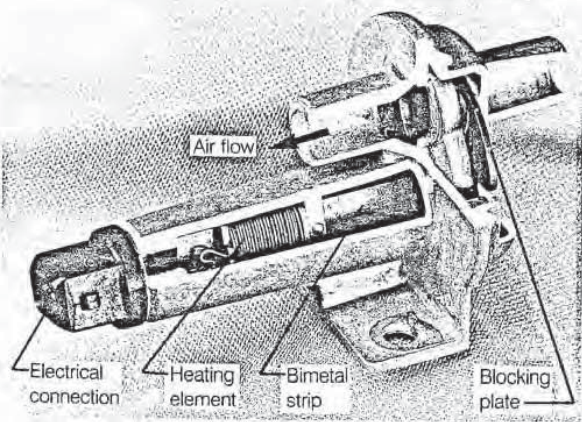


Fig. 2-39. Electric heating element closes auxiliary-air bypass in a maximum of 8 minutes from freezing.

The position of the bimetal depends on engine temperature and the length of time current flows through the heating element. When the engine is warm, the bimetal is influenced primarily by the block temperature. When the engine is cold and the plate is open, the heating element is the main influence on the bimetal. Where the delivery of auxiliary fuel for starting is generally timed in seconds, the delivery of auxiliary air is timed in minutes. From the coldest, the heater will close the bypass in about 8 minutes, faster than block warm-up would close it.

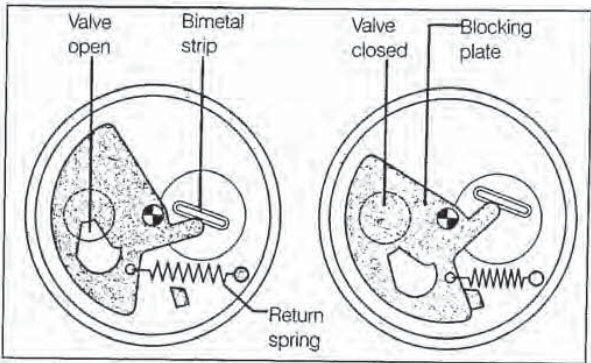


Fig. 2-40. Bypass opening closes when bimetal strip bends and spring pulls rotary valve.

Proper operation of the auxiliary air valve is important to driveability:

- for cold starts, and post-start, this valve must be open
- when the engine is warm, it must be closed to prevent fast-idle

In chapter 4, you will see two ways to check if the auxiliary air valve is functioning properly.

Post-Start and Warm-Up

You've already seen how the cold-engine idle rpm is affected by the auxiliary-air bypass. For post-start and warm-up fuel enrichment, pulse time of the port injectors is increased, but much less than during start control.

Bosch considers post-start, sometimes called after-start, as the first several seconds after the cold engine fires. The engine is running, but it needs a hefty enrichment factor. When the key is released from START to RUN, that ends the enrichment from the injectors, as much as 250%. For a start from ordinary temperatures, 70°F (20°C), the engine might need an enrichment factor of 150%, decreasing rapidly with time. This compensates for poor mixture formation and fuel coating of the manifold walls. The richer mixture increases torque, and therefore driveability.

After 20–30 seconds, the engine is considered into the warm-up phase, and the enrichment factor tapers off. Remember, driveability must be balanced with emission control; some engines can fail the EPA cold run test in the first 30 seconds. Warm-up driveability improves with more enrichment (or slower reduction of enrichment), but at the cost of high emissions.

Acceleration

How do L-Jetronics supply the acceleration enrichment ordinarily delivered by the accelerator pump of a carburetor?

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Part-throttle. For part-throttle acceleration, the mixture is enriched by over-swing of the air vane. When you open the throttle quickly, the vane swings beyond the required position. This over-swing adds compensation pulse-time for a second or so until the vane stabilizes for the new air flow. During warm-up, the engine temperature sensor operates through the control unit to add additional enrichment compensation to the over-swing.

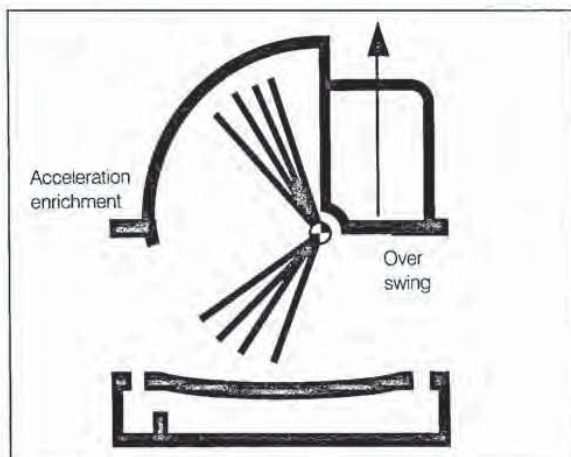


Fig. 2-41. Acceleration enrichment momentarily increases pulse time by over-swing with sudden throttle opening.

In some engines, over-swing enrichment is enhanced with electronic acceleration enrichment. The control unit evaluates how fast the air-flow sensor signal is changing. In effect, it looks at the velocity of vane movement. Above a certain voltage jump, acceleration enrichment begins, adding to the pulse-time. Electronic acceleration enrichment is modified or cancelled:

1. when the engine is warm
2. during starting
3. during manual shifting
4. at higher air flows

Full-throttle. Full-throttle acceleration enrichment is handled differently. When you floor the throttle, over-swing enrichment is delivered. But more importantly, a full-throttle signal is sent by the switch mounted on the throttle shaft. See Fig. 2-42. Sometimes you'll find microswitches out in the open; usually they are enclosed in a single unit as shown in Fig. 2-43. The full-load contact is closed by the cam on the throttle shaft, signalling the control unit to add enrichment. Full-throttle acceleration requires a rich mixture, so the control unit switches the system from closed-loop operation to open-loop, with the mixture determined by factory-programmed air-fuel ratios.

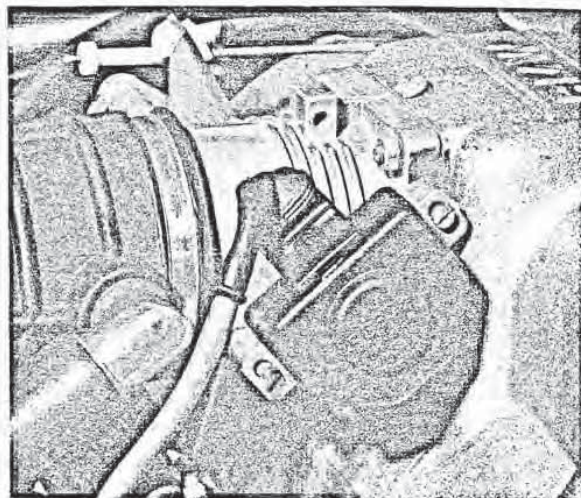


Fig. 2-42. Throttle switch is usually mounted directly on throttle shaft.

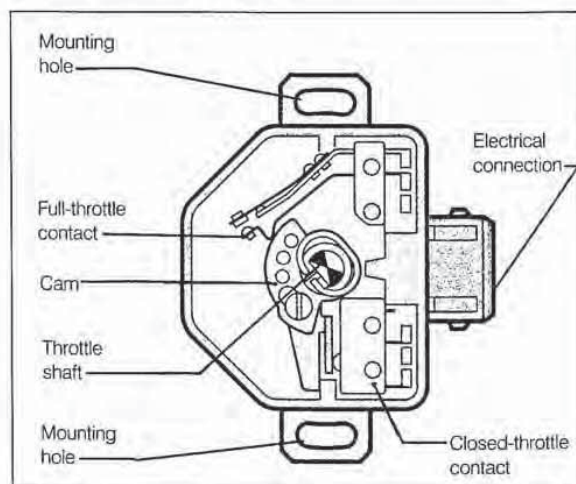


Fig. 2-43. Throttle switch signals full-throttle and fully closed throttle.

Idle and Drive-Off

Idle enrichment is usually signalled by the closed-throttle switch, shown above in Fig. 2-43. This switch was originally called the idle-switch, but in recent cars it signals closed throttle during coasting, and that's not idle, hence the name change. The switch is also closed by the cam on the throttle shaft, when the throttle is fully closed. When the computer receives an input that the throttle is closed, it adds compensation pulse-time to the basic flow rate, enriching the idle mixture. In chapter 4, you will see how simple it is to check the throttle switches for continuity.

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Increased fuel for drive-off from idle can improve driveability, particularly when the engine is cold, something like an accelerator pump improves drive-off of cold carbureted engines. In some cars, to improve driveability, when the closed-throttle contact circuit opens as the throttle is opened from idle, a special circuit adds compensation fuel, usually temperature-compensated.

Coasting Cut-Off

In later L-Jetronics, fuel is cut off during coasting, or deceleration, when closed-throttle is signalled. This improves emission control and also fuel economy. In the control unit, the closed-throttle input is combined with inputs from engine temperature and rpm to determine the beginning of cut off and the end of it. Remember, as rpm drops toward idle, the closed-throttle switch may first signal for zero fuel, then at idle will signal for enrichment.

Anti-Search Circuitry

In some L-Jetronics, transition from one mode to another is smoothed by anti-search circuitry. This part of the control unit looks for sudden changes in rpm, either deceleration or acceleration. It keeps the engine from searching for the proper flow during the transition, improving driveability.

RPM Limitation

When some engines approach red line, the computer compares engine rpm to a programmed limit-rpm. As soon as engine rpm rises above the limit, the injectors receive pulse-time signals once per every two crankshaft revolutions, cutting fuel flow in half. As soon as rpm drops, every-revolution signals resume. You'll feel as if the the car is first decelerating, but if you hold the throttle open, you'll feel the engine surge as rpm cycles around the limit. See Fig. 2-44. In some cars, drivers report rpm limitation differs slightly from the tachometer red line. During a quick run-up through the gears, good drivers shift before the rpm-limitation cut-off.

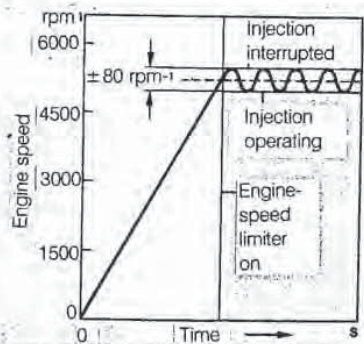


Fig. 2-44. Engine-speed limiter holds rpm at maximum allowed ± 80 rpm, only one injection per 4-stroke cycle.

Pulse-Period Limitation

Recall the earlier discussion of pulse period, the time available for injector-open pulse time. Pulse-period limitation circuitry operates under two conditions to limit pulse time:

1. Lower limit: at high revs, in overrun or coasting, minimum pulse time must be limited to prevent excess Hydro Carbons from too-lean mixtures;
2. Upper limit: at low revs, during full acceleration, maximum pulse time must be limited to prevent too-rich mixtures, causing stumbling, depending on temperature.

Lambda Control

You'll remember from chapter 2 the discussion of the ideal air-fuel ratio (lambda) and its relation to emissions. On most L-Jetronic systems, the air-fuel ratio for best emission control is achieved by sensing the oxygen content of the exhaust gas with a lambda sensor, shown in Fig. 2-45. The lambda sensor's signal is monitored by the control unit, which then adjusts pulse time to maintain the ideal air-fuel ratio. The system operates closed-loop.

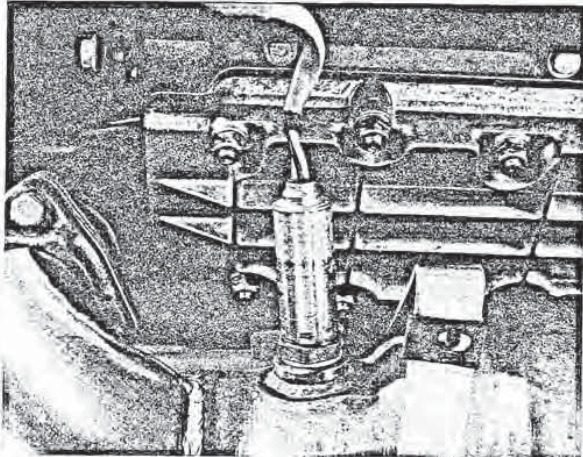


Fig. 2-45. Lambda sensor looks something like a spark plug installed in exhaust pipe or exhaust manifold to sense oxygen content of exhaust gas. The closer to the exhaust valves, the faster it heats up.

Lambda Sensor Design and Operation. The lambda sensor is essentially a small battery that generates a voltage signal based on the differential between the oxygen content of the exhaust gas, and the oxygen content of the ambient air.

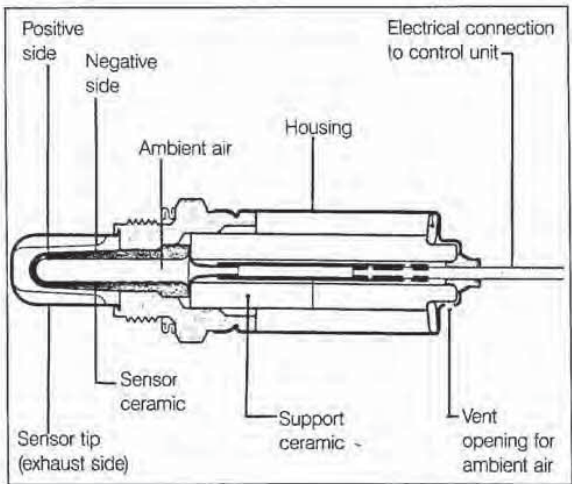
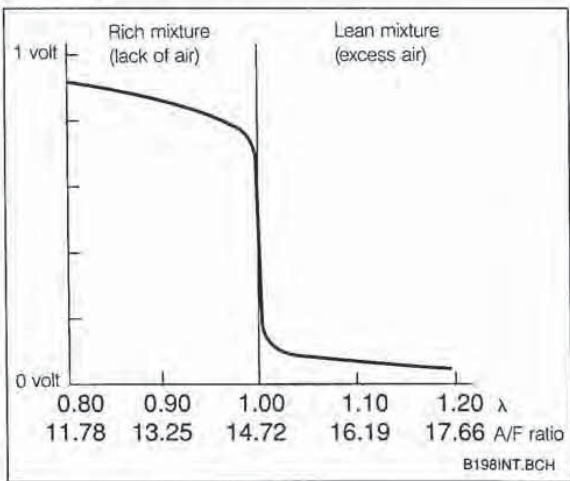
A cutaway view of the lambda sensor is shown in Fig. 2-46. The tip of the sensor that protrudes into the exhaust gas is hollow, so that the interior of the tip can be exposed to the ambient air. Both sides of the ceramic tip of the sensor are covered with metal electrodes that react to create a voltage under two conditions:

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- 1. the ambient air has a higher oxygen content than the exhaust
- 2. the ceramic material is hotter than 575°F (300°C)

When these conditions are met, voltage is generated between the two sides of the tip. The voltage is usually about 1 volt. But if the engine is running lean, the exhaust gas has about the same amount of oxygen as the ambient air, so the lambda sensor will generate little or no voltage; if the engine is running rich, the oxygen content of the exhaust will be much lower than the ambient air and the sensor voltage will be larger. See Fig. 2-47.

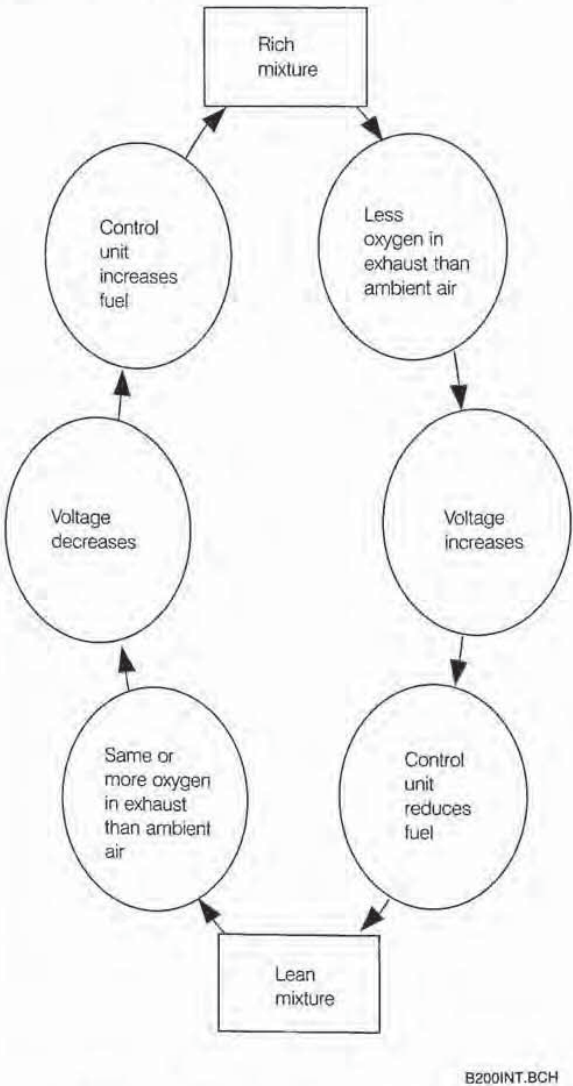


Some cars have a lambda sensor that has a heating element built-in to speed warming of the sensor to improve the driveability and reduce the emissions of a cold engine. On a

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cold engine, it may take 90 to 120 seconds for an unheated lambda sensor to get warm enough to start generating voltage, while a heated sensor may be warm enough after 10 to 15 seconds.

Lambda Closed-Loop Control. Recall the discussion of open-loop/closed-loop systems in chapter 2. The lambda sensor and the control unit form a closed-loop system that continually adjusts the air-fuel ratio by means of the fuel-injector pulse time. For example, the sensor generates a high voltage because the mixture is rich, so the control unit reduces pulse time to lean the mixture. Sensor voltage falls, so the control unit increases pulse time to enrich the mixture. Sensor voltage increases, etc....



The lambda sensor voltage is always fluctuating as shown in Fig. 2-49, so it is hard to maintain the exact point at which the air-fuel ratio is ideal. Instead, the ratio tends to oscillate to either side of the ideal ratio, but the oscillation is so fine (about 0.1% change in the air-fuel ratio) that it is not noticeable in engine performance. The rate of the air-fuel ratio oscillation is related to the quantity of exhaust passing the sensor. At idle, the cycle from lean to rich and back again may take 1 to 2 seconds. At cruising speed, the cycle may happen several times a second.

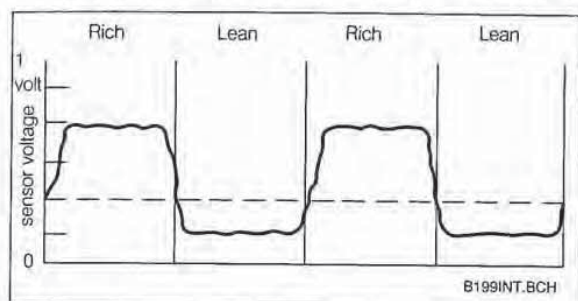


Fig. 2-49. Closed-loop lambda sensor voltage cycles back and forth from slightly rich to slightly lean. In chapter 4, you'll measure the effects of this cycling.

This closed-loop system can compensate to some degree for changes in the engine over time. For example, if a valve is leaking slightly, or if there is an intake air leak, the lambda sensor senses the change in combustion and brings the system back within its design limits. This has been described as having a skilled technician under the hood, continuously tuning the mixture for best operation under all conditions. Changes beyond the system's range, though, can still lead to driveability problems.

When the oxygen sensor is cold and not generating a voltage signal, the control unit is programmed to operate open-loop at a programmed injection rate. The same thing happens if you disconnect or cut the lambda sensor wire, or if the sensor is fouled by leaded gasoline. This becomes important when you are trying to make closed-loop adjustments at idle, but the sensor cools off because not enough exhaust is passing it. Many service procedures depend on closed-loop operation, so remember that the sensor has to be warm enough.

As you'll see in the service chapters, the lambda control system is properly adjusted when engine-out CO is the same whether the system is closed-loop or open-loop. This adjustment point allows the system its full range of compensation for operating conditions.

L-Jetronics have been used since 1974. Engines adapt easily to L-Jetronic. In 1980, when tighter U.S. emission limits were mandated, virtually every European car imported to the U.S. which had used carburetors in 1979 switched to L-Jetronic. Those that did not, switched to K-Jetronic.

2.6 LU-Jetronic

LU-Jetronic is a refinement of L-Jetronic, used in few cars in the U.S. In fact, the U stands for U.S.; it is a lambda-control version of a refined Jetronic used in Europe: LE-Jetronic. Its main features are optimized circuitry in the control unit, and a start control system. The control unit is analog. You'll find it in:

- a few BMW 3 series, used before switching to Motronic
- 1983-84 California AMC Alliances when the Bendix central fuel-injection system could not meet California emission limits
- a few late-model Renault Fuego and 18i

3. LH-JETRONIC

LH-Jetronic is a further refinement of L-Jetronic. The main difference between the two systems is the method of measuring air flow on LH-Jetronic. Instead of an air-flow sensor, LH systems use something called an air-mass sensor, which you'll learn more about later. All LH-Jetronics use lambda control, and the control unit is digital, not analog.

Volvo was the first user of LH-Jetronic systems on the 1982 Volvo GL with the 2.3 liter 4-cylinder engine. By 1987 all Volvo engines, including the 2.6 liter V6, were using LH-Jetronic. The first Volvo system is identified as LH 1. In addition to the differences mentioned above, it uses a vacuum switch to signal inlet pressure (instead of a throttle switch), and uses an auxiliary air valve, the same as on L-Jetronic.

Since 1984, LH systems are identified as LH 2. Instead of the auxiliary air valve, LH 2 has an idle-speed stabilizer for automatic idle speed control. The LH 1 vacuum switch is replaced by the throttle switch. Since 1988, LH-Motronic combines the air-mass sensor with control of ignition timing as well as adaptive control and diagnostics. See 4. Motronic Systems.

3.1 Air-Mass Sensor

The air-mass sensor is completely electronic. It depends on the measurement of current flowing through heated wires to measure air flow. It is also known as the hot-wire sensor because of its heated-wire design, hence the "H" in LH. It has several advantages over the vane-type air-flow sensors of L-Jetronic.

1. It measures air mass, or weight, so it requires no correction for changes in density due to temperature or altitude. The air-fuel mixture ratio depends on mass: so much weight of fuel mixed with so much weight of air. Measuring mass eliminates the need for compensation sensors: air temperature, and altitude. It also reduces correcting computations in the control unit.

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- 2. It has no moving parts. That means mechanical simplification. It responds even faster than the moving vane of the air-flow sensor. Measurements follow changes in air-mass in 1–3 milliseconds.
- 3. It offers insignificant resistance to the passage of air. Even at maximum air flow, drag force on the wire is measured in milligrams.

Air-mass measurement by hot-wire improves driveability, stability, and reliability. It is used in racing. In my opinion, air-mass sensing will probably supplant the measurement of air flow by vane-type sensors.

Air-Mass Sensor Design and Operation

Underhood, between the air cleaner and the manifold, you'll see a simple black plastic cylinder with an electronic box, as shown in Fig. 3-1. If you remove it and look inside the protective screens, you may be able to see the small platinum resistance, or hot wires, that are suspended inside the cylinder so that the intake air can flow over them. See Fig. 3-2. How fine are these wires? The diameter is 70 micrometers—that's less than 1/10 millimeter, finer than a human hair. By careful design of the sensor and its mounting, the fine wires survive automobile vibration. In the unlikely event a wire should break, the warm engine runs, though without fuel compensation, in a limp-home mode. You can simulate limp-home mode by driving the car after pulling the air-mass sensor connector of a warm engine.

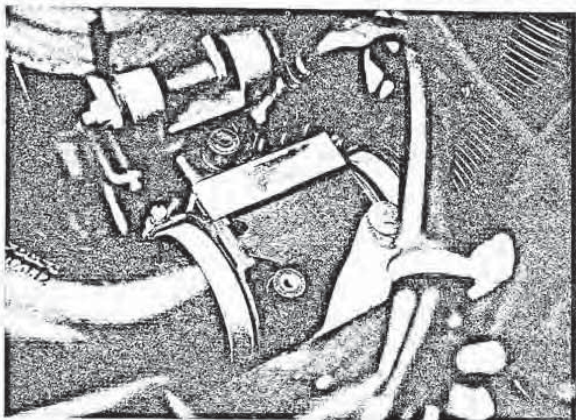


Fig. 3-1. Look for air-mass sensor between air cleaner and intake manifold.

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

LH control circuits use this effect to measure how much air passes the LH hot wire. The hot wire is heated to a specific temperature differential 180°F (100°C) above the incoming air

when the ignition is turned on. As soon as air flows over the wire, the wire is cooled. The control circuits then apply more voltage to keep the wire at the original temperature differential. This creates a voltage signal which the control unit monitors; the greater the air flow (and wire cooling) the greater the signal.

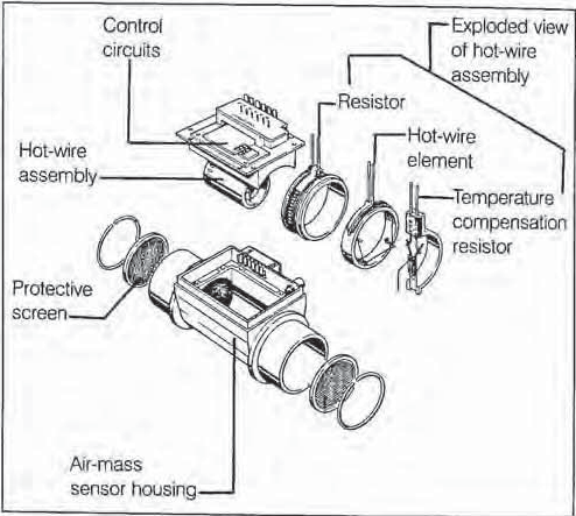


Fig. 3-2. Air-mass sensor includes hot-wire assembly and control circuits.

Control Circuits. The LH control circuits use a Wheatstone bridge, as shown in Fig. 3-3. The hot wire is one leg of a bridge circuit whose output voltage is held to zero by regulating the heating current. The hot wire, known as R_H , changes resistance with temperature. Incoming air passes over the hot-wire, R_H , and also over another resistance wire, R_K . The same voltage is applied to both wires. In series with R_K are two fixed resistances, R_1 and R_2 ; in series with our hot wire, R_H , is fixed resistance R_3 .

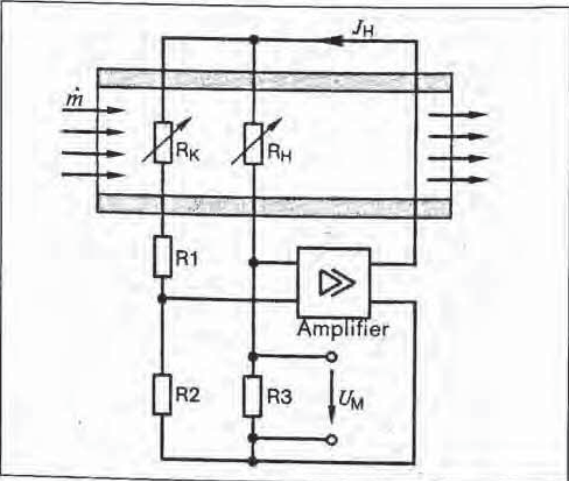


Fig. 3-3. Wheatstone bridge principle explains maintenance of hot-wire temperature.

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The Rh wire is controlled to be 180°F (100°C) hotter than the intake air flowing through. For example, if the air is at freezing, 32°F (0°C), the wire will be heated to 212°F (100°C). On a hot day, if the air is at 86°F (30°C), the control circuits heat the wire to the same 180°F (100°C) difference, to 266°F (130°C).

The air mass changes when the driver changes the throttle opening:

1. more air passes over both resistance wires in the air-mass meter;
2. both Rh and Rk are cooled by the increased air mass;
3. Rh decreases its resistance, because of its Positive Temperature Coefficient;
4. current flowing through Rh increases more than the current through Rk;
5. that unbalances the bridge circuit;
6. comparator increases its output;
7. amplifier increases current (Jh) to bring Rh back to its original resistance, and thus its original temperature back to 180°F (100°C) above ambient temperature of the intake air;
8. the heating current is measured as a voltage drop (Um) across the fixed resistance R3;
9. this voltage drop is a measure the air mass and is used as the output signal to the control unit.

All this happens is 1–3 milliseconds.

The air mass can also change because air temperature or altitude changed its density.

Control Unit Inputs and Outputs. LH-Jetronic control of injection pulse time is the same as in L-Jetronic. Low engine speeds mean a smaller air flow. As the air mass increases, the air-mass sensor control circuits provide an output voltage signal to the control unit, and pulse time is adjusted accordingly. Note that in contrast to L-Jetronic, the LH-Jetronic air-mass signal increases with air flow.

For limp-home operation, pulse time is fixed. Each pulse is delivered to the injectors with no compensation. For any rpm above idle, the control unit is programmed to deliver fixed pulses, typically 7.5 milliseconds. Of course, the faster the engine turns, the more pulses are delivered and the more fuel is injected. When the closed-throttle switch completes its circuit, each fixed pulse is a little shorter, typically about 5 milliseconds to keep the idling engine from running too rich.

Shut-Off, Hot-Wire Cleaning. With the air-mass sensor connected for normal operation, the hot wire does not glow. It does not look hot, any more than the heated wires in a rear-window defroster do.

But shortly after you shut off the engine, the control system will heat the wire red hot for about one second, hot enough to burn off any dirt. See Fig. 3-4. Because of the hot-wire cleaning, LH is ready to start every time with a clean wire.

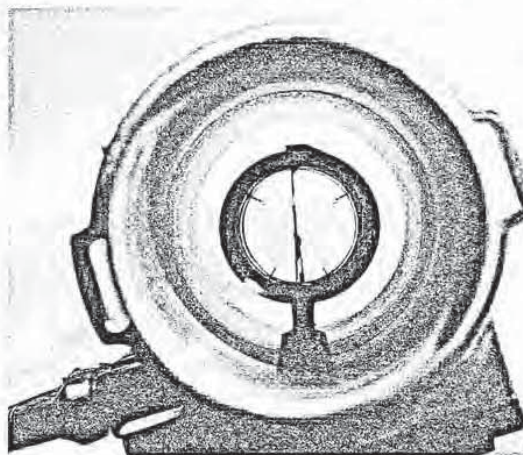


Fig. 3-4. LH hot wire glows at 1800°F (1000°C) during burn-off at engine shut-down.

How's this for attention to detail: There's no burn-off unless the engine has run above 3000 rpm; that usually happens normally each time the car is driven. That way, restart won't normally happen with an 1800°F (1000°C) hot wire. Further, there's no burn-off if the engine stops running at less than 200 rpm; the engine would not be running at such a low rpm, so it has stalled. This prevents the hot wire from glowing after an accident.

In normal operation, don't suspect the wire is inoperative if it fails to glow. The wire is so fine you may not even see it unless the light is right, so don't suspect it is broken if you can't see it right away. You can measure the output signal, as described in chapter 4.

Mixture Adjustment. You'll find the idle-mixture adjustment screw on the side of the air-mass sensor, under a seal. Electronic circuits inside this sensor are not serviceable. When you adjust idle mixture, you adjust the voltage signal from the air-mass sensor by turning a potentiometer, a variable resistor. Because it is an electrical adjustment, it feels different; it turns more turns than the mechanical adjustment of L-Jetronic air-flow sensor.

3.2 Idle-Speed Stabilizer

On most LH-Jetronics (LH 2 and later) the idle-speed stabilizer replaces the auxiliary-air valve. See Fig. 3-5. Idle-speed stabilizers can have different shapes, but they all work the same. They change the amount of air that bypasses the closed throttle. You'll remember this is measured air so it changes the amount of air and fuel to the engine, which changes idle speed, not mixture.

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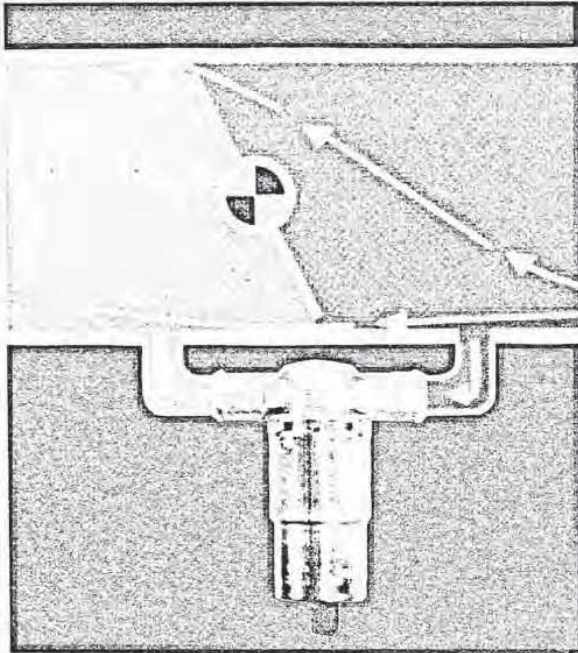


Fig. 3-5. Idle-speed stabilizer allows measured air to bypass closed throttle.

In a cutaway in Fig. 3-6, you can see the rotary valve that turns slightly to change the opening for the bypass air. The stabilizer may look like a motor, but it's not. Signals from the control unit drive the valve toward open.

Bosch also calls the idle-speed stabilizer an actuator. On other cars, a similar device could be called an idle-air control, idle-speed compensator, or idle-speed control. The distinction is whether it actually controls rpm by measuring rpm—a closed-loop system—or on some preprogrammed basis—an open-loop system.

Experts can be fooled by other terminology. Some call idle-speed stabilization CIS—Constant Idle Speed. For our purposes, CIS means Continuous Injection System.

Dwell Signals

The opening of the idle-speed stabilizer depends on the percent dwell—the on-off ratio—of the digital control signals from the control unit. Note that digital signals are on-off, nothing in between. Measuring the on-off ratio tells you the percentage of time that current is on, something like a dwell meter measures ignition-points closing time. The greater the on-off ratio, the further open the stabilizer and the more air will bypass the throttle. For a normal warm engine at idle, the stabilizer is open part-way with a typical dwell of 32%. You can use a dwell meter to measure the on-off ratio, as discussed in chapter 4.

LH-Jetronic

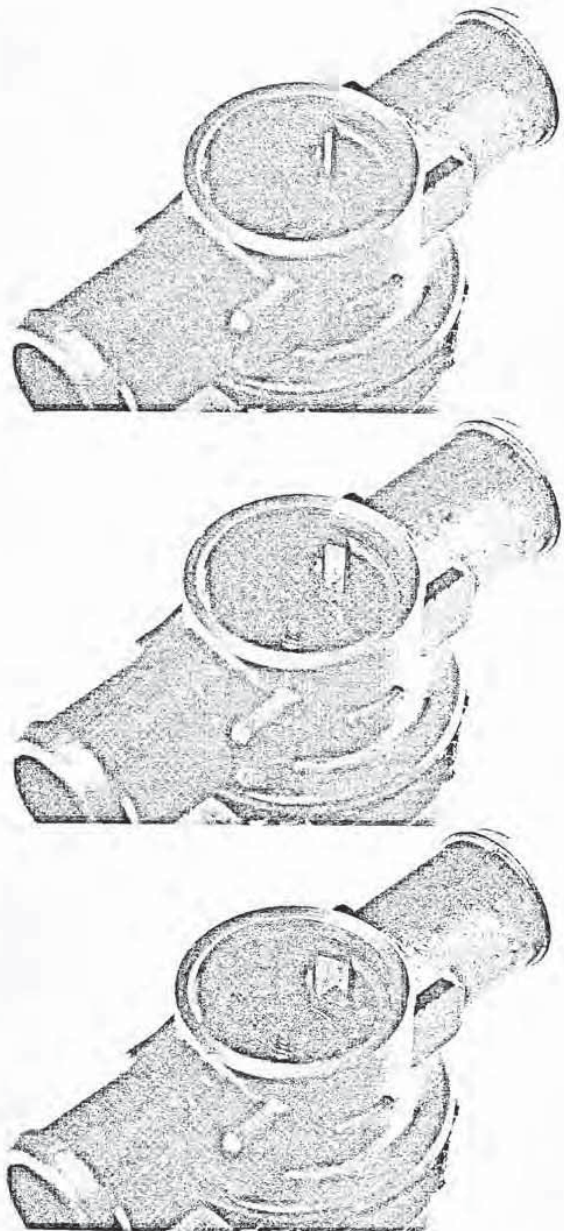


Fig. 3-6. Idle-speed stabilizer valve controls rpm. Smaller opening (top) reduces idle rpm. Medium opening (middle), normal rpm. Larger opening increases idle rpm.

RPM Stabilization

The idle-speed stabilizer is a closed-loop governor that holds a steady rpm. If load is added to the engine—such as when the lights are turned on, increasing alternator drag—the control unit increases the on-off ratio; that keeps the engine speed steady at normal idle. It can keep engine rpm steady for other loads too, such as power steering, or shifting the automatic transmission from Neutral to Drive.

On some cars with automatic transmission (A/T), the idle-speed stabilizer operates to reduce creep at stoplights. While the transmission is in Neutral, engine idle rpm might be governed at 1000 rpm at a temperature of -4°F (20°C). When the engine is warm, Neutral idle rpm might be 750. But while the A/T is in Drive, the stabilizer may cut back the idle rpm to 670. This luxury touch pleases some drivers, and is possible if the engine does not exhibit roughness at the lower revs.

On the other hand, the stabilizer can work to increase rpm. Turning on the air conditioner (A/C) usually requires higher idle speeds to insure adequate A/C cooling. The input signal to the control unit may be one or more switches:

- driver's actuation of the A/C switch
- closing of the circuit for the A/C magnetic clutch
- pressure increase in the high-pressure side of the compressor

Idle-speed stabilization can also avoid an rpm drop when switching on the A/C. The engine control unit talks to the A/C control, and delays energizing the A/C compressor for about $\frac{1}{2}$ second after the A/C is switched on at idle. This gives the stabilizer time to hold or increase idle rpm as necessary for the load of the A/C compressor. On the other hand, while in Drive, A/C operation will not raise the rpm, which could cause creep of a stopped car idling in Drive.

When you service the engine, it can be important to know the difference between:

- closed-loop idle-speed stabilizer
- open-loop systems, such as:
 - Bosch auxiliary-air valve
 - fast-idle cam
 - fixed-position throttle positioner

While open-loop systems increase the air flow into the engine, with most of those, rpm will vary according to engine temperature, engine condition, weight of oil in the crankcase, whether the transmission is in Drive or Neutral, and many other variables. Unless rpm is sensed, fast-idle rpm must usually be set higher to handle unforeseen variations, higher rpm than would be necessary on an engine with an idle-speed stabilizer.

Because the idle-speed stabilizer usually operates closed-loop on the basis of engine rpm, it needs to increase rpm less for cold conditions. This saves stop-light fuel and reduces emissions. In closed-loop, it will maintain idle rpm with small-load changes. As rpm drops, the stabilizer receives control unit dwell signals to bypass extra air to keep the engine from stalling.

Cranking the engine will cause an open-loop signal to increase the air flow as needed. Cold engine temperatures will increase idle rpm, usually only a few hundred rpm from the normal warm idle speed.

When the car coasts, the stabilizer will receive a brief open-loop increase-bypass signal, based on how rapidly the air-flow signal drops toward zero. Functioning in a manner similar to a throttle dashpot, this provides a gradual drop in manifold pressure, helping to reduce the emission of Hydro Carbons.

Adaptive Control

Beginning with some 1984 systems, idle-speed stabilization can be adaptive. That means that, during the lifetime of the engine, it will adapt the idle rpm setting to compensate for changes in internal friction. Adaptation takes place as the engine idles for a few minutes. This dwell value is stored in the control unit non-volatile memory which then becomes the center point for increase/decrease rpm signals.

Because the idle-speed stabilizer automatically controls engine rpm, you must be alert when making an rpm drop test for the injectors or ignition. The fact is, with the idle-speed stabilizer working, you probably won't get any rpm drop; that can be confusing if you don't realize what the stabilizer does. For example, suppose you disconnect one injector. When the stabilizer is working, the engine does not slow down the way you'd expect it to. As soon as the rpm starts to drop off, the stabilizer opens, to increase rpm back to normal.

Idle Speed Adjustments

Although idle speed is automatically controlled, in some cars you may still need to set the basic idle speed (lower than curb idle) with a knob, changing the amount of bypass air. You have to ground the idle-speed stabilizer as mentioned above, so it is fixed. When you remove the grounding, the engine will seem to take a gulp of air as the stabilizer rapidly opens; then rpm steadies at normal idle.

On the newest systems, idle-speed stabilization has become so well controlled by adaptive circuits in the control unit that no adjustment is provided for idle mixture or idle rpm. For more on adaptive circuits, see 4. Motronic Systems.

4. MOTRONIC SYSTEMS

In simple terms, Motronic is an engine-management system with a single control unit for control of ignition timing as well as fuel-injection. Many of the sensors important for fuel injection are also needed for ignition-system control, as shown in Fig. 4-1, so the integration of the two systems can accomplish many things that L-Jetronic and LH-Jetronic can't:

- Integrated control of fuel injection and ignition can manage the engine better than control of either one alone. That is, timing is sometimes dependent on the air-fuel ratio, and vice versa; also, emissions can be reduced by coordinated control

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- Engine control can be based on actual needs of each engine model based on large amounts of engine-test data during different operating conditions stored in the Motronic Read Only Memory (ROM)
- Many additional operating functions can be provided. Important from the standpoint of service are the adaptive functions, and the self-diagnostics for troubleshooting
- Motronic advantages are better driveability and fuel efficiency, and reduced emissions. More specific benefits:
 1. fuel savings achieved from best combination of mixture and timing
 2. dependable starting, cold or hot
 3. stable idling at reduced rpm

4. relative freedom from maintenance

5. good torque characteristics, allowing longer gear ratios

Applications — Identifying Features

Motronic systems use the same pulsed fuel injection principle as the L-Jetronic systems described earlier, so many of the functions and components are the same. This section covers those Motronic functions and components which are additional to basic L-Jetronic fuel injection.

Underhood, how do you tell a pulsed Motronic system? Most "L" Motronic systems use the vane-type air-flow sensor as in L-Jetronic. Some Motronic systems also operate with the air-mass sensor of the LH-Jetronic, as in BMW 750i V12 (known as LH-Motronic). So checking these components won't immediately identify a pulsed Motronic system.

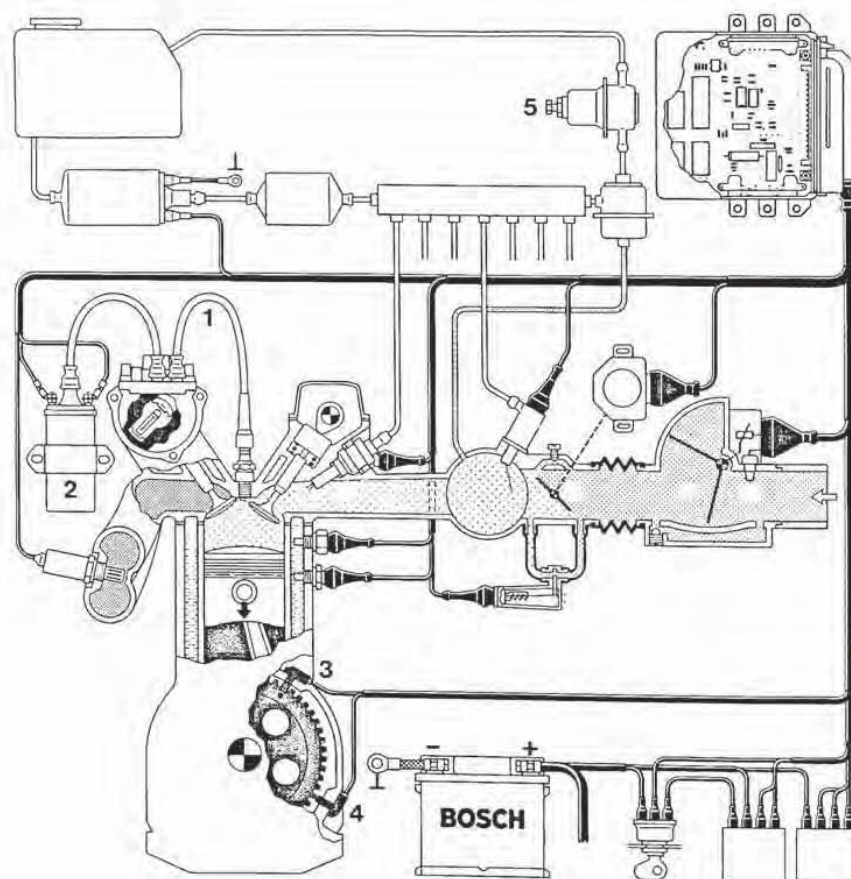


Fig. 4-1. Motronic schematic shows ignition system (1, 2), crankshaft signalling (3, 4), and pulsation damper (5) added to L-Jetronic.

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Try looking at the distributor as shown in Fig. 4-2; a Motronic distributor will not have vacuum hoses—or centrifugal weights inside. But even this can be confusing. Some 6-cylinder Porsche 911 engines use centrifugal weights to advance the rotor during high rpm for better contact between the rotor and the cap contacts, but not to affect ignition timing. Several cars, such as Porsche 928 and Peugeot 505STX have separate electronic ignition controls, no vacuum hoses or weights, and are not considered Motronic systems. Don't be confused by systems that control distribution of ignition-firing pulses, so-called distributorless ignition.

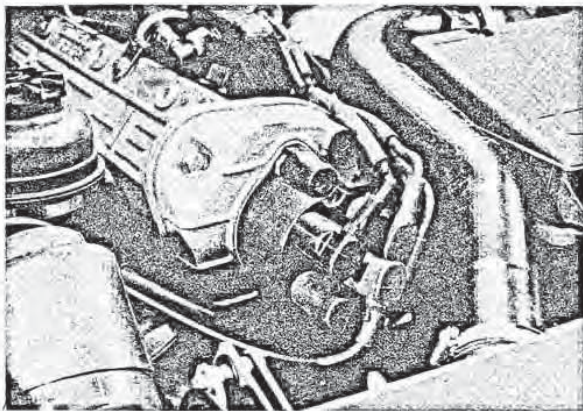


Fig. 4-2. Most Motronic distributors are simple; no vacuum hoses, no centrifugal weights. With distributorless ignition, the control unit times and distributes power to multiple coils.

The best way to identify Motronic is to check your vehicle specs. With modern, complex engines, you cannot guess about engine management systems; you must have the vehicle shop manual.

4.1 Ignition Timing Control

I'm talking here about more than electronic ignition—the systems that have replaced the points and condensers of yesterday. I'm talking about microcomputer control of ignition-advance angle for every plug firing, or at most, every two plug firings. The millisecond response time of electronic ignition-advance control is far faster than the traditional mechanical flyweight/vacuum advance systems.

In a mechanical system (and that includes electronic ignition), as rpm increases, centrifugal weights advance timing. Changing load (manifold pressure) can further change timing advance with a vacuum diaphragm. As rpm increases, there is less dwell time for the coil to charge when perhaps the engine needs more spark energy.

Traditional curves for distributor timing show the limited control of timing advance possible. A timing point that is proper for one combination of rpm and load is probably wrong for other combinations of centrifugal weight position and vacuum

diaphragm action. Once the vacuum control or the centrifugal weights reach their limits, advance control is fixed. Mechanical timing has been patched with more vacuum hoses, temperature and delay valves, and other servicing headaches; it's still a compromise. Even at its best, this control falls far short of the precise and rapid timing needed by today's cars.

In Motronic systems, however, the control unit processes a number of inputs as shown in Fig. 4-3, and then adjusts timing for all conditions based on its internal data map.

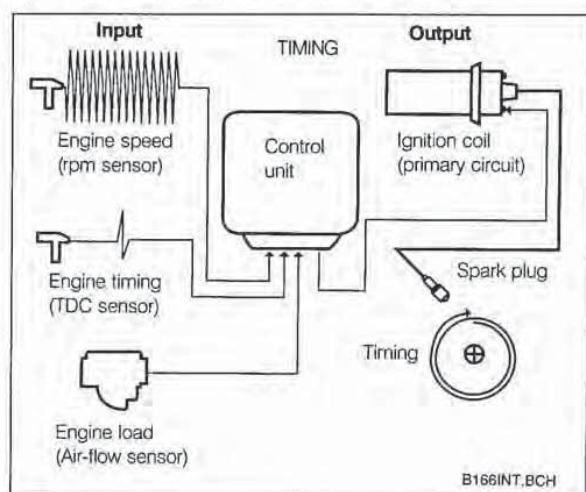


Fig. 4-3. Timing is controlled by the control unit by inputs of rpm, TDC, and load. Control unit controls charging of coil.

Timing Data "Maps"

To determine precise timing-advance requirements, each family of engines is tested to learn the best timing for each condition of speed, load, and other variables in heat and cold, on the dynamometer and in the mountains. The goal is to find the timing for best power, for best economy, all the while meeting emission limits.

The result of these tests is a series of data "maps", as shown in Fig. 4-4. Literally thousands of data points from these tests are stored in the computer memory of the Motronic control unit ROM (Read Only Memory) for readout during engine operation. As you may know, a ROM cannot be changed. For any combination of engine load and rpm, the control unit can supply the best ignition timing. For example, for an rpm-input signal of 2000 rpm, at a load signalled by the air-flow sensor, the computer would look up the timing advance angle, let's say it should be 22 degrees BTDC.

But control is even more precise. Suppose the rpm were 2050, and the memory contained only data points for 2000 and 2100; then the computer would look up both 2000=22 degrees BTDC, and 2100=24 degrees BTDC, and interpolate. It would calculate an advance for the 50 rpm difference between

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2000 and 2050, and would output timing of 23 degrees BTDC. In the control unit, timing is computed so fast that Motronic can adjust timing for every firing of each spark plug!

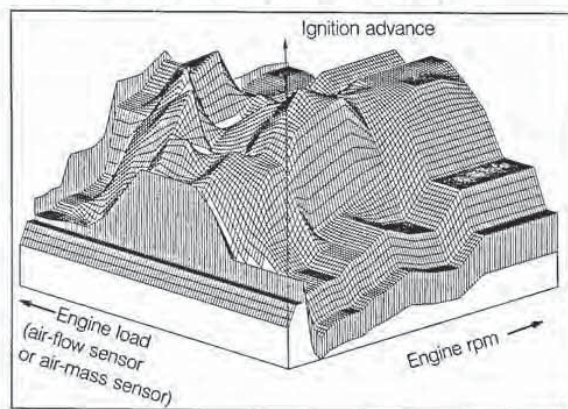


Fig. 4-4. Ignition advance map shows electronic timing control according to engine load and speed. Maps are symbolic of thousands of data points stored in control unit memory. Don't confuse these maps with term MAP, commonly applied to Manifold Absolute Pressure.

Distributor

Because it does not control timing or signal rpm, the Motronic distributor's only job is to distribute the secondary, that is to send the control-unit-timed spark to the proper cylinder.

While timing and dwell were formerly dependent on each other, Motronic memory provides separate dwell-angle data, based on battery voltage and rpm. Later, we'll see how timing and dwell control improve starting and other variations, but here are the principles.

Dwell-Angle Control

As engine rpm increases on mechanical advance systems, there is less dwell time for the coil to charge between firings, resulting in a fall-off of coil voltage. In Motronic systems, dwell angle is electronically controlled so the coil receives the proper current at the time of plug firing. The more battery voltage, the less dwell angle needed. On the other hand, as rpm increases, more dwell angle is needed for the time to charge the coil. By controlling dwell angle, the coil is charged properly for each ignition firing, no more, no less. The objective is to provide the required secondary power at the plug at the moment of firing with minimum losses in the ignition output transistor and the coil.

To reach the nominal value of primary current at the moment of firing, the dwell angle is changed according to the battery voltage as shown in Fig. 4-6. When battery voltage is less, dwell time is increased. In effect, the dwell control answers the question: "When should the primary circuit be closed for the

optimum time for the coil primary current to rise to proper value at moment of opening primary circuit?" In addition, the control-unit output stage limits current so that if, due to rapid engine speed changes as in acceleration, current reaches the nominal value before the ignition point, current is held constant.

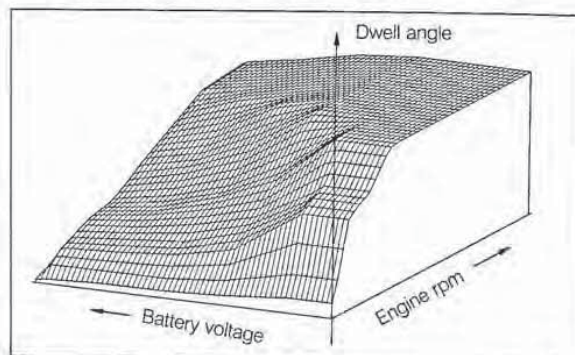


Fig. 4-5. Dwell angle is controlled for battery voltage and engine speed, according to memory map in control unit.

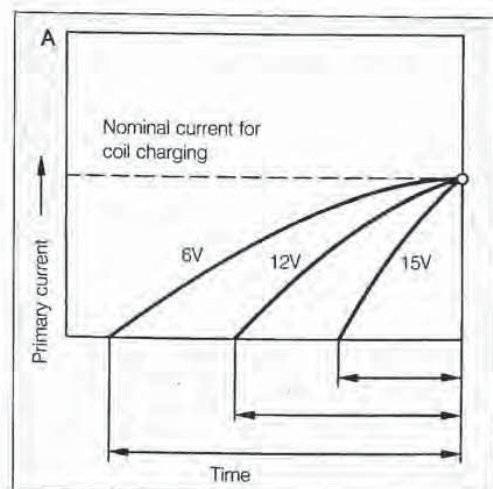


Fig. 4-6. The lower the battery voltage, the longer it takes to charge the primary in the coil.

So engine rpm, and battery voltage are inputs to the control unit. From dwell-angle data in the ROM, control unit output is the dwell, or charge-time control, that conserves energy and prevents overheating the coil. Also, if the rpm signal indicates less than 30 rpm, as when the engine stops or the key is left on with the engine stopped, primary cut-off prevents coil overheating.

Now that you understand the basics of Motronic ignition control, let's look at the rest of the Motronic system and draw similarities and differences from the Jetronic systems described earlier.

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4.2 Air and Fuel Systems

The basic flow rate is still determined by the air-flow signal and by the rpm signal. But in Motronic systems, the rpm signal comes from the flywheel rpm sensor instead of from the distributor. Also, the pulsed Motronic air-flow sensor signal increases with increasing air flow, a direct relationship. Remember, in the L-Jetronic air-flow sensor, the signal decreases with increasing air flow.

Pulsation Damper

The Motronic fuel system is quite similar; see the L-Jetronic section for details of the pump, distributor pipe, pressure regulator, and injectors. Some Motronic cars add a pulsation damper on the fuel rail, to reduce pressure fluctuations and noise in the system. It looks similar to the pressure regulator as shown in Fig. 4-7, so learn to tell them apart. Although each has a hose connection on its base, the pulsation damper hose does not have a pressure function; it provides for a possible rupture in the diaphragm, dumping the fuel into the manifold instead of spilling it on the engine. How else do you tell the difference? The pressure regulator is on the high pressure side; the damper is on the low pressure, or return side.

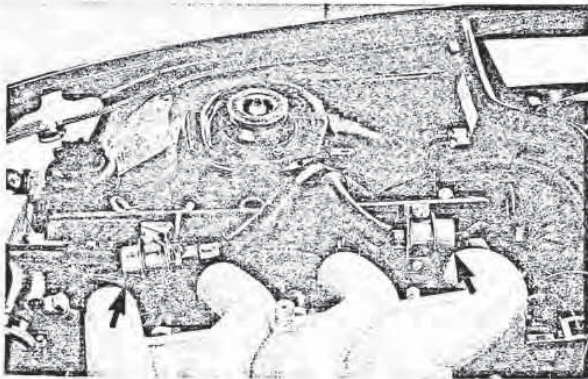


Fig. 4-7. Fuel pressure regulator (right) and fuel pulsation damper (left) look similar, so be careful when servicing them.

4.3 Control Unit

Motronic systems make extensive use of other data maps stored in ROM for many of the control unit functions, including:

1. fuel injection
2. lambda closed-loop control
3. warm-up
4. acceleration

5. ignition timing
6. dwell angle
7. EGR
8. idle-speed control

Data "Maps"

The main map in the control unit is a set of lambda memory-points used to determine the desired air-fuel ratio for the fuel injection pulses. The lambda memory map, shown in Fig. 4-8, is derived from lab and road tests, and modified for the requirements of the vehicle and the country where it will operate:

- at part load, maximum economy and minimum emissions
- at wide-open throttle, maximum torque while avoiding knocking
- at idle, maximum smoothness
- during throttle opening, maximum driveability

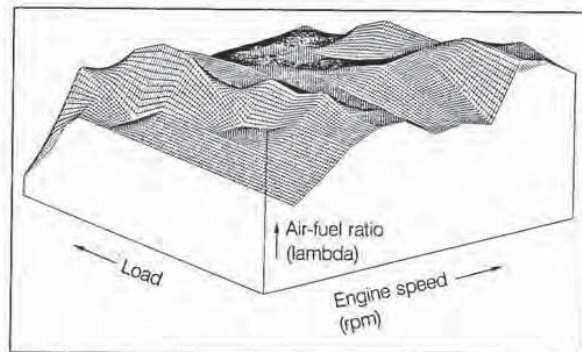


Fig. 4-8. Lambda "map" establishes lambda, or air-fuel ratio for each load/speed point.

Air quantity and the requirements for control of injected fuel can vary due to many factors such as manifold-pressure variations resulting from individual piston pumping, and intake-valve opening/closing. As shown in Fig. 4-9, idling manifold absolute pressure can vary by 50 kPa from an average 425, over more than 10% plus or minus. For this and other variations, the lambda map insures the best possible adjustment of the air-fuel ratio as corrected by inputs that control fuel injection, and without affecting other operating points.

Air flow and rpm set up basic pulse time. Other inputs can change that basic pulse time, and compensate for other variations. Later, you'll see how each of these works for each driving condition.

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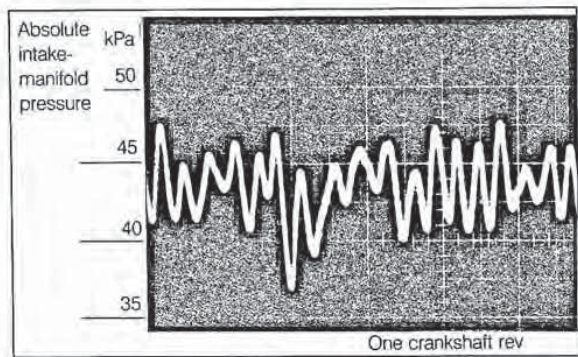


Fig. 4-9. Manifold pressure fluctuates rapidly (as much as 10%) as a result of intake valves opening and closing. This can cause changes in fuel-injection requirements.

Timing Signals: RPM, TDC

For the most accurate measure of engine timing and speed, Motronic systems read the position of the crankshaft directly, instead of from the ignition system as in L-Jetronic. Special sensors, shown in Fig. 4-10, pick up signals from the flywheel teeth. Taking RPM and TDC timing signals from the crankshaft avoids inaccuracies from gear-lash or belt-drive such as when rpm and timing are determined in a camshaft-driven distributor, causing "spark scatter".

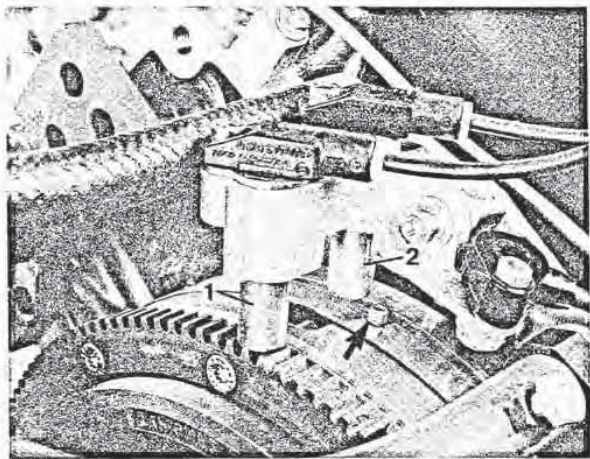


Fig. 4-10. RPM sensor (1) sends engine-speed signals from flywheel teeth; TDC sensor (2) sends one pulse per passing of set screw (arrow) each crankshaft revolution.

The rpm sensor (also called the engine-speed sensor) is an inductive-pulse sender that picks up pulses from a toothed wheel, usually the flywheel. The rpm signal can be displayed on a scope just as it is sent to the control unit, one blip or spike for each tooth as shown in Fig. 4-11. It is so accurate it can sense an rpm change while the crankshaft turns only a few degrees.

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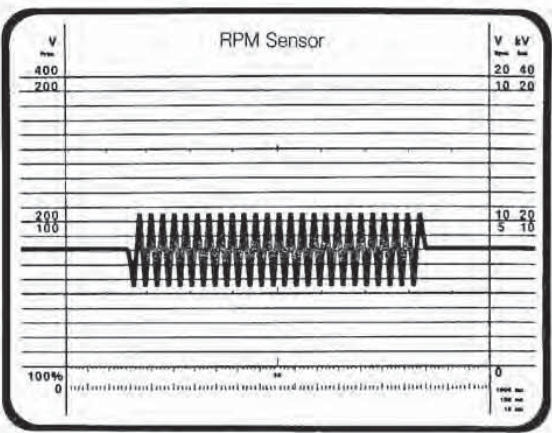


Fig. 4-11. RPM sensor scope pattern shows one pulse per flywheel tooth.

The TDC, or reference-mark sensor (reference from cylinder #1 TDC), is triggered by a set screw on the flywheel. Each time the screw passes the TDC sensor, the sensor signals one blip for each crankshaft revolution as shown in Fig. 4-12. Both sensors are magnetic, with a soft iron core that stores the magnetic field. When a tooth in the flywheel or the reference pin moves through the magnetic field, the change induces an electrical voltage in the winding. This voltage is the input signal to the control unit. The sensor is known as a passive diffusion-field sensor because it does not require a current supply.

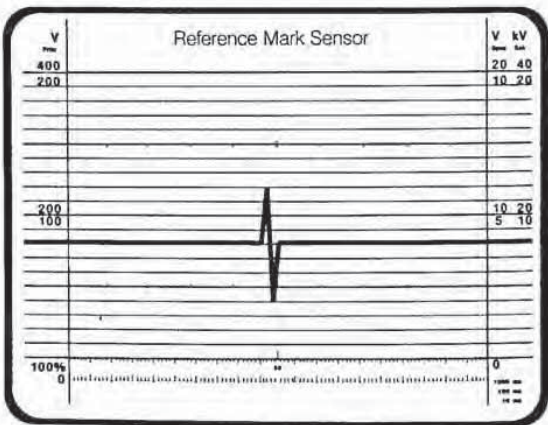


Fig. 4-12. TDC sensor scope pattern shows one pulse per crankshaft revolution.

One of these flywheel sensors provides input of rpm to the control unit. The other sensor provides input of TDC reference. The air-flow sensor provides input of engine load. From the control unit ROM, an output signal to the coil primary sets timing advance and dwell for the next spark firing.

Some engines operate with only one sensor that combines both functions, using a toothed timing-wheel instead of the flywheel. Two missing teeth signal TDC, as shown in Fig. 4-13.

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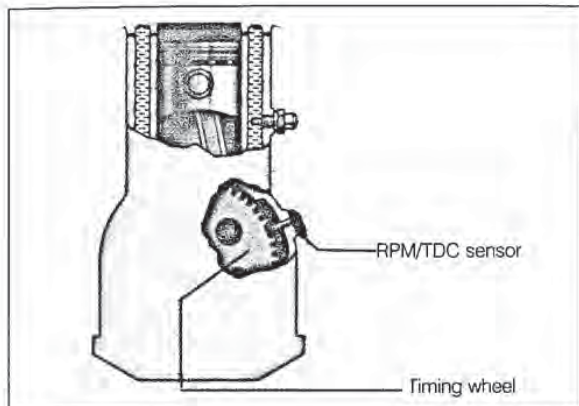


Fig. 4-13. In some Motronics, special timing wheel replaces starter gear ring or is mounted on front of crankshaft. Single sensor picks up rpm from teeth, and picks up TDC from gap in teeth.

Injector Pulse Patterns

On the scope, Motronic injector patterns look different from other Jetronic injector patterns because the digital control signals are different. See Fig. 4-14. The small blip on the left is the TDC reference signal. The injector is opened by the first negative, or grounding pulse, and held open by a series of smaller pulses. When the injection signal ends, a sharp counter voltage shows as a plus spike.

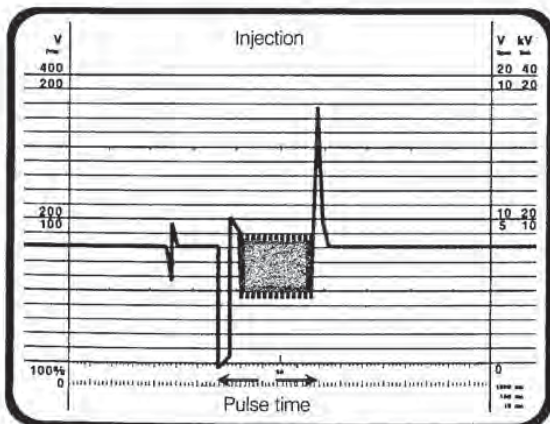


Fig. 4-14. Injection pulse on scope shows large pull-in signal and pulse time. Notice signal drops to 0 (ground) to open injector

Adaptive Circuitry

Some Motronic control units (those identified as ML3) include adaptive circuitry so your engine is controlled based on its individual operating conditions, and on how you drive it. It adapts or learns what is best for you and this engine, which

may be different from the engine tested to develop the basic data for the memory maps.

If the concept seems hard to handle, think of it in this way: Remember from earlier discussion that closed-loop control depends on the oxygen sensor signal that fine tunes the air-fuel ratio, and that the air-fuel mixture is properly adjusted when the output of CO is the same whether the system is open-loop or closed-loop. In effect, the adaptive circuits do the same thing. The control unit looks at the basepulse-time signals during closed-loop, then adapts the open-loop basepulse-time signals to match. The result is less worry about intake air leaks, as the system adapts to such variations. It also adapts to the thinner air at higher altitudes, reducing the need for an altitude sensor.

The adapted values are stored in the control unit's volatile memory—that means that if the battery cable is disconnected for any reason, even something as remote as installing the anti-theft alarm, that adapted value will be lost. If the value is lost, you may find the car drives differently when it's first restarted. Driving it for about 10 minutes should give it time to re-adapt. Adaptive time is carefully considered: anything shorter than 10 minutes would cause the control unit to be adapting to every little change. Anything longer than 10 minutes would cause concern to the driver: "What did they do to my car when they put in that alarm system?" It pays to know when someone disconnects your battery.

Drivers who drive their adaptive-engine GNX or other hot cars to the dragstrip often find they've lost a few tenths of a second in strip times as the engine adapted to the street. Their times picked up when they ran the strip a few times to re-adapt.

Canister Purge Control. You may know that the evaporative fuel control system stores fuel vapors in a charcoal canister to be drawn into the running engine upstream of the throttle, as shown in Fig. 4-15. Motronic ML3 considers the adaptive function in the canister-purge control in the control unit. The air-fuel mixture is controlled to lambda 1 by the lambda sensor system as the control unit slowly operates the canister-purge valve. During any purge of the evaporative canister, the adaptive value is forced to neutral by a so-called "forget" function, and the adaptive circuits are turned off. Adaptive control is allowed only when no canister flow is feeding fuel vapors into the manifold. All this adds up to proper emptying of the evaporative fuel vapors without interfering with driveability.

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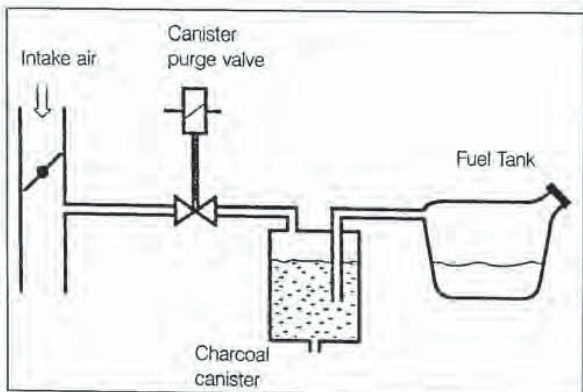


Fig. 4-15. Motronic ML3 controls canister-purge valve to admit fuel vapors to the intake manifold without affecting adaptive system.

Sequential Injection

Sequential injection means delivering fuel separately from each injector in sequence—in firing order. With an increase in computing power, and an increased demand for idle smoothness and reduced emissions, Bosch Motronic ML3 can provide sequential injection. Each injector is timed to cut off just before the intake valve opens. During acceleration, the ECU can deliver additional enriching pulses, cylinder by cylinder for the rapidly changing conditions.

In spite of its increased cost, you'll see more pulsed Motronic sequential injection because:

- each individual injector pulse can be much longer than simultaneous injection, as long as 720° crankshaft rotation less intake valve opening, permitting lower idle speeds
- less variation between cylinders in air-fuel ratio for smoother idle and reduced emissions
- injector fuel-rail pressure is more constant because only one injector opens at a time, meaning smoother operation
- improved acceleration enrichment because it can be applied to the "next cylinder"
- soft rpm limitation by reducing fuel flow cylinder by cylinder

Some people think "sequential" means injecting the fuel just as the intake valve opens, but it is not that simple. Depending on the engine, the injection may be timed before the valve opens. It is all based on the desired stratification in the manifold, swirl effects in the cylinder, emissions, and other considerations.

4.4 Idle Speed Control

Most Motronics control idle rpm by a combination of the idle-speed stabilizer and ignition timing. The stabilizer is described in the section on LH-Jetronic. Inputs include rpm, closed-throttle signal, and engine temperature. The control unit sends on-off, or digital signals to the idle-speed stabilizer. Early Motronics use the auxiliary air valve to increase air flow during warm-up, also described in the L-Jetronic section. In these, cold-engine idle rpm is increased according to temperature; it is an open-loop system.

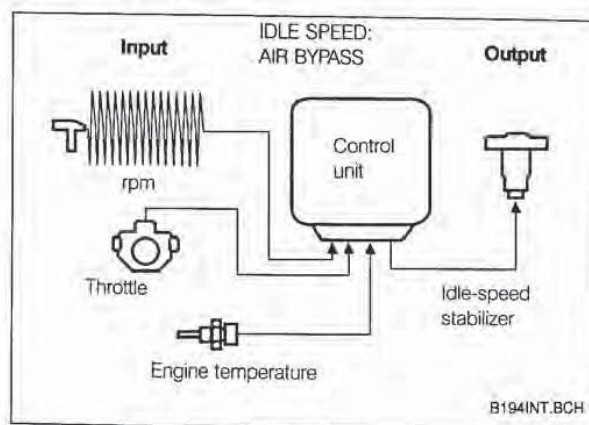


Fig. 4-16. Idle-speed control by idle air bypass. Idle-speed stabilizer handles coarse rpm corrections.

Ignition Timing

Even before the idle-stabilizer acts on air flow, Motronic idle rpm is first stabilized by changing ignition timing. If idle rpm falls, the control unit advances ignition timing to increase rpm. On the other hand, if rpm rises, it retards timing to cut back rpm. Ignition timing handles small rpm changes, handles them in milliseconds. The idle-speed stabilizer handles larger changes, and takes a bit longer.

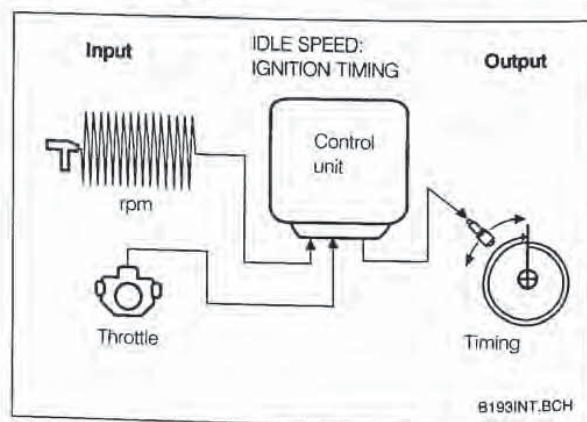


Fig. 4-17. Idle-speed control by ignition timing responds in milliseconds.

4.5 Operating Conditions

In this section, let's look at operating conditions to see how Motronic controls injection and ignition as well as idle-speed bypass air for good engine management.

Starting

Start Control, Fuel. In most Motronics, start enrichment is provided by the port injectors rather than the separate start injector/thermo-time switch. For start control, the important inputs are rpm and engine temperature. The control unit monitors cranking rpm, and also the number of revolutions since the time cranking began. The injection pulses may be longer than normal, once per crankshaft revolution, as you've seen in L-Jetronic.

But at low engine temperatures, the control unit may deliver instead several shorter injection pulses per revolution to improve starting. Remember, these are 10 millisecond pulses in a pulse period, or crankshaft-revolution time of 200ms. To prevent flooding, fuel quantity will cut back after a measured number of revolutions, or after the engine has reached a cranking rpm that is temperature related, for example 200–300 rpm.

Start Control, Ignition Timing. With a cold engine at low cranking speeds, timing will be controlled near TDC. For normal cranking rpm, a large advance in timing might fire too early, damaging the starter. Further, starting would be difficult if not impossible. With a cold engine at higher cranking rpm, however, timing will be advanced for better starting.

For hot starts, or high intake air temperatures, timing will be retarded because a hot cylinder can fire easier while the piston is rising at cranking rpm. Retarded timing prevents knocking that can occur in high-compression engines, and may be masked by the starter sound.

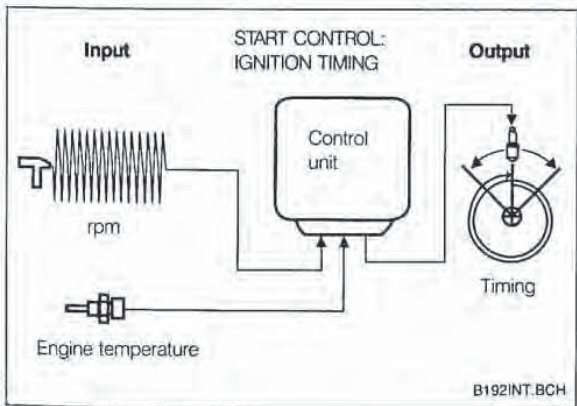


Fig. 4-18. Start control sets ignition timing based on rpm and engine temperature.

Start Control, Air. As in L-Jetronic, the idle-speed stabilizer is normally driven open more by increased dwell signals to provide extra bypass air for cold starting.

Post-Start

Post-start—the 5–30 seconds when you want the engine to keep running after you release the key from CRANK—is affected by engine temperature as well as a timer in the control unit. Colder engines get more fuel injected. Also, colder engines get more timing advance. Based on the start-up temperature, and the time since start, post-start enrichment is gradually reduced. The idle-speed stabilizer maintains rpm.

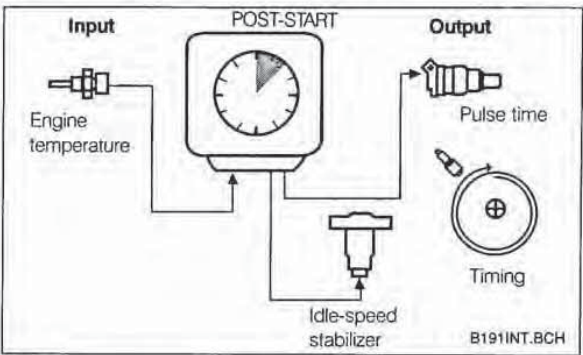


Fig. 4-19. Post-start temperature and time determine injection pulse time, ignition timing, and idle-speed stabilizer bypass opening.

Warm-Up

During warm up, the most important input, besides engine load and rpm for basic pulse time, is engine temperature. The control unit includes a ROM map of warm-up characteristics to apply a correction factor based on load and engine speed, greater at low loads and rpm than at high loads and rpms. See Fig. 4-20. Control unit outputs include injection pulses for the proper mixture, ignition timing for driveability (advance under part-load acceleration, retard on deceleration to reduce HC emissions), and idle stabilization to help keep the engine running at idle.

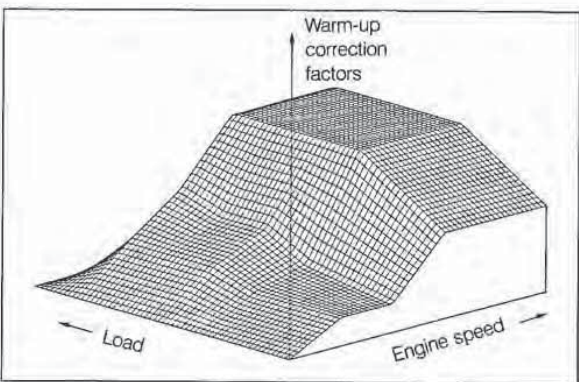


Fig. 4-20. Warm-up correction is greatest at low speeds and low loads, represented by the back of this "map." At the front, correction is least for high loads and high rpm.

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Remember, during warm-up, the temperature of the lambda sensor is important. Unheated lambda sensors can be heated faster by changing ignition timing. Motronic retards timing to cause a hotter exhaust. That heats the oxygen sensor much quicker and also heats the catalytic converter faster for more efficiency.

Closed-Loop Operation

Based on the inputs of a warm engine, and oxygen-sensor voltage when hot, the system normally operates closed-loop. The oxygen sensor fine-tunes the fuel-injection delivery for proper air-fuel ratios.

For every combination of inputs, the control unit looks in its memory for the best timing, the best dwell angle, the best lambda, or air-fuel ratio. On the basis of engine temperature, Motronic controls ignition timing with independent calibrations for starting, idling, deceleration, and acceleration, both part-load and full-load or WOT (Wide Open Throttle). For example, control of timing advance at idle reduces the need for idle fuel enrichment.

Part-Throttle Acceleration

Just as in L-Jetronic, the overswing signal of the air-flow sensor increases fuel delivery, compensated by temperature. For air-mass sensors, the rate of increase of the voltage signals acceleration. As shown in Fig. 4-21, during part-throttle acceleration, the normal pulse for steady cruise increases for just about one second while you open the throttle. Then the pulse cuts back even as the engine picks up speed; this saves fuel and reduces emissions.

In addition, ignition timing can be retarded to avoid the brief acceleration knock that could occur for the first few cycles of engine acceleration. Ignition timing control also reduces the formation of NO_x, which is normal with acceleration.

Rate of ignition timing change is also controlled;

- to avoid knocking, the control unit allows fast change
- to reduce jerk during transition, the control unit normally changes ignition advance gradually

Full-Load Acceleration

Full-load enrichment is signalled by the throttle switch. As long as the throttle is full-open, longer injection pulses will be delivered for enrichment. Rich mixtures reduce the tendency to knock. This enrichment is based solely on rpm, and programmed from engine tests. The air-flow signal is ignored.

At the same time as rpm and throttle position control full-load injection enrichment, air temperature and engine temperature supply inputs to control the advance of ignition timing for

best acceleration without approaching knock. For engines without knock sensors, timing advance is based on engine test data stored in the timing map. The engine can operate close to the ignition-advance limit, developing maximum torque over the entire rpm range with least chance of knocking based on three factors:

1. the timing curve can be programmed specifically for each engine operating point
2. the system operates with narrow tolerances and freedom from mechanical wear
3. timing is compensated according to engine temperature and intake-air temperature

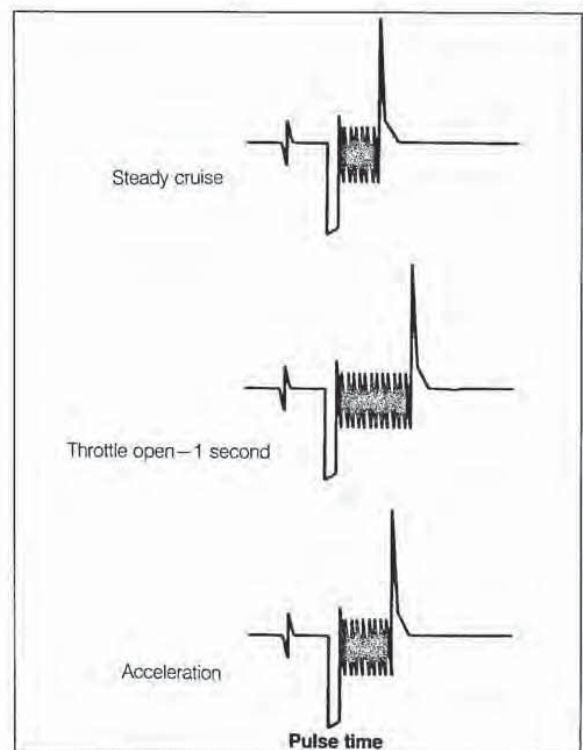


Fig. 4-21. Part-throttle acceleration enrichment is limited to the time the throttle is opening, usually about one second.

In some turbocharged cars, a second air-temperature sensor is mounted in the manifold downstream of the turbo or the intercooler to sense the temperature of the air entering the engine. This is a special fast-response sensor overriding the first air-temperature sensor to handle the quick changes in temperature that can occur during full-throttle acceleration.

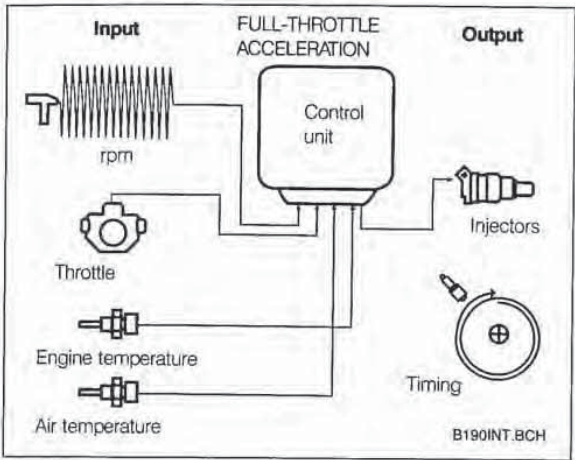


Fig. 4-22. Full-throttle acceleration controls injection and ignition timing, based on inputs of rpm, throttle switch, air temperature, and engine temperature.

Knock Control

Programmed timing accuracy, even with compensations, can be improved by a knock-sensor system that causes timing to advance to just before the point where knock could damage the engine. With a knock sensor controlling timing advance in a separate closed-loop system, power output can be maximized without endangering the engine.

Some engines, particularly turbocharged engines, include knock sensors to pick up vibrations from the engine at the first signs of knock. See Fig. 4-23. Some systems use two control units, mounted inside the passenger compartment, one for Motronic, and a related knock control regulator, called KLR. Knock-sensing inputs help both control units to work together. The first and fastest output changes the timing. If the engine is turbocharged, the second output controls the boost. See Fig. 4-24. In the Motronic known as ML3, knock sensing and engine management are combined in one control unit.

When the engine knocks, it vibrates with characteristic frequencies of 5–10 kilohertz together with corresponding harmonics. These vibrations must be sorted from other engine vibrations in a recognition circuit in the control unit. The Motronic control unit has accurate information on crankshaft position and firing order so it is possible to determine which cylinder is knocking (one cylinder usually knocks before the others). Further, circuits operate with such speed that ignition timing can be retarded only for the knocking cylinder, and advanced for the firing of the next cylinder. Each knock signal can modify timing in milliseconds. When ignition retard eliminates the knock, timing is advanced slowly in steps to the original value or until knocking again occurs.

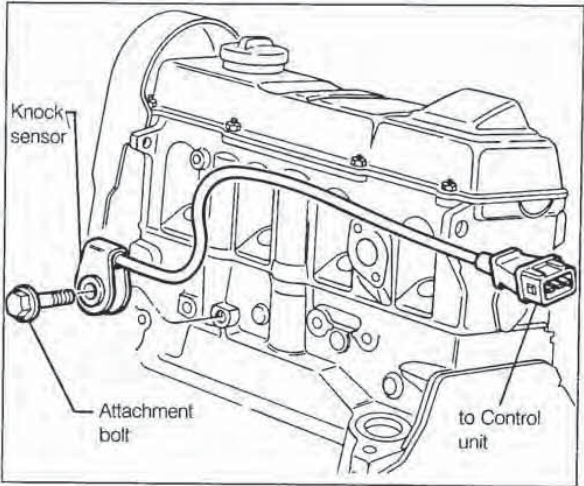


Fig. 4-23. Knock sensor is fastened to selected part of block or head. It is coated with plastic to reduce the effect of changes due to engine temperature.

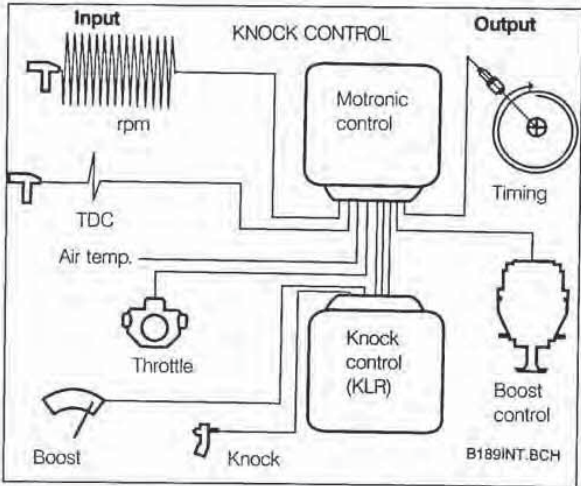


Fig. 4-24. Knock control uses several inputs to control ignition timing and boost, sometimes with a separate knock control computer, known as KLR.

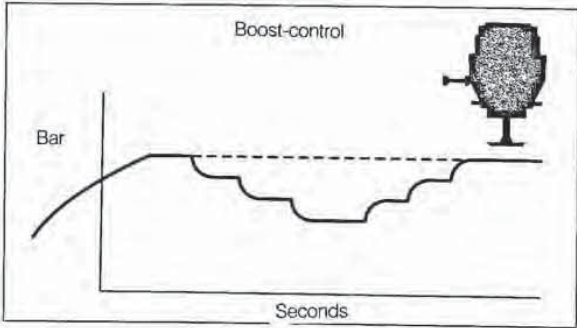


Fig. 4-25. Boost control cuts back pressure in steps until knocking stops, then gradually restores boost.

Motronic Systems

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On turbocharged engines, if knock continues for seconds, boost control reduces manifold pressure. Knock control permits more boost, and higher compression ratios for greater power. Automatically, it tends to adjust for the octane-rating of the fuel being burned.

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

- intake air temperature
- engine temperature
- engine deposits
- combustion-chamber form
- mixture composition—A/F ratio, and stratification
- fuel quality
- air density

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

RPM Limitation

If the rpm signal is greater than max-allowable rpm stored in the computer memory, the control-unit signals a cutback of the fuel-injection quantity. A scope set to read four pulses for simultaneous injection for four cylinders shows the limitation cutback of every other pulse, one pulse every other crankshaft revolution. See Fig. 4-26. If you press the engine into the rpm-limitation range, you will feel a surge as the limitation of fuel injection cuts in and out.

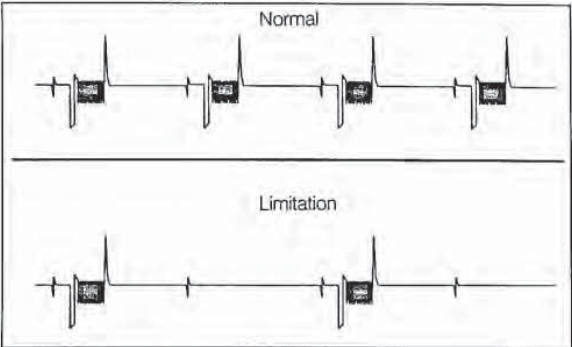


Fig. 4-26. Normal 4 pulses per two crankshaft revolutions, or two 4-stroke cycles. RPM limitation cuts every other injection pulse.

Motronic Systems

Coasting Cut-Off

Signals of rpm, closed throttle, and engine temperature control coasting cut-off of injection. On the scope during coast-down, the single-injection pattern looks blank except for the TDC pulse. See Fig. 4-27. No fuel is being injected. As rpm approaches idle speed, the normal pulse will show again. If the engine is colder, normal fuel injection returns at some higher rpm, to prevent stalling. See Fig. 4-28. Motronic adds one refinement: as fuel-delivery resumes, perhaps as the driver resumes speed, ignition timing is gradually advanced to smooth the transition from fuel cut-off to cruise or acceleration.

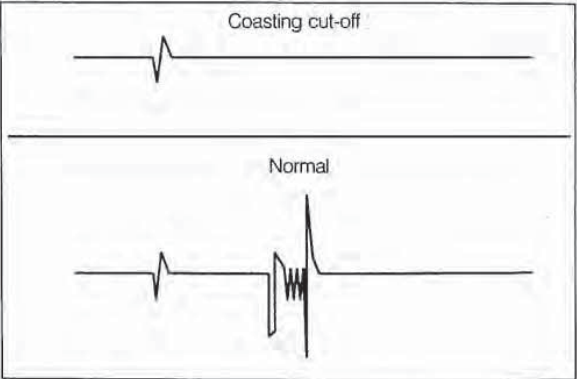


Fig. 4-27. Scope pattern for coasting cut-off shows only TDC pulse until injection resumes to prevent stalling.

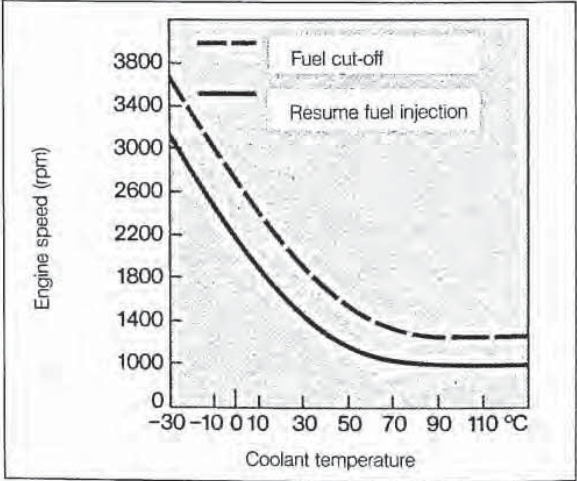


Fig. 4-28. Warm engine cuts off and resumes fuel at lower rpm than cold engine. RPM difference between cut-off and resume fuel prevents hunting.

Electronic Throttle—Drive-By-Wire

Some of the newest Motronic systems have an electronic throttle (also known as a drive-by-wire system). The electronic throttle has no mechanical link between the accelerator pedal and the throttle valve. Instead, as shown in Fig. 4-29, an accelerator sensor picks up your movement or position of the accelerator pedal. It signals the control unit about pedal movement, and the control unit signals the servomotor on the throttle shaft to open. The electronic throttle (Bosch calls it EGAS) may sound like something none of us needs, but it has many benefits.

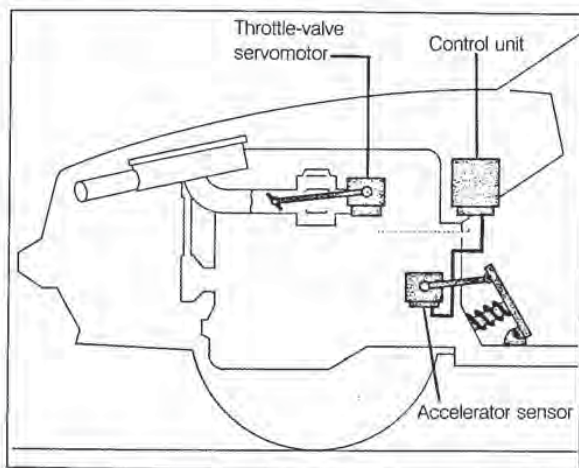


Fig. 4-29. Electronic throttle sends accelerator signal to Motronic control unit. DC motor moves throttle valve, modified by engine temperature, idle rpm, and maximum rpm.

The throttle opening signal may be modified according to engine rpm and engine temperature. It can provide simplified cruise control. It can also control minimum rpm, replacing the idle-speed stabilizer, and control maximum rpm, replacing the alternate-injector cut-out.

But there's more. For traction control, the electronic throttle links with the ABS (Anti-lock Braking System). The same wheel-speed sensors of ABS also feed the ASR (Anti-Slip Regulator). When any driving wheel starts to slip, a slight brake application prevents that wheel from slipping so much that the differential delivers no power to the other driving wheel. If both driving wheels show signs of slipping, the electronic throttle cuts back power for maximum traction. Traction control gives the car the max acceleration the tires can deliver to the road. If laying down tire smoke is your thing, avoid ASR. But for making the fastest takeoff, you cannot beat it.

Can you trust the electronic throttle? Will it provide unintended acceleration? The system checks its safety circuits before start-off, and reports defects to the driver. If a defect is found, a limp-home circuit may disable some of the functions, but it will allow you to get to the house or the shop. It may well be more reliable than some cable actuated throttles.

Diagnostics

Beginning with Motronic ML3, diagnostic systems in the control unit provide troubleshooting information. Each time you turn the key ON, the computer checks itself. Then it checks the sensors. Any defects are stored in the fault memory for later readout by a diagnostic device. During servicing or troubleshooting, the actuators can be driven by short pulses so the technician can hear or feel the actuation to pinpoint the problem. See Fig. 4-30. You'll see more about diagnostics in chapters 4 and 6.

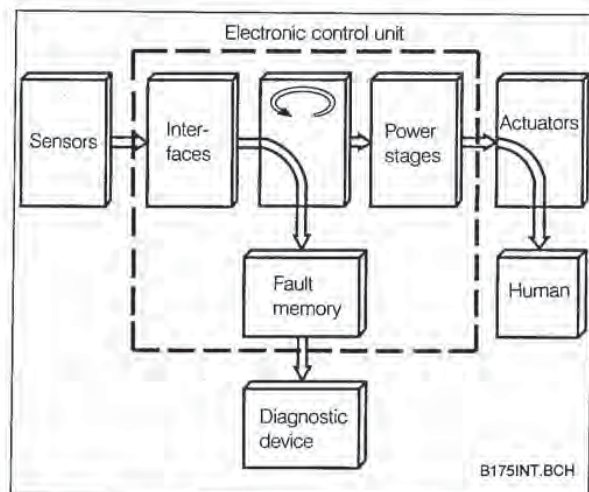


Fig. 4-30. Diagnostics store trouble codes in fault memory for readout by diagnostic device.

The more you study the manuals for different applications, the more you'll realize how well engines can be managed by Motronic injection and ignition control, and idle-speed stabilization.

5. D-JETRONIC

D-Jetronic was the first of the Bosch pulsed injection systems. I write about it at the end because the most recent cars with Bosch D-Jetronic were the 1975 Volvo 164E and the 1975 Mercedes 450. In 1976, both changed to K-Jetronic. It's most interesting to see how L-Jetronic evolved from D-Jetronic. At the 1967 introduction, Bosch called it ECGI, Electronically Controlled Gasoline Injection, contrasting this new electronic system with a long background of mechanically-driven injection pumps.

Based on a cross-licensing of the Bendix Electrojector system, which was briefly used in the U.S., D-Jetronic depends on sensing manifold pressure as an indication of engine load.

You can refer to the L-Jetronic section for details concerning most of D-Jetronic. The major differences are:

- manifold-pressure sensor senses engine load

Motronic Systems

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- trigger-contacts in the distributor synchronize injection pulses
- Injectors are operated in two groups
 - 4-cylinder, 2 groups of 2: VW, Porsche, Saab, Volvo
 - 6-cylinder, 2 groups of 3: Mercedes, Volvo
 - 8-cylinder, 2 groups of 4: Mercedes

Bosch now regards manifold-pressure sensing as a less accurate measure of load than measuring air flow, as in L-Jetronic, and in K-Jetronic, or measuring air mass, as in LH-Jetronic. For certain Bosch racing applications, however, manifold-pressure sensing is sometimes used. Manifold-pressure sensing is widely used by GM, Ford, Chrysler, AMC, and some Toyotas, but the trend in passenger cars is away from manifold-pressure sensing.

Manifold Pressure Sensing

As shown in Fig. 5-1, the pressure sensor is connected to the intake manifold between the throttle and the intake valves. The air-temperature sensor signals for correction for colder, denser air.

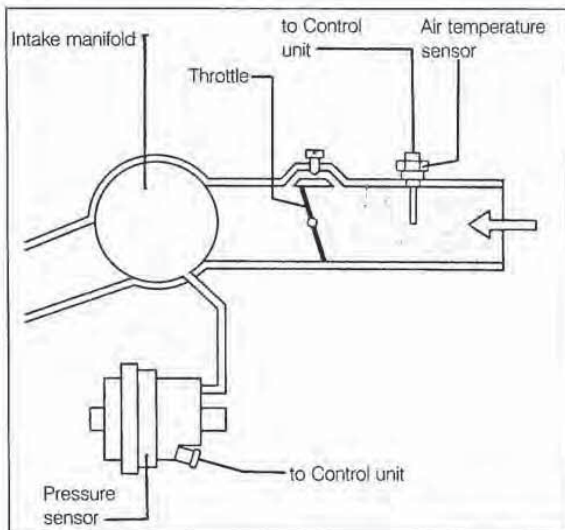


Fig. 5-1. Pressure sensor signals manifold absolute pressure (MAP) downstream of throttle.

As shown in Fig. 5-2, the pressure sensor contains two pressure diaphragm cells that expand and compress according to pressure. The inside of one is vented to the atmosphere; the outside of both is connected to the intake manifold pressure. When manifold pressure increases, the cells compress and pull an iron core armature into a coil, changing the electrical signal to the control unit. Increasing manifold-pressure

signals increasing load so the control unit increases the pulse-time of the injectors. This is a succession of analog actions, requiring no digital computation. D-Jetronic control units are analog. When manifold pressure is low, as at idling, the diaphragm cells expand, pushing the core into the coil; the electrical signal to the control unit reduces the pulse-time, reducing the fuel injected per stroke.

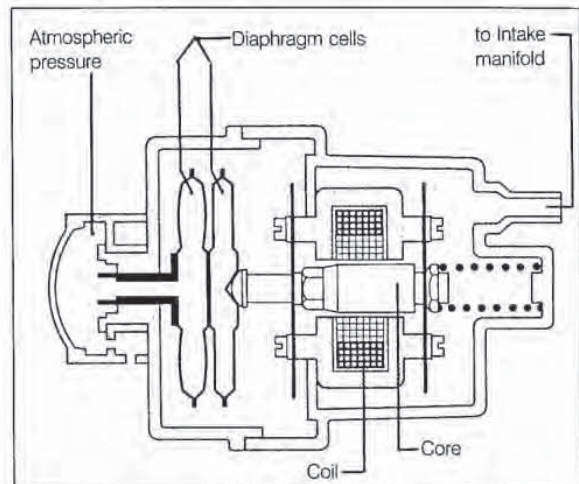


Fig. 5-2. Cutaway view of manifold pressure sensor.

Altitude, or density compensation is provided by the venting of one cell to the atmosphere. In the part-load range, both manifold pressure and atmospheric pressure are reduced with altitude, so the fuel-injection signal is tailored to the thinner air.

Trigger Contacts

Injection timing is determined by a set of trigger contact points in the distributor. See Fig. 5-3. These contacts are mounted below the centrifugal weights of the ignition advance mechanism. They are operated by a special cam on the distributor shaft. Bosch makes the distributor, too. The trigger contacts provide a signal of crankshaft position for timing, and of crankshaft rotation for rpm input. Because they are mounted below the centrifugal weights, the trigger contacts are not affected by distributor ignition timing action.

D-Jetronic injectors are triggered in two groups. Each 4-stroke cycle, D-Jetronic fires each group once instead of firing all twice as in L, LH, and Motronic systems.

Acceleration

Acceleration is compensated at the throttle switch. See Fig. 5-4. This switch contains the full-load contact and the closed-throttle contact as in L-Jetronic. But in D-Jetronic, it also contains a contact path for acceleration enrichment. As the throttle is opened during acceleration, the signal enriches the mixture by increasing the pulse time, and also by increasing the number of injection pulses.

Motronic Systems

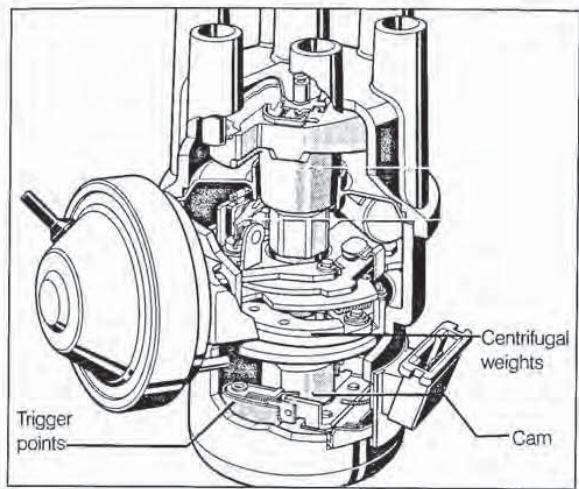


Fig. 5-3. D-Jetronic trigger contacts are built into the distributor.

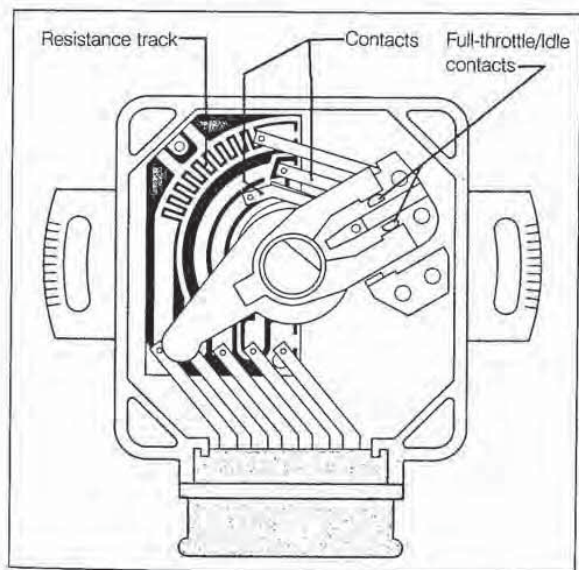


Fig. 5-4. D-Jetronic throttle-position sensor compensates for part-throttle acceleration.

Pressure Regulator

The final difference in D-Jetronic is the fuel pressure regulator shown in Fig. 5-5. It maintains constant pressure at 2 bar, less than the 2.5 or 3 bar of L-Jetronics. Unlike L-Jetronic, fuel pressure can be adjusted by the nut on the bottom of the regulator to control pressure on the spring. Increasing the fuel pressure will enrich the mixture and increase power, but not equally in all rpm ranges. Also unlike L-Jetronic, fuel pressure does not need to be related to manifold pressure because the system is already controlling pulse-time, and therefore mixture, according to manifold pressure.

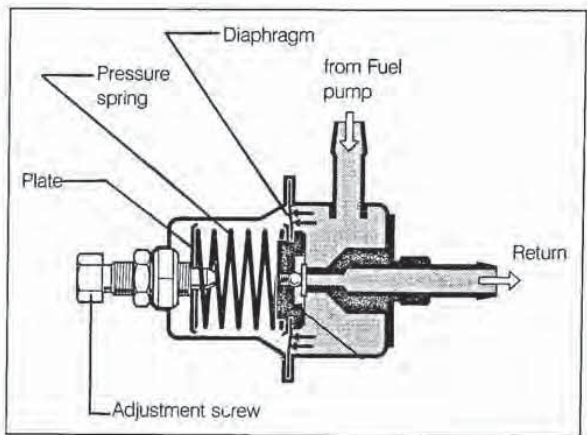


Fig. 5-5. D-Jetronic fuel pressure can be adjusted at regulator.

6. DIGIFANT II

Digifant II is a Volkswagen cousin to Bosch Motronic, controlling pulsed fuel injection, electronic ignition, and idle speed from the same control unit. It includes a knock sensor for ignition-timing control. First use is on 1988 8-valve engines in Golf and Jetta, replacing Bosch CIS.

Similarities to Motronic:

- vane-type air-flow sensor on un-supercharged engines (VW Corrado uses pressure sensor)
 - A/F mixture is adjusted by bypass of unmeasured air
 - intake air temperature sensor
- electrically-opened pulsed injectors
- ignition timing controlled by control unit
- coolant-temperature sensor
- switches on throttle shaft
 - closed throttle (idle)
 - WOT

Similarities to CIS:

- idle-speed stabilizer valve with throttle bypass adjusting screw
- fuel system: pump, relay, filter; no accumulator

Digifant II differences from Motronic or CIS are few:

- system pressure is specified with engine idle: 2.5 bar (36 psi) instead of engine off. Actually, engine-off pressure (comparable to Bosch specs) is 3.0 bar, 0.5 bar higher than many pulsed systems

Digifant II

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- service port for fuel-pressure testing
- idle-speed stabilizer circuit delivers fixed (higher) idle rpm when coolant temperature sensor is disconnected
 - measuring current flow to stabilizer at idle shows fluctuation 400–460mA, closed loop, causing 790–850 rpm. Disconnecting sensor shows fixed 430mA, causing 930 rpm, open-loop
- ignition timing is set with coolant sensor disconnected for fixed idle rpm
- control unit increases idle rpm for hot start

Digifant II

Chapter 5

Continuous Injection – Theory

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1. GENERAL DESCRIPTION

This chapter covers the operating theory of Bosch continuous fuel-injection systems. Continuous Injection System (CIS) is the term widely used to refer to this branch of the Bosch fuel injection family. Do not confuse this with the Volvo term CIS (Constant Idle Stabilization), which is their term for the Idle-Speed Stabilizer, an unfortunate overlap of terminology. The continuous systems I'll discuss in this chapter include:

- K-Jetronic (I'll call it K-basic)
- K-Jetronic with lambda control (I'll call it K-lambda)
- KE-Jetronic and its variations: KE3-Jetronic, and KE-Motronic (I'll call them KE systems)

I'll begin this chapter with a general description of how Bosch continuous systems meter fuel to match a given air flow. I'll then examine in detail how the different subsystems of CIS—air flow measurement and fuel delivery—interact mechanically to create this basic fuel metering function. Finally, I'll explain how K-basic, K-lambda, and KE control systems fine-tune this basic fuel metering to compensate for different operating conditions.

For more information on the general principles of fuel-injection, see chapter 1 and chapter 2. To determine which Bosch system is installed on your car, see **1.2 Applications - Identifying Features**, or the detailed applications table at the end of chapter 1.

1.1 Continuous Injection System (CIS)

As I described in chapter 1 and chapter 2, the aim of the fuel-injection system is to measure the amount of air the engine is taking in and to meter a precise amount of pressurized fuel to match that air and create the correct air-fuel mixture. All Bosch continuous systems provide this basic air-measuring and fuel-metering function in the same way: in the mixture-control unit.

Mixture-Control Unit

The mixture-control unit is the heart of continuous injection. As Fig. 1-1 shows, it is where the air-flow measurement system and the fuel delivery system interact. The mixture-control unit measures the engine's intake air, and then meters fuel in proportion to that air flow.

The mixture-control unit is actually the combination of two separate components: the air-flow sensor, and the fuel distributor. See Fig. 1-2. The air-flow sensor measures the air entering the engine. The fuel distributor, in turn, delivers a proportional amount of pressurized fuel to the injectors.

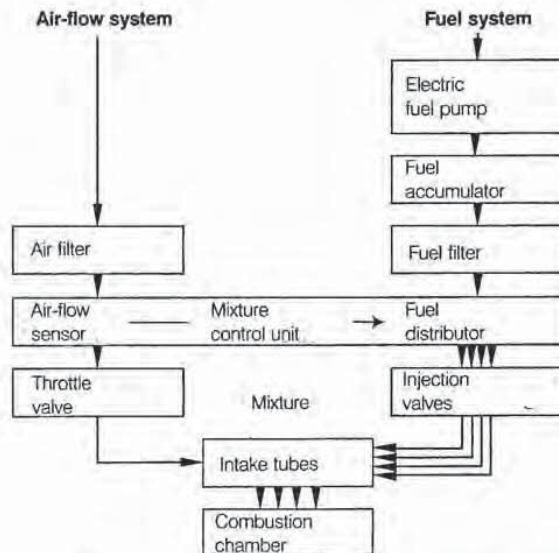


Fig. 1-1. Air-flow measurement system and fuel delivery system interact in mixture control unit to deliver the basic air-fuel mixture.

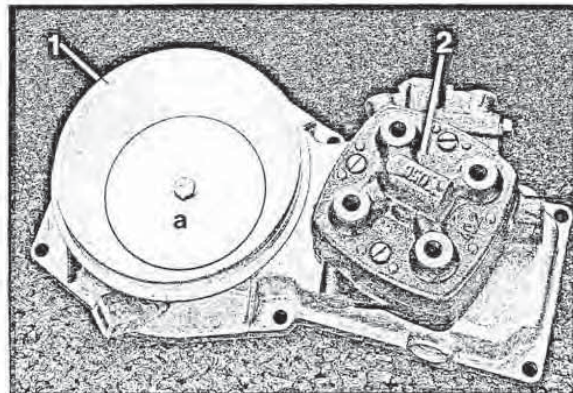


Fig. 1-2. The mixture-control unit is the combination of the air-flow sensor (1) and the fuel distributor (2). Circular sensor plate (a) is lifted by flow of engine intake air.

Air Flow Measurement and Fuel Metering

Fig. 1-3 is a schematic view of the operation of the mixture-control unit. The circular air-flow sensor plate is positioned in the intake tract so that all air entering the engine flows past it. The plate is attached to a lever which pivots, allowing the plate to move up and down. Intake air flowing through the housing raises the sensor plate. The movement of the sensor plate and lever is in direct proportion to the volume of the incoming air.

General Description

4 CONTINUOUS INJECTION — THEORY

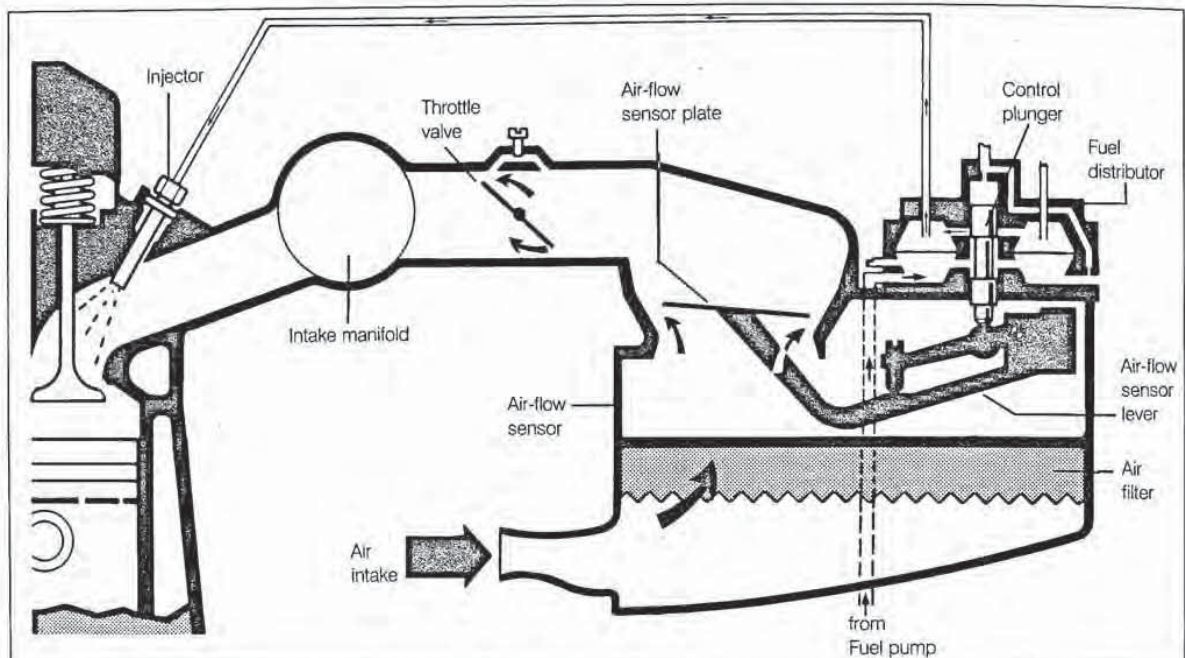


Fig. 1-3. Schematic of continuous injection air-flow measurement and fuel metering. Air entering intake manifold raises air-flow sensor plate. Rise of sensor plate mechanically raises control plunger. This basic fuel metering function applies to all systems in this chapter.

This air measurement is turned into an injection quantity by the control plunger in the fuel distributor. The plunger rests on the air-flow sensor lever, and it rises and falls at the same rate as the sensor plate. The position of the plunger controls fuel flow to the injectors. When air flow into the engine increases and raises the air-flow sensor and plunger, the rise of the plunger increases fuel flow proportionally. This maintains the correct air-fuel ratio. See Fig. 1-4. This mechanical lift of the control plunger by the air-flow sensor is how all continuous injection systems perform basic fuel metering.

In continuous injection all fuel metering takes place in the fuel distributor. The fuel injectors flow fuel continuously while the engine is running; their only function is atomization of the fuel. This is in contrast to the pulsed systems described in previous chapters, where fuel metering is controlled by opening and closing of the injectors.

Now you can see why continuous systems are often referred to as "mechanical" fuel injection, because basic fuel metering is controlled by the mechanical relationship between the air-flow sensor and the control plunger in the fuel distributor. As you'll see later in this chapter, continuous systems are also referred to as "hydraulic" fuel injection. This is because their control systems alter this basic air-fuel mixture for different operating conditions by changing fuel pressures in various parts of the system.

General Description

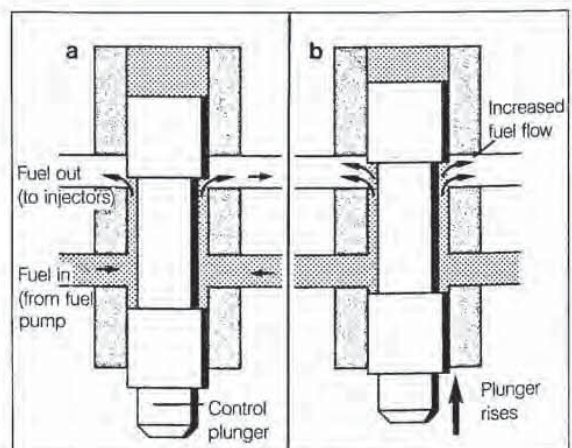


Fig. 1-4. Fuel metering by control plunger in the fuel distributor: At low air flow (a), rise of air-flow sensor and control plunger is low so less fuel flows to injectors. At increased air flow (b), when air-flow sensor rises higher, control plunger in turn rises, so more fuel flows to injectors.

1.2 Applications - Identifying Features

Bosch continuous injection systems are installed only by European car manufacturers. As of 1989, no Japanese or U.S. manufacturer is installing K-Jetronic fuel injection or its derivatives. With a large installed base on Volkswagen models, several million continuous systems are on the road in the U.S. Other makers using Bosch continuous systems include: Audi, BMW, Ferrari, Lotus, Mercedes-Benz, Peugeot, Porsche, Rolls-Royce, Saab, and Volvo. The 12-cylinder Ferrari Testarossa and Mercedes-Benz engines both use twin KE-Jetronic mixture control units, one for each 6 cylinders. Clearly, Bosch continuous systems are capable of performing well in many different applications.

To identify continuous systems, look for the separate mixture-control unit. It is usually mounted on a fender panel with flexible air duct leading to the throttle body and intake manifold. Also, continuous systems have separate injector fuel lines delivering fuel to each injector, instead of the common fuel rail found on pulsed systems. The fuel lines are usually flexible lines enclosed in protective metal braiding. See Fig. 1-5.

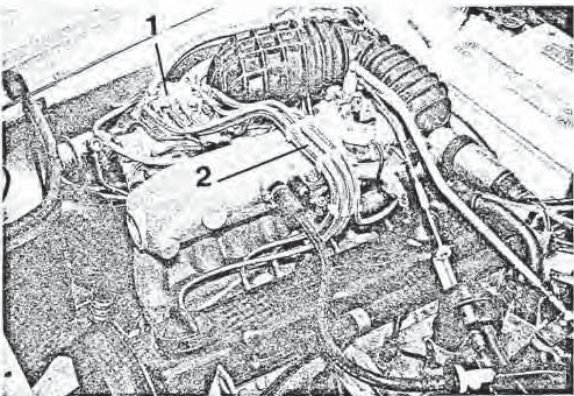


Fig. 1-5. Separate continuous mixture-control unit (1) between air cleaner and intake manifold. Each injector gets fuel through separate fuel line (2). No fuel rail, as in pulsed injection.

There are exceptions: On Mercedes cars, and on Peugeot, Renault, and Volvo cars using the PRV V-6 engine, the mixture-control unit is mounted directly on the intake manifold, as shown in Fig. 1-6. It usually delivers fuel through rigid metal lines to the injectors. The large air cleaner covers most of this so it may look like a carbureted engine at first glance.

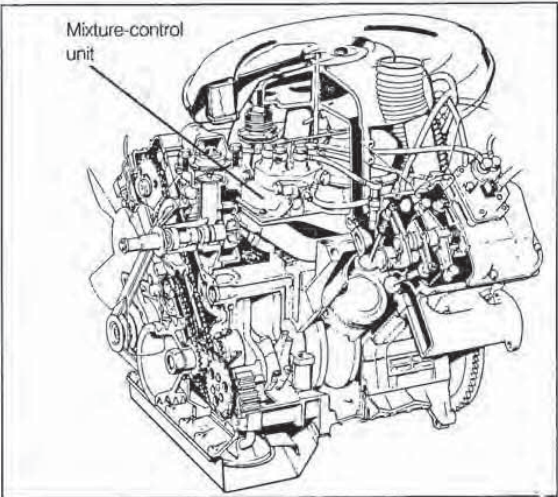


Fig. 1-6. On the PRV V-6 engine used by Peugeot, Renault, Volvo, the mixture-control unit hides under air cleaner. Location on Mercedes 4-cyl., 6-cyl. and 8-cyl. engines is similar.

How can you tell the systems apart? You can distinguish between each by component and function.

K-Jetronic and K-Jetronic with Lambda Control (K-Basic and K-Lambda)

K-basic and K-lambda fuel distributors are made of cast iron and usually painted black. K-lambda systems are further distinguished from K-basic by the solenoid-type lambda valve next to the fuel distributor; it has an electrical connector and looks almost like a pulsed injector. See Fig. 1-7.

Table a. Bosch Continuous Fuel Injection Systems

Name	First use	Fuel pressure	Computer/pins	Lambda control
K-basic	1974 Porsche 911T	4.8–5.2 bar (70–75 psi)	no	no
K-lambda	1980 almost all mfrs.	4.8 bar (70 psi)	analog/25	yes
KE-Jet 2	1984 Mercedes 190E	5.4 bar (78 psi)	digital/25	yes
KE-Jet 3	1986 Mercedes 300/560	5.4–5.8 bar (78–84 psi)	digital/25	yes
KE-Motronic	1988 Audi 4-cylinder	6.2 bar (90 psi)	digital	yes

General Description

6 CONTINUOUS INJECTION—THEORY

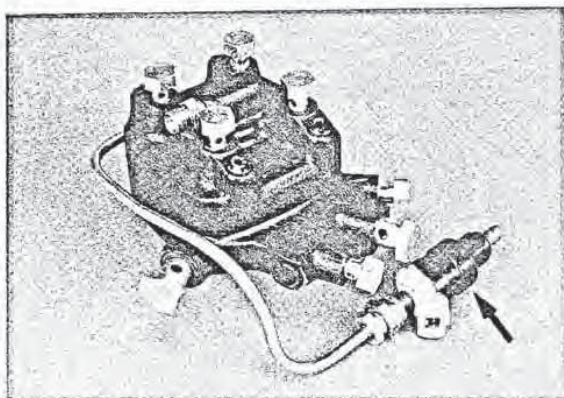


Fig. 1-7. You can tell both K-basic and K-lambda by the black color of the fuel distributor. Only K-lambda has the lambda control valve (arrow), which looks something like a pulsed injector.

KE-Jetronic, KE3-Jetronic, and KE-Motronic

(KE Systems)

All KE systems have a pressure actuator fastened to the fuel distributor as shown in Fig. 1-8. Also, KE fuel distributors are usually unpainted aluminum. Further differences which distinguish the three different KE systems are mostly in the electronics; not immediately apparent. For example, KE-Motronic systems lack vacuum lines to the distributor, but some KE-Jetronics also lack such vacuum lines (1988 Audis with separate electronic ignition-timing control, for example). Check your manual to identify which KE system you have.

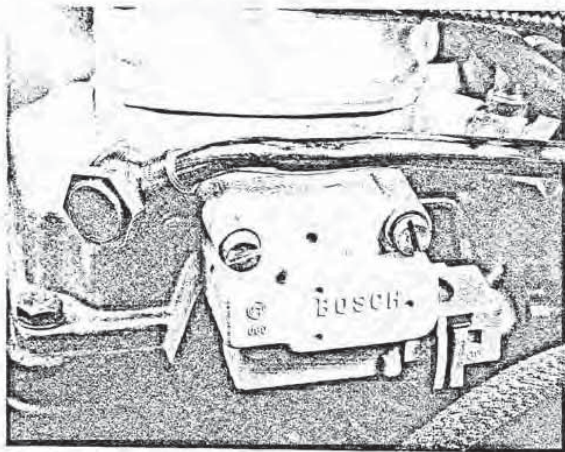


Fig. 1-8. You can identify KE systems by the attached pressure actuator. Some are gray, some are black; all have electrical connector for control-unit wiring connection.

General Description

2. AIR-FLOW SYSTEM

The most basic function of a fuel-injection system is to measure the amount of air drawn in by the engine and to meter a proportional amount of fuel. The air-flow system performs this air measurement function. The air flow system also includes the throttle valve which controls engine speed by regulating engine air intake. See Fig. 2-1.

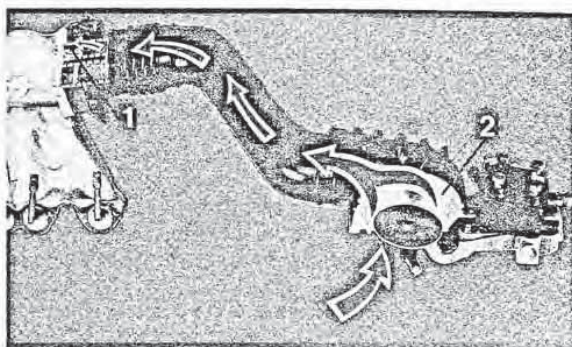


Fig. 2-1. Continuous injection air-flow system. Throttle valve (1) regulates air flow into intake manifold and engine. Air-flow sensor (2) measures volume of intake air.

The air-flow system includes the air-flow sensor (part of the mixture-control unit), the ducting to the throttle body, the throttle valve, and the intake manifold. The throttle valve controls the amount of air entering the engine. The air-flow sensor is deflected by that air, measuring its volume. The movement of the sensor in turn controls the basic fuel metering in the fuel distributor. The air-flow system also provides adjustment for engine idle speed.

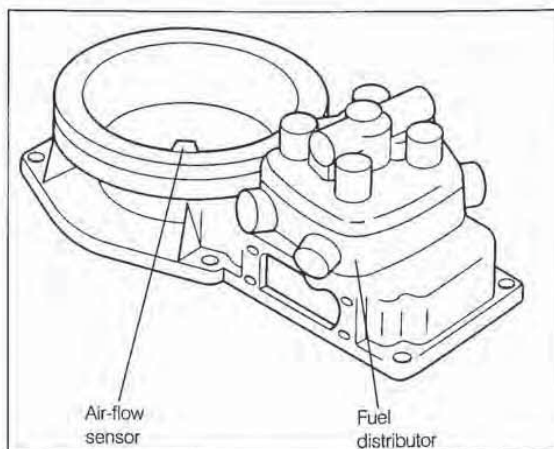


Fig. 2-2. The air-flow system measures engine air intake at the air-flow sensor, and turns that measurement into a proportional amount of fuel in the fuel distributor. Together, the fuel distributor and air-flow sensor are known as the mixture-control unit.

2.1 Air-Flow Sensor

The key to air-flow sensor operation is a circular sensor plate that is deflected by engine intake air moving through the sensor plate housing. The movement of the plate in turn lifts the control plunger in the fuel distributor.

Sensor Plate and Control Plunger

When the engine is off, the sensor plate rests on a spring support, as shown in Fig. 2-3. This is known as the Zero Position. The plate is carried by a pivoting main lever. This allows the sensor plate to move in the intake air flow. The fuel distributor's control plunger rests directly on the same lever that carries the sensor plate.

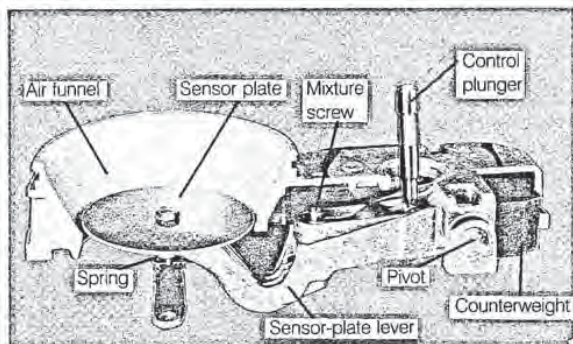


Fig. 2-3. Cut-away view of air-flow sensor shows sensor plate carried by a lever on a pivot, balanced by a counterweight. Shown with fuel distributor removed.

As the engine takes in air, the sensor plate rises as shown in Fig. 2-4. The more air flow, the more the plate and lever rise. The control plunger, because of its position on the lever, rises at the same rate as the sensor plate. This is a linear relationship: a doubling of air flow doubles sensor-plate lift, which in turn doubles the lift of the control plunger. The height of the plunger determines fuel flow to the injectors, so the higher it rises the greater the fuel flow. It is this mechanical relationship between the air flow sensor and the control plunger in the fuel distributor that determines basic fuel metering.

There are actually two types of air-flow sensors that are used in continuous injection, updraft and downdraft. In updraft sensors, as you've just seen, intake air flows from below and lifts the sensor plate **up**. In downdraft sensors, air flows from above and pushes the sensor plate **down**. Although the direction of air flow through the two sensors is different, the operating principles are identical: as the sensor plate is deflected by the intake air, the control plunger **rises**, increasing fuel flow. See Fig. 2-5.

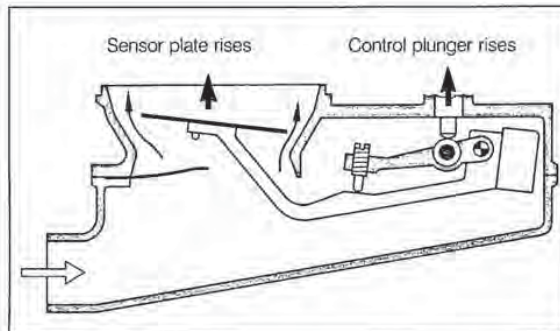


Fig. 2-4. As air is drawn into the engine, the sensor plate lifts, floating on the column of air. The movement of the sensor plate also lifts the control plunger.

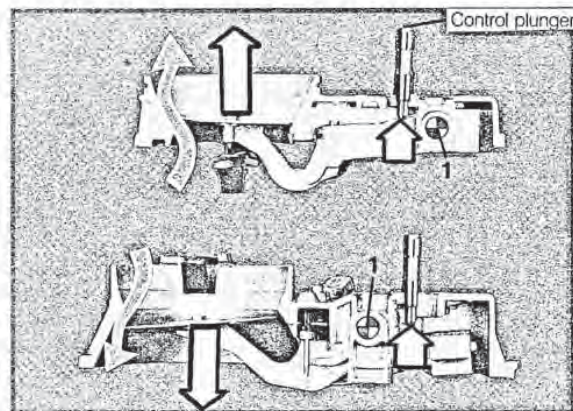


Fig. 2-5. When an updraft sensor plate rises, it lifts the plunger—on the same side of the pivot (1). When a downdraft sensor plate is forced down, it also lifts the plunger—on the opposite side of the pivot.

In both types of air-flow sensors, the weight of the sensor plate and lever is balanced by a counterweight. This means that the plate acts as though it were weightless in the intake air stream. The force of the air flow easily lifts the sensor plate, so much so that a counter-acting force is necessary to stabilize the movement of the plate. As you'll see later, fuel pressure force is used, applied to the top of the control plunger.

In later continuous systems, the counterweight is replaced by a balance spring; the spring has less inertia than the weight. This permits the sensor plate to adjust more quickly to changing air flow, so fuel metering and throttle response are faster.

Funnel Angles

The operation of the air-flow sensor is based on something called the "floating body principle." This principle states that under the right conditions a column of pressurized air will support and move an object, and that the movement of this object will be in direct (linear) proportion to the volume of air flowing past.

Air-Flow System

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In the air-flow sensor, all intake air flows through the sensor air funnel to create a column of air. Because the counter-weighted sensor plate is positioned in the middle of the air funnel, it floats on the column of air. As the engine uses more air, the flow through the funnel is greater and the sensor plate rises a proportional amount in the column of air.

The shape of the sides of the funnel is tailored so that for a given air flow, the strength of the column of air is greater or less, and the lift of the sensor plate will be greater or less. See Fig. 2-6. The funnel is designed for each system on which it is installed, according to the power characteristics of the particular engine design.

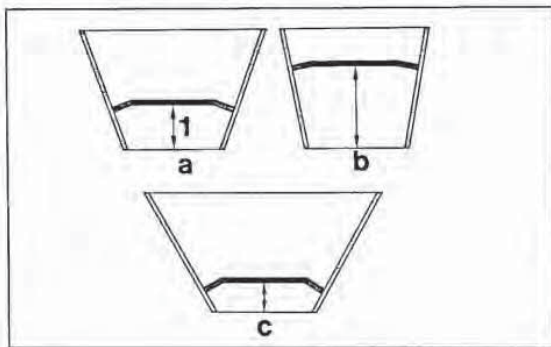


Fig. 2-6. Air-flow sensor funnel shape affects lift of sensor plate. For a medium cone angle (a), the sensor plate lifts to height 1 for a given air flow around the sensor plate. If the funnel walls are steep (b), the plate would have to lift much higher to pass the same amount of air. If the funnel wall angle is shallow (c), the same amount of air pushes with much less lift.

If you remember that sensor-plate lift affects control-plunger lift and basic fuel metering, you can see that funnel angles can be changed to affect the air-fuel ratio for a given air flow.

For example, in K-basic systems, the funnel is usually shaped with different angles according to engine needs for different operating conditions, as shown in Fig. 2-7. A steeper wall section near the top of the funnel causes more sensor-plate and plunger lift for the air flow, giving a richer mixture for full load. A shallower wall section in the middle causes less lift for a leaner mixture at part-load. At the bottom of the funnel, another steeper wall section gives more lift and a richer mixture for idle/off-idle conditions. In K-lambda and KE systems, the funnel shape is usually conical, so the proportion of the basic fuel metering is constant for the entire range of sensor plate lift.

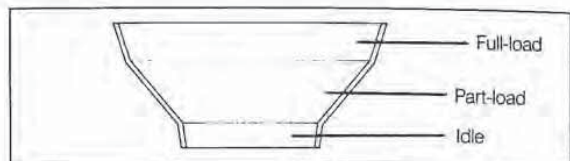


Fig. 2-7. In K-basic, funnel shape is designed to fit specific engines for enrichment at different air flows. Funnel shape is matched to each engine and model; do not interchange funnels.

Control-Plunger Counterforce

Some additional force is needed to balance the air-flow force that raises the sensor plate and control plunger. Otherwise, the movement of the plate would be too quick, and when the engine is started the plunger would rise to the top of its travel and stay there.

Fuel pressure supplies this counterforce, applied to the top of the control plunger in the fuel distributor. This pushes down against the upward force of the air flow sensor and the upward movement of the control plunger, regulating their movement and allowing the sensor plate to float in the air stream. The counterforce pushes the plunger back down for less fuel flow when there is less air flow, and returns the control plunger to its rest position when the engine stops running.

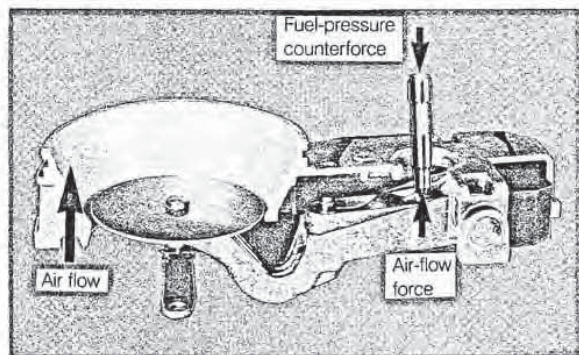


Fig. 2-8. Air-flow force lifts sensor plate and control plunger. Fuel-pressure counterforce presses down on the plunger. Balance of these two forces determines amount of plunger lift for a given air flow.

As you'll see later, this fuel-pressure counterforce can be varied to affect control-plunger lift for a given air flow, changing the proportion of fuel injected, and therefore changing the basic air-fuel ratio. In K-basic and K-lambda, the counterforce is known as the control pressure. I'll explain control pressure in 5. **Control Systems.**

Air-Flow System

Beginning with 1983 models, a return spring atop the control plunger ensures that the plunger follows the movement of the air-flow sensor during starting and engine deceleration. This improves starting and reduces hydrocarbon emissions during coasting. See Fig. 2-9.

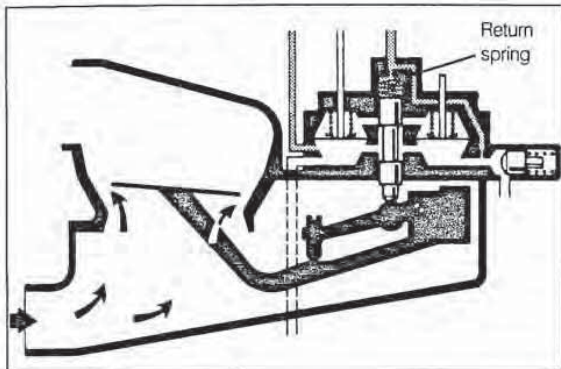


Fig. 2-9. Beginning in 1983, a small spring presses down to ensure control plunger follows sensor lever more closely.

Backfire Protection

The clearance between the edge of the sensor plate and the small part of the air-flow sensor funnel is very small, only about .10 mm. Because the plate effectively blocks the intake tract, any backfire in the intake manifold could build up reverse pressure and blow the ductwork, bend the sensor plate, or damage vacuum-operated systems.

To prevent damage in the event of a backfire, the air-flow sensor is designed with a secondary relief area in the funnel. See Fig. 2-10. Any backfire explosion in the manifold drives the sensor plate against its spring support and rubber bumper so that the pressure is vented around the edge of the plate. The sensor plate is driven past the zero position, down against its stop. (In downdraft sensors the plate is driven up against its stop).

KE Sensor-Plate Positions

Up until now, I've been talking about principles that apply to all continuous air-flow sensors. KE sensors operate in the same basic way as K-basic and K-lambda sensors: intake air lifts the air-flow sensor plate, which lifts the control plunger to meter fuel. But in KE, you'll find a big difference in the rest position of the control plunger due to some design changes. Because this difference affects restarting, it's important to know for chapter 6 when you'll be making checks of the air-flow sensor.

In K-basic and K-lambda, the control plunger rests on the lever when the engine is off (zero position); the sensor plate's rest position is determined by its stop. In contrast, KE is designed so that, at zero position, the plunger rests on an O-ring seal in the fuel distributor; there is a small amount of clearance between the plunger and the lever so the plunger seats firmly on the O-ring. See Fig. 2-11. This seals off fuel pressure more completely when the engine is off, and helps prevent vapor lock in the fuel lines.

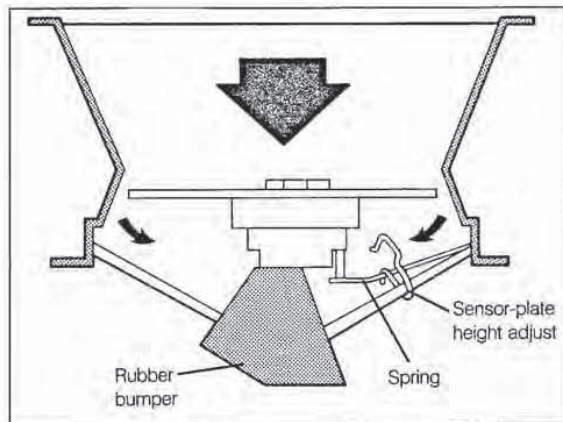


Fig. 2-10. In case of backfire, plate is pressed into second part of funnel relieving pressure in manifold.

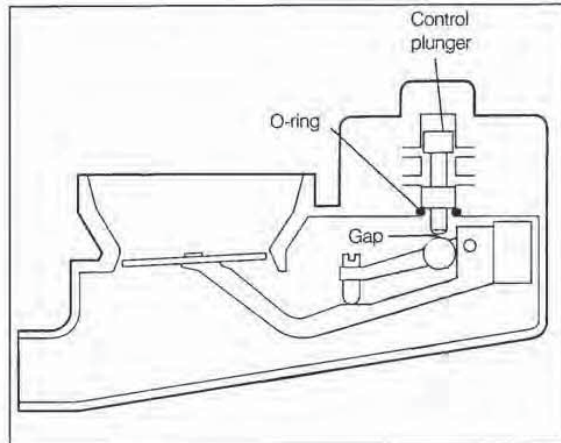


Fig. 2-11. KE control plunger rests on O-ring that seals in fuel pressure at base of plunger.

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This difference in KE means that there are actually two important KE sensor-plate positions. The first is the zero position as described above, where a wire-clip supports the sensor plate when the engine is off and there is clearance between the control plunger and the lever. The second is the basic position (and that's only in KE), the position of the plate in the air funnel when it is lifted so the lever just touches the control plunger. See Fig. 2-12.

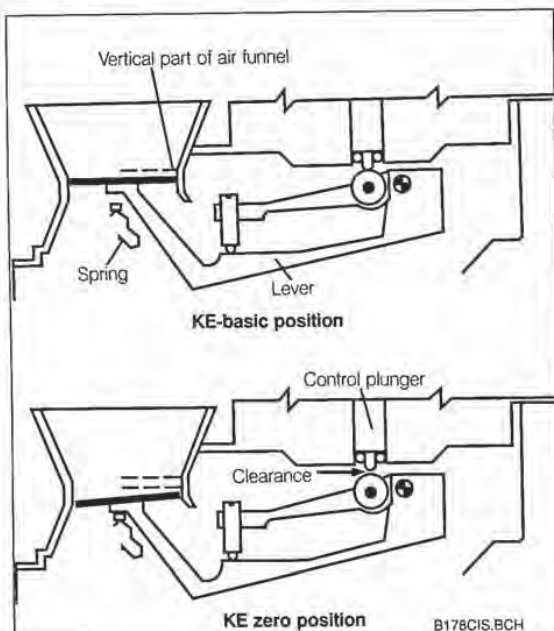


Fig. 2-12. In updraft KE basic position (top), sensor plate is at top of vertical part of air funnel (dotted line) and lever just touches control plunger. In zero position (bottom), plate rests on spring, and there is a gap between plunger and lever. You should be able to see all of the vertical part of funnel (dotted lines) around the sensor plate.

Incorrect clearance between the sensor lever and the control plunger will cause problems. If there is no clearance, the plunger will not seal against the O-ring, and residual fuel may dribble down into the mixture-control unit when the engine is off. This can cause flooding-type restart problems and, in a worst case, a potential fire hazard.

In contrast, if there is too much clearance between the sensor plate lever and the plunger you may experience a different start problem. During cranking, the air flow must lift the sensor plate a certain amount before the lever contacts the plunger to lift it and increase fuel flow. If there is excess clearance the lever will not lift the plunger soon enough for the air flow, upsetting the basic air-flow and fuel-metering function.

In chapter 6 you'll see how to check these important KE sensor plate positions. Also, remember the distinction between how updraft sensors and downdraft sensors operate: In updraft KE air-flow sensors, the sensor plate is lifted up from the zero position to the basic position; in downdraft air-flow sensors, the plate is pushed down from the zero position to the basic position.

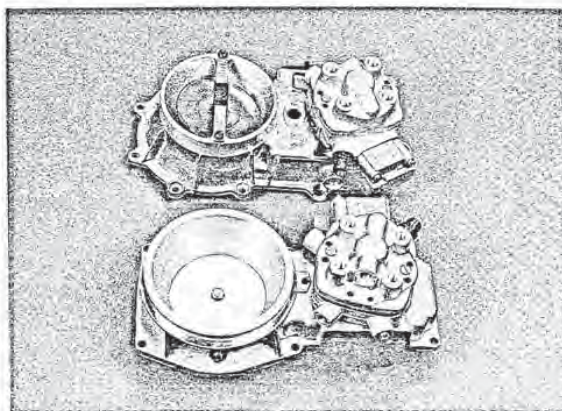


Fig. 2-13. KE-Jetronic air-flow sensors; downdraft (top) and updraft (bottom). Note that on downdraft sensors, sensor plate is angled.

Mixture (CO)

To ensure that the basic air-fuel mixture is in the best range for emission control, all continuous systems have a provision for mixture adjustment. Although this adjustment is made at idle, it affects the basic sensor-plate and control-plunger relationship over the entire range of operating conditions. For a given lift of the sensor plate, the lift of the control plunger is adjusted to change the amount of injected fuel, and therefore the air-fuel mixture. This adjustment is also known as the CO adjustment because the change in the air-fuel mixture changes the amount of CO (carbon monoxide) in the exhaust. The accuracy of the mixture adjustment is commonly checked by measuring exhaust CO.

You adjust mixture with the mixture-control screw, which is shown in Fig. 2-14. You can see that the air-flow sensor lever is actually two parts, and that turning the mixture screw in or out moves the mixture lever only. This moves the control plunger without changing the position of the sensor-plate lever or sensor plate.

For example, for a constant air flow at idle, turning the mixture screw clockwise pushes the mixture lever up. This lifts the control plunger further and more fuel is injected for the same air flow, enriching the mixture. If the screw is turned counterclockwise, the control plunger is lowered and the mixture is leaned. As you'll see in chapter 6, because the mixture screw is located in the air-flow sensor you'll need a special tool to reach it.

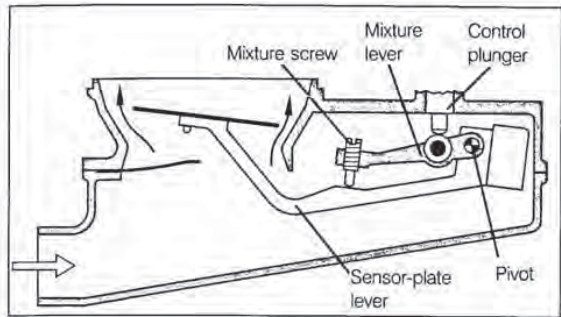


Fig. 2-14. Schematic view of air-flow sensor showing location of mixture-control screw.

2.2 Throttle Valve

The throttle valve regulates air flow into the engine. The more it is open, the greater the air flow into the engine. The throttle valve is downstream of the mixture-control unit, usually mounted on the intake manifold, and is controlled by the accelerator cable. The throttle valve does not control idle speed. This is done by a separate idle screw as described below.

Idle Speed

You adjust idle speed on continuous systems not by fine adjustment of the throttle valve, but by controlling a small amount of air that is allowed to bypass the throttle. This is more reliable since it's independent of accelerator-cable stretch or wear in the throttle valve mechanism.

The idle air bypass is regulated by the idle screw, as shown schematically in Fig. 2-15. The screw is usually on the throttle-valve housing. Turning the screw in or out changes the amount of bypass air. The screw is downstream of the air-flow sensor. Any change in bypass air results in a corresponding change in the amount of fuel injected, so idle speed adjustments do not affect the mixture adjustment.

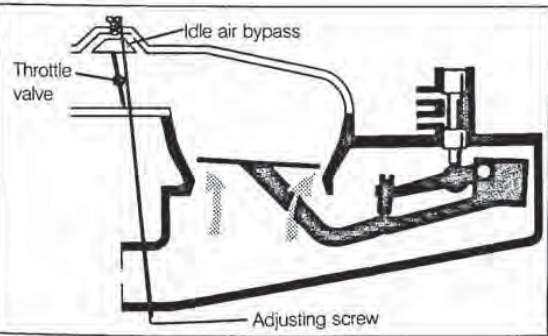


Fig. 2-15. Schematic view of air-flow sensor and throttle valve shows idle air bypass and adjusting screw.

3. FUEL SYSTEM

In continuous systems control of fuel pressure is extremely important, even more so than in pulsed systems. As you'll see, fuel pressure opens the fuel injectors, and the control systems manipulate fuel pressure to alter the basic air-fuel mixture when compensating for different operating conditions. It's vital that the fuel system not only supply adequate fuel for the amount of air the engine is using, but also that the fuel be under pressure, maintained and controlled within a narrow range.

The fuel system includes the fuel tank to store the fuel, the electric fuel pump to pressurize the fuel, the fuel accumulator to damp pressure surges in the system, the filter, the fuel distributor to meter and distribute the fuel, the pressure regulator to maintain primary system pressure, and the fuel injectors to atomize the fuel. See Fig. 3-1. The electric pump and the filter operate similarly to those used in pulsed systems. For a discussion of how they operate see chapter 3. Some cars have an additional electric low-pressure in-tank pump, called the pre-supply or transfer pump. It ensures delivery to the main pump without vapor lock.

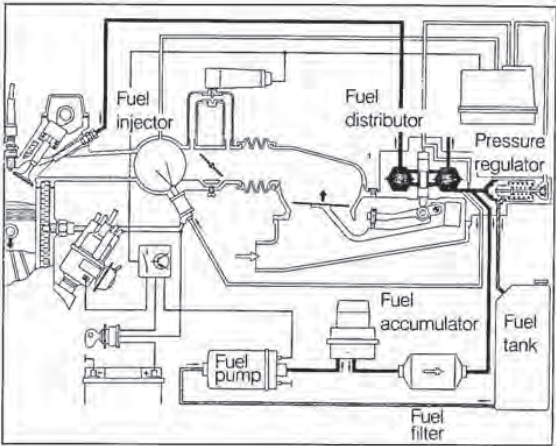


Fig. 3-1. Continuous injection fuel system. Supply components (fuel pump, filter) are generally similar to those of pulsed systems, with addition of accumulator. K-basic shown, K-lambda and KE systems similar.

3.1 Fuel Accumulator

Most continuous systems include a fuel accumulator, shown in Fig. 3-2, which damps fuel-pressure surges and holds residual pressure in the system when the engine is shut off. The accumulator's damping action protects the fuel distributor from the rapid build-up of fuel-pressure during startup, and reduces fuel pump noise when the engine is running. When the engine stops, the accumulator holds fuel pressure to help prevent vapor lock and improve hot restarts.

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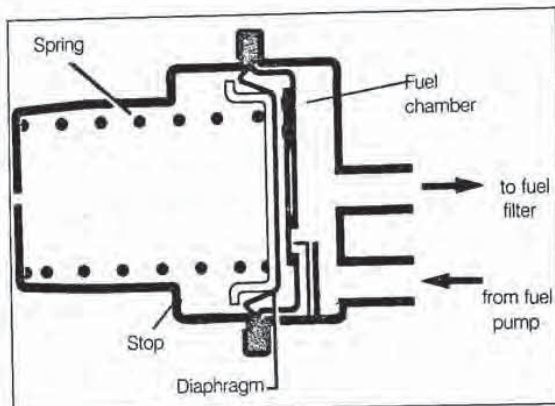


Fig. 3-2. Fuel accumulator. When engine starts, fuel chamber fills with fuel. Pump noise is dampened by the diaphragm. With engine off, accumulator spring maintains pressure in lines to help hot starts.

The main components of the accumulator are a spring and a diaphragm that separates a spring chamber and a fuel chamber. When the pump begins running, pressure builds in about 1 second as fuel fills the fuel chamber and presses the diaphragm against the stop. At pump shut-off, the pressure drops rapidly to about 2 bar (30 psi). See Fig. 3-3. This residual pressure is maintained by the force of the spring pressing against the diaphragm and the fuel in the fuel chamber. The accumulator holds pressure for a half hour or more to prevent vapor lock caused by fuel vaporization in the fuel lines of a hot engine.

3.2 Fuel Distributor

The fuel distributor is the part of the mixture-control unit that meters the fuel and then distributes it to the individual injectors. See Fig. 3-4. All fuel metering takes place in the center of the fuel distributor at the control plunger as it rises and falls. Secondary mixture control by the control systems to fine-tune the basic air-fuel mixture takes place through the manipulation of fuel pressures in the fuel distributor. The fuel distributor's role in fuel metering is discussed in **4. Fuel Metering**; the action of the control systems to further manipulate fuel pressures is discussed in **5. Control Systems**.

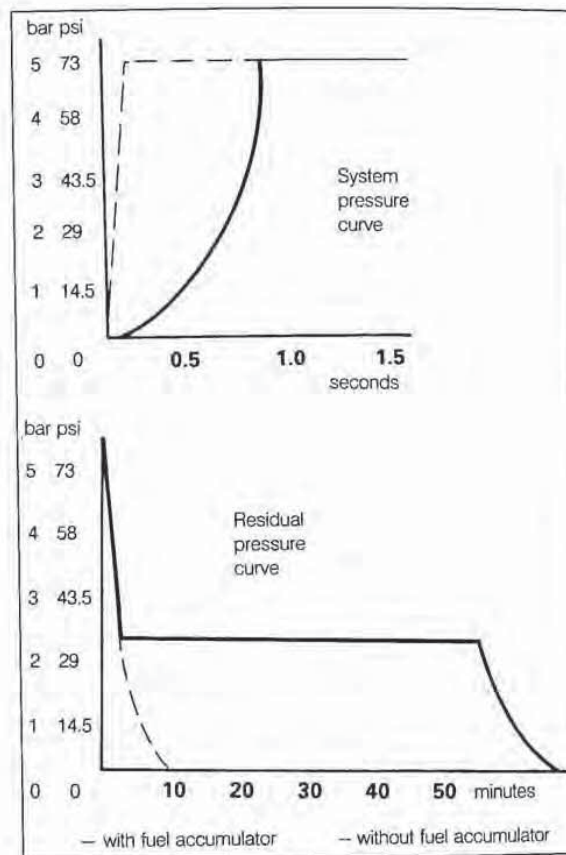


Fig. 3-3. Fuel pressure builds rapidly during cranking, damped by accumulator (**top**). After shut-off, pressure falls rapidly to close injectors, preventing fuel dribble at injector tips (**bottom**). Then accumulator maintains pressure in lines to aid hot starts. As engine cools over time, pressure falls—rate depends on minor leaks in lines and injectors.

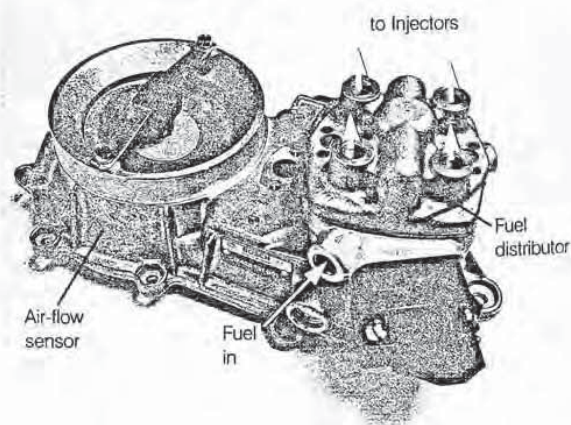


Fig. 3-4. Fuel distributor is part of mixture control unit; bolted to air-flow sensor. It meters and distributes fuel to the injectors.

Fuel System

3.3 System-Pressure Regulator

Continuous injection depends on fuel pressure to manipulate the air-fuel mixture, so that pressure must be closely regulated. The system-pressure regulator maintains system pressure (sometimes called primary pressure) in the fuel system at the specified level. There are two different types of pressure regulators, depending on the system. K-basic and K-lambda use a pressure relief valve located in the fuel distributor housing; KE systems use a separate diaphragm pressure regulator. Both regulate pressure by recirculating excess fuel back to the fuel tank.

K-Basic, K-Lambda

In K-basic and K-lambda, the system-pressure regulator is built into the fuel distributor. System pressure is set by spring force against the regulator relief valve. When the pump is turned on, fuel pressure builds until it overcomes spring pressure and opens the relief valve, returning excess fuel to the tank. See Fig. 3-5.

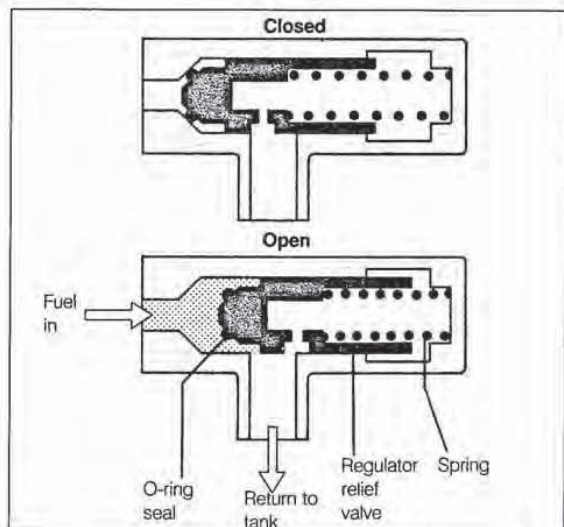


Fig. 3-5. Basic operation of K-basic and K-lambda system-pressure regulator. Fuel-pressure force overcomes spring force and opens regulating valve at specified pressure, returning excess fuel to the fuel tank.

There are actually two variations of the K-basic and K-lambda system-pressure regulator, depending on when the system was manufactured. The first one, shown above, was used until about 1978 and controls only system-pressure. Beginning about 1978, a new type of system-pressure regulator performs a second pressure-control function. See Fig. 3-6.

This slightly larger type includes what is known as a push valve. In the push-valve regulator, the opening of the relief valve also opens the push valve. The push valve controls the return of fuel from something called the control-pressure regulator. You'll see more about the control-pressure regulator in 5. **Control Systems**, but for now, all you need to know is that the push valve O-ring shuts off fuel return from the control-pressure regulator to better maintain residual system pressure. The difference between the two regulators will affect how you measure fuel pressure in chapter 6; you can tell the two apart by the position of the system-pressure regulator on the fuel distributor. See Fig. 3-7.

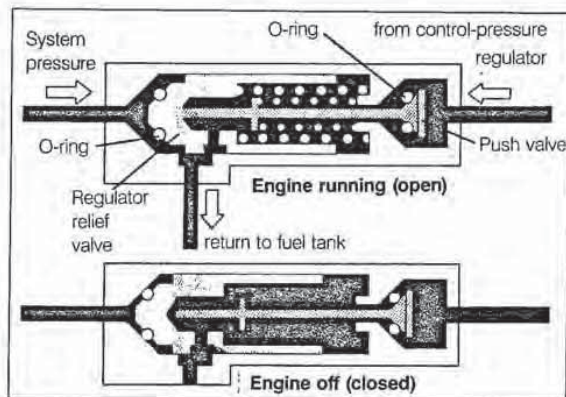


Fig. 3-6. Post-1978 K-basic and K-lambda system-pressure regulator with push valve. When engine is running, relief-valve plunger opens push valve. With engine off, larger spring closes relief plunger and smaller spring closes push valve, sealing control pressure in the system.

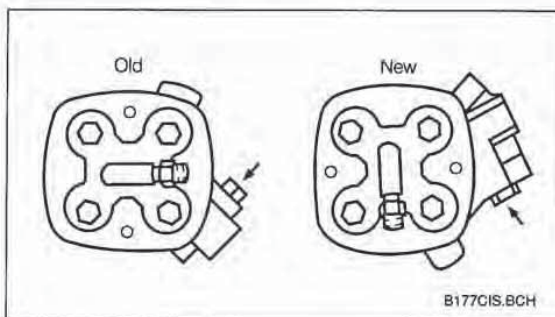


Fig. 3-7. K-basic and K-lambda system-pressure regulator (arrows) is built into the fuel distributor casting. Learn the difference between old (used before 1978) without push valve, and new with push valve.

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KE Systems

The KE system-pressure regulator is mounted outside the fuel distributor as shown in Fig. 3-8. System pressure is set by fuel-pressure deflecting a diaphragm. See Fig. 3-9. When the fuel pump is running, fuel pressure builds until it overcomes spring pressure in the regulator and moves the diaphragm. This opens the regulating valve to return excess fuel to the tank and maintain pressure at the specified level. The thinner return line carries fuel from the fuel distributor to the regulator; the thicker line supplies fuel from the pump.

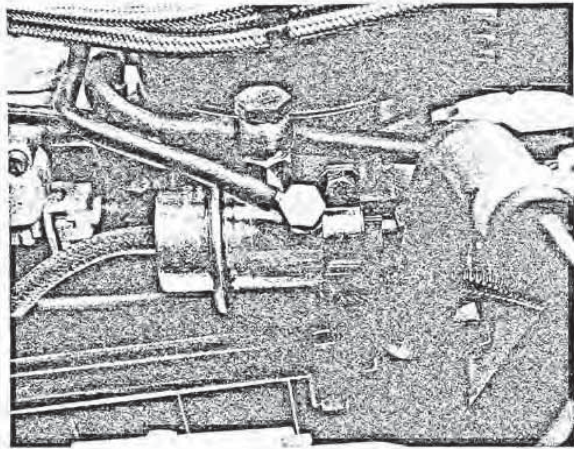


Fig. 3-8. KE pressure regulator looks like that of pulsed systems. It controls system pressure, and also controls return flow from the fuel distributor.

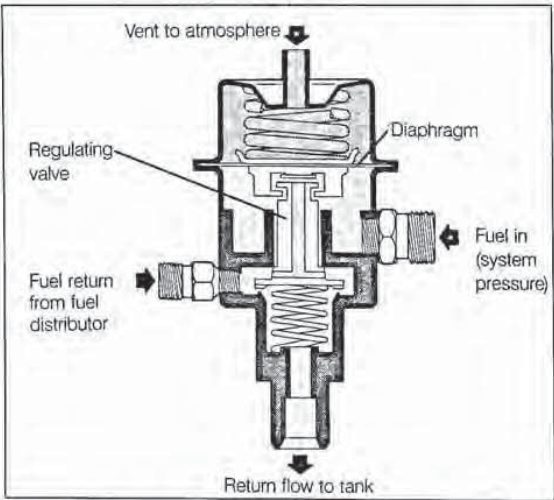


Fig. 3-9. KE fuel pressure regulator in open position.

Fuel System

3.4 Fuel Injectors

The fuel injectors used on continuous systems are mechanical. See Fig. 3-10. Pressure of the fuel delivered from the mixture-control unit overcomes spring pressure and opens the injector. Injector opening pressure is determined by the spring in each injector. There are no electric signals, and the injectors do not meter the fuel; they just continually inject fuel and atomize it. When an injector is working, you can hear a chatter as fuel pressure vibrates the open valve pins to atomize the fuel. Delivery stops when fuel pressure drops; the injector closes to keep fuel in the injector lines.

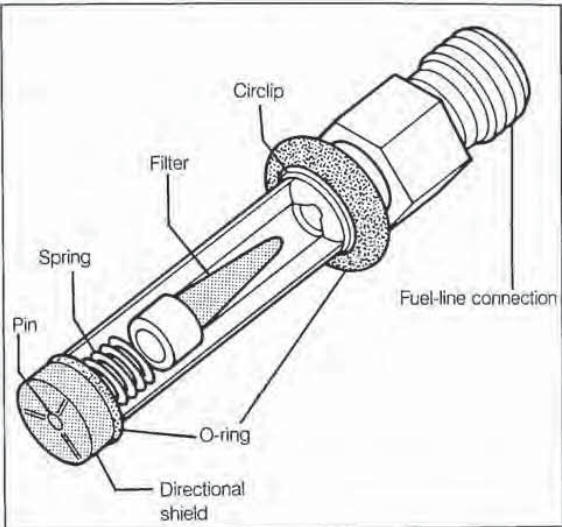


Fig. 3-10. Mechanical injectors are simple, no electrical connections. K-basic, K-lambda, and KE are all similar.

Air-Shrouded Injectors

Beginning in 1984, some KE systems have air-shrouded injectors to improve fuel atomization. Better fuel atomization means more efficient combustion. This saves fuel and reduces exhaust emissions. The injectors are mounted in a special air shroud in the intake manifold as shown in Fig. 3-11. At idle, lower manifold pressure at the injector tips induces air flow from upstream of the throttle to flow around the injected fuel stream.

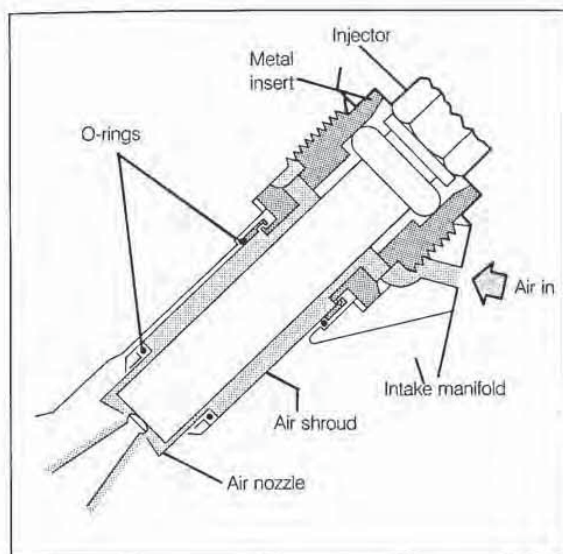


Fig. 3-11. Most KE injectors are air-shrouded to improve fuel atomization for smoother idle, better fuel economy and reduced emissions.

4. FUEL METERING

In continuous systems, all fuel metering takes place in the fuel distributor. This section describes basic fuel metering for all systems: matching a proportional amount of fuel to the air entering the engine to create the correct air-fuel mixture. This basic air-fuel mixture is then fine-tuned by the control system to compensate for different operating conditions. The control systems for each system are different; I'll describe them in detail in the next section, 5. **Control Systems**.

4.1 Basic Fuel Metering

Basic fuel metering occurs when air entering the engine lifts the sensor plate, which in turn lifts the control plunger in the fuel distributor, allowing fuel to flow to the injectors. See Fig. 4-1. You've already seen how the air-flow sensor measures air flow and lifts the plunger, now I'll show you just how the control plunger and fuel distributor turn that air-flow measurement into a proportional fuel quantity.

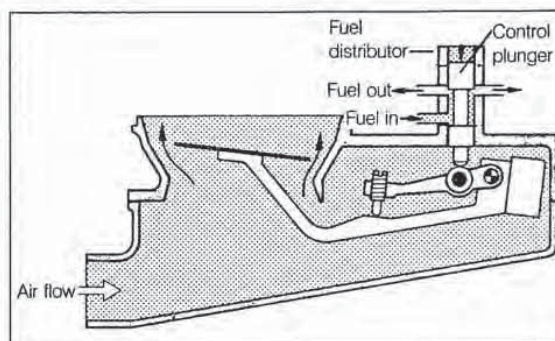


Fig. 4-1. Schematic view of mixture-control unit. Basic fuel metering begins when air-flow sensor lifts control plunger in fuel distributor, allowing fuel to flow to injectors.

Control Plunger Movement and Slit Size

The control plunger is mounted in the center of the fuel distributor, in a precision housing called the "barrel". See Fig. 4-2. The fuel pump supplies fuel at system pressure to the lower portion of the barrel. As the plunger is lifted, the fuel flows through upper slits to the injectors. See Fig. 4-3. There is one slit for each injector.

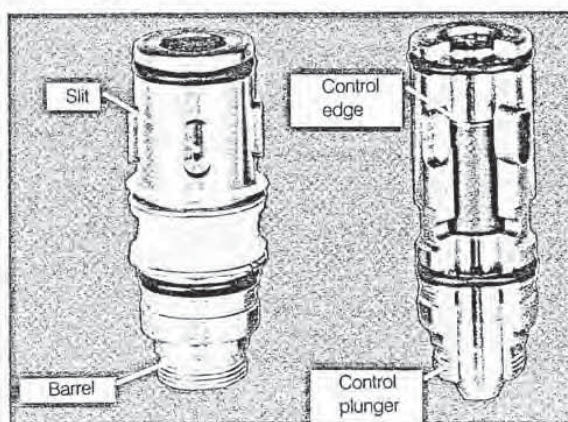


Fig. 4-2. The control-plunger and its barrel. Metering of fuel takes place at precision slit, one for each cylinder. Same for K-basic, K-lambda, KE.

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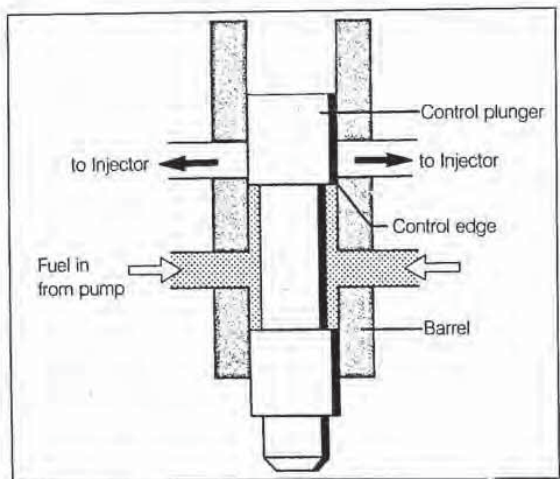


Fig. 4-3. Fuel flow through control-plunger barrel. As the plunger control edge rises, it uncovers the slits. Precisely sized slits are very narrow: approximately 0.2 mm (.008 in.).

The key to control-plunger fuel metering is the control edge of the plunger. This controls the amount that the upper slits are open, and therefore the amount of fuel that flows through the slits to the injectors. See Fig. 4-4. As the plunger is lifted in the barrel, the control edge of the plunger exposes more of each slit. Low air flow into the engine causes a small lift of the sensor plate and plunger; a small amount of each slit is exposed, delivering a small quantity of fuel through each slit. Increased air flow increases sensor-plate and plunger lift; more of each slit is exposed and fuel flow increases.

This relationship between the air flow, sensor plate, and control-plunger lift is linear: a doubling of air flow doubles plunger lift to meter proportional fuel through the slits.

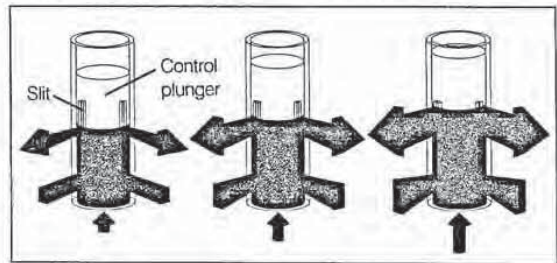


Fig. 4-4. The more the control plunger rises, the greater the flow of fuel through each slit.

Fuel Metering

Fuel Metering and Pressure Drop

Fuel flow to the injectors is influenced not only by the size of the exposed slit, but also by the pressure drop at the slit. Think of it this way: the pressure drop at the metering slits is the pressure differential between system pressure inside the slit pushing fuel out, and the lower pressure outside the slit in the fuel distributor. If the pressure drop changes for a given air flow and plunger lift, fuel flow through the slit also changes. For example, increased pressure drop forces more fuel to flow through the slit; fuel delivery increases.

Changing pressure drop at the slits causes problems with the linear relationship between air flow and fuel flow. When the control plunger rises, a more open slit changes the pressure drop and upsets the basic proportional relationship between air flow and fuel flow. So while increased air flow produces a linear increase in plunger lift, it does not necessarily provide a linear increase in fuel flow. At a certain point the change in pressure will cause the air-fuel mixture to be incorrect.

To hold constant pressure drop at the slits for the entire range of plunger lift, all continuous systems have something called Differential-Pressure Valves in the fuel distributor.

Differential-Pressure Valves and Pressure Drop

The differential-pressure valves maintain a constant pressure drop at the metering slits of the control plunger by reacting to the increased fuel flow that comes with a larger slit opening. There is one differential-pressure valve for each injector. They are mounted in chambers in the fuel distributor, and have a flexible metal diaphragm that separates the upper and lower halves of the chamber. See Fig. 4-5.

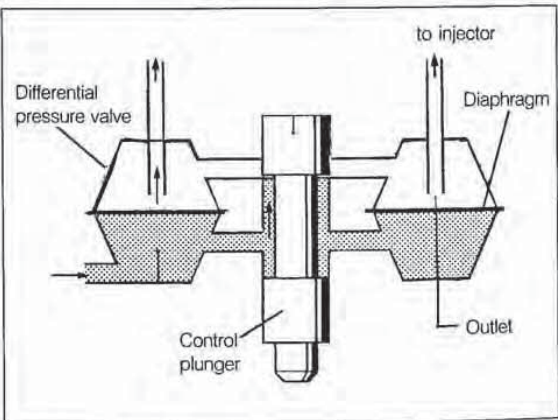


Fig. 4-5. Schematic view of fuel distributor shows location of differential-pressure valves. There is one valve for each fuel injector. Arrows indicate fuel flow through the control plunger and differential-pressure valves.

As the control plunger rises, and fuel flow into the differential-pressure valve increases, the fuel pressure deflects the diaphragm. This causes a proportional increase in the area of the fuel outlet to the injector and maintains the same pressure drop at the control-plunger slit. Even though there is more fuel flow through a more open slit, the differential between pressure inside the slit and pressure outside the slit is constant. Fuel flow is kept linear in direct proportion to the air flow lifting the plunger.

It may seem, because the deflection of the diaphragm enlarges the outlet to the fuel injectors, that fuel metering is a function of how close the diaphragm is to the outlet. But this is not the case. All fuel metering takes place at the control-plunger slits. The movement of the diaphragm acts only to maintain constant pressure drop—to eliminate pressure drop as a variable and maintain accurate metering to each injector, regardless of changing fuel flow rates.

As you'll see in 5. **Control Systems**, the differential-pressure valves play an important part in how the control systems fine-tune the basic air-fuel mixture. The control systems manipulate fuel pressure in the differential-pressure valves to change the pressure drop at the slits for a given plunger lift.

Comparison of Differential-Pressure Valves

In each differential-pressure valve the diaphragm separates the flow of injector fuel through the upper chambers from the fuel in the lower chambers. The upper chambers are separate so that the pressure-drop regulating function is independent for each injector and its line.

In K-basic and K-lambda, there is a spring which pushes down on the diaphragm to reduce the pressure in the upper chamber by 0.1 bar (1.5 psi). See Fig. 4-6. It is this pressure drop which causes fuel to flow out through the slits to the upper chambers and from there to the injectors.

In K-basic, the lower chambers are always at system pressure so the job of each diaphragm is to flex up and down to maintain the constant 0.1 bar pressure drop regardless of flow in the upper chamber.

In K-lambda systems, the electronic control systems operate to change the lower-chamber pressure. The flexible diaphragms still move up and down to equalize the pressures in between the upper and lower chambers, except as modified by the spring in each differential-pressure valve and by the change in lower-chamber pressure.

In KE systems, the control systems also change the lower chamber pressure, but the valves are different from K-lambda. The spring presses up from the bottom as shown in Fig. 4-7. The reasons for this difference are explained in detail in 5. **Control Systems**.

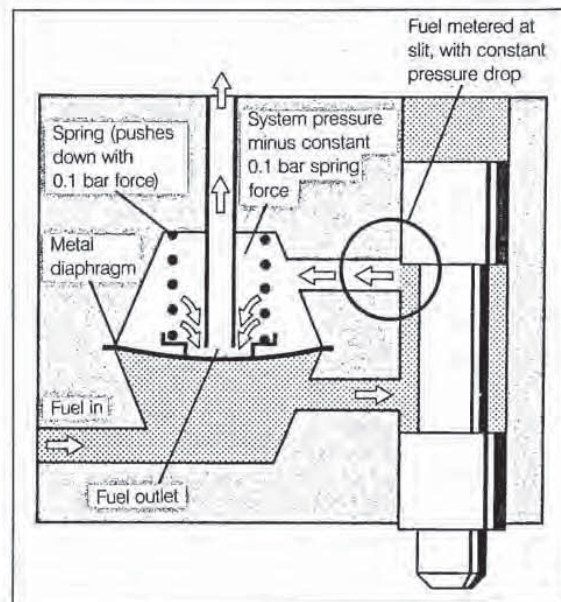


Fig. 4-6. Cross-section of K-basic differential-pressure valve in fuel distributor shows deflection of diaphragm from fuel flow. Accuracy of fuel metering is precise, based on constant pressure drop for each cylinder slit regardless of changing fuel flow rates.

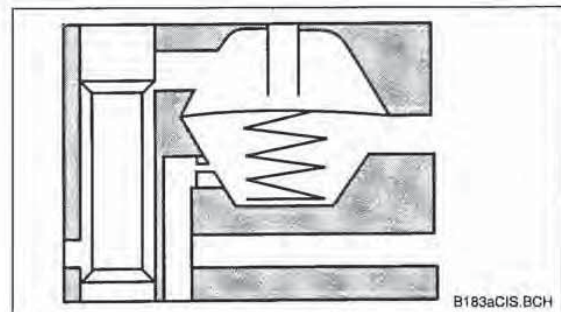


Fig. 4-7. In KE systems, spring in differential-pressure valve presses up against diaphragm. Flexible metal diaphragm still deflects with fuel flow, as modified by lower-chamber pressure.

Summary of Basic Fuel Metering

To briefly summarize basic fuel metering of continuous systems: Air flow entering the engine lifts the sensor plate and, in turn, the control plunger in the fuel distributor. Fuel-pressure counterforce applied to the top of the plunger balances the force of the air entering the engine and stabilizes plunger and sensor-plate movement. As the control plunger rises, its control edge uncovers the metering slits in the plunger barrel. As the slits open, fuel flows through the differential-pressure valves and out to the injectors. Fuel pressure opens the injectors, and the injectors atomize the fuel.

Fuel Metering

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Because of the direct mechanical link between the air-flow sensor lever and the control plunger, the lift of the plunger and the amount of fuel metered through the slits is proportional to air flow into the engine. To ensure that the air-fuel ratio is proportional over the entire lift of the plunger, the differential-pressure valves maintain a constant pressure drop at the control-plunger metering slits.

5. CONTROL SYSTEMS

In 4. **Fuel Metering**, I've described the basic fuel metering function of the air-flow sensor and the fuel distributor—the basic matching of fuel and intake air in the proper proportions. As I've described in chapter 2, modern fuel injection systems must make even finer adjustments to the mixture to maintain the stoichiometric air-fuel ratio and to compensate for the demands of different operating conditions.

This section describes how control systems manipulate fuel pressures in the system to fine-tune the basic air-fuel mixture. For any given air flow the basic fuel metering system creates the basic air-fuel mixture, and the control systems enrich or lean the basic mixture for more precise control of fuel metering.

There are two methods that the control systems use to adjust the basic mixture—changing slit size, and changing pressure drop at the slits. Later, you'll see how the control systems of each of the three continuous systems, K-Basic, K-Lambda and KE, apply these methods in different ways.

Changing Slit Size

The first method of adjusting fuel metering is to change the position of the control plunger for a given air flow by changing the counterforce on the plunger. You've seen how the fuel pressure counterforce is used to oppose the lift of the control plunger (against the air-flow force). Reducing the counterforce allows the sensor plate to lift the plunger higher for the same air flow, exposing more of the slits and allowing more fuel to flow for a richer mixture. Increasing the counterforce reduces plunger lift for a given air flow, exposing less of the slits and resulting in less fuel flow for a leaner mixture. This control is a fine adjustment to the basic movement of the plunger by the air-flow sensor; I'll refer to it as "changing slit size."

Changing Pressure Drop

The second method the control systems use for mixture adjustment is the manipulation of pressures on either side of the differential-pressure valves. This changes the deflection of

the diaphragm and, in turn, changes the pressure drop at the slit. Remember, pressure drop here is the difference between pressure inside the slit and pressure outside the slit. For any given air flow and plunger lift, a change in the pressure drop changes the amount of fuel flowing through the slit, enriching or leaning the mixture. This control is in addition to the normal action of the differential-pressure valves; I'll refer to it as "changing pressure drop."

5.1 K-Basic—Changing Slit Size

K-basic systems use fuel under pressure as a hydraulic control fluid to maintain counterforce on the control plunger. This is called control pressure. To fine-tune the basic fuel metering, K-basic systems vary control pressure to change the counterforce on the control plunger. This changes the lift of the plunger and the size of the metering slit for a given air flow. The K-basic control system does not affect the differential-pressure valves. They deflect in a normal way to keep the pressure drop at the control-plunger metering slits constant.

Control-Pressure

As shown in Fig. 5-2, control pressure is applied through passageways in the fuel distributor. A flow restrictor admits fuel pressure from the system-pressure side to the control-pressure side without delivering full system pressure to the top of the plunger. A damping restrictor admits control-pressure force to the top of the plunger in order to balance the air-flow force of the air-flow sensor plate. The damping restrictor is large enough to permit transfer of pressure, but small enough to dampen any possible oscillation of the sensor plate and plunger which could result from pulsating air flow.

Control-Pressure Regulator

The control-pressure regulator adjusts control pressure by returning excess fuel from the control pressure circuit to the fuel tank. See Fig. 5-3. If more fuel is bled off to the tank, control pressure is reduced. If less fuel is bled off, control pressure is increased.

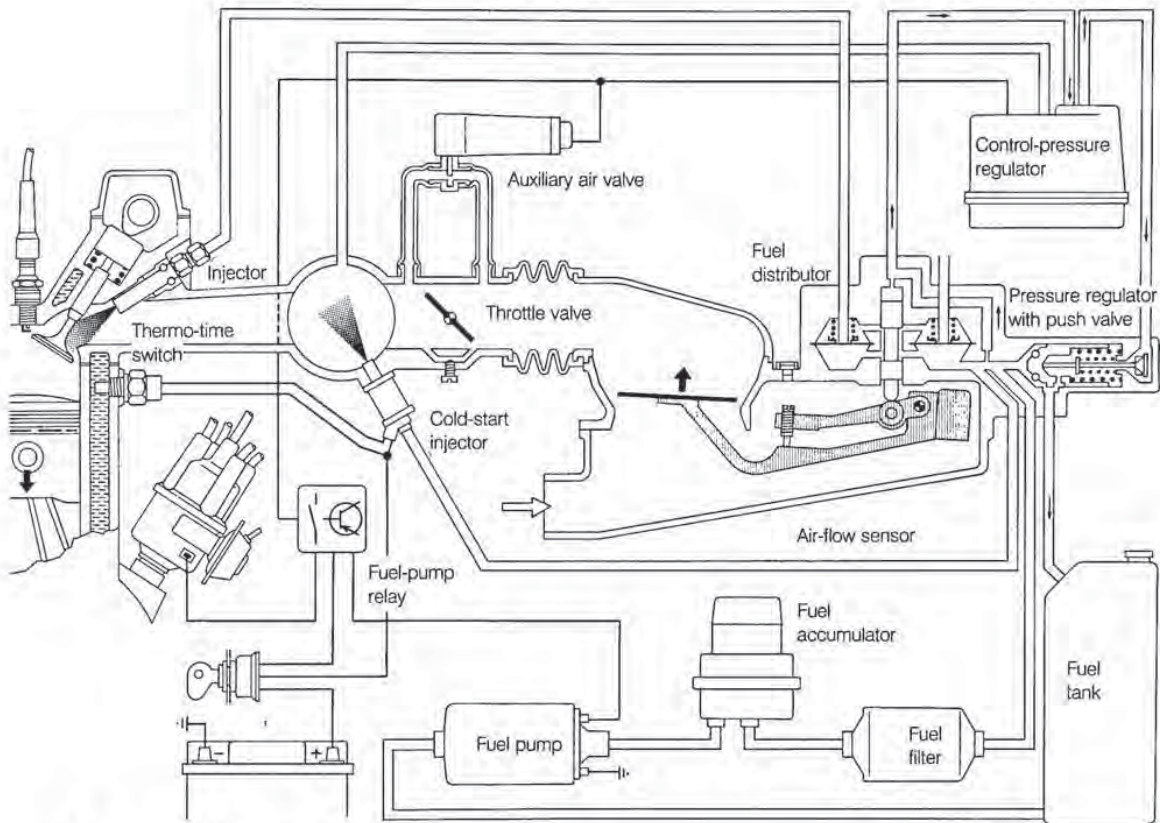


Fig. 5-1. Schematic of K-basic system shows all of the components. Control-pressure regulator and its compensation of the basic air-fuel mixture is described in this section.

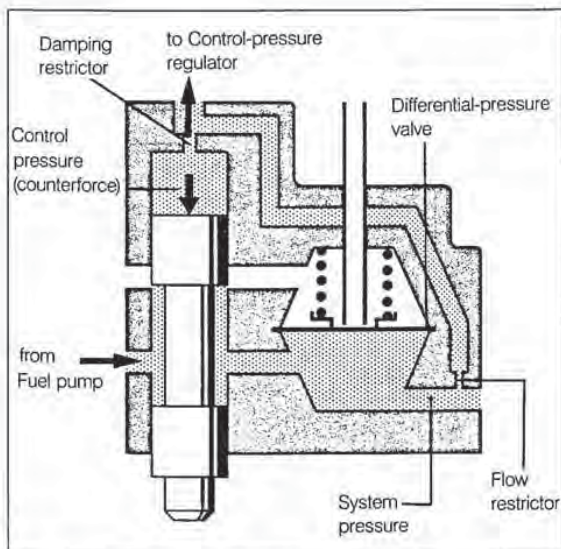


Fig. 5-2. Relationship of control pressure and system pressure in K-basic. System pressure is constant, control pressure varies.

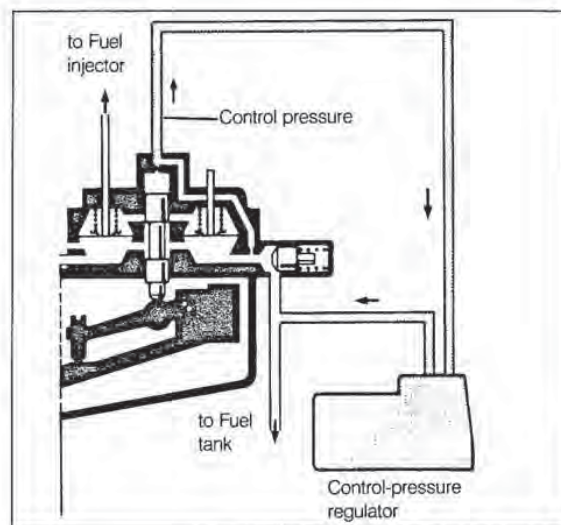


Fig. 5-3. Control pressure regulator adjusts control-pressure counterforce on the plunger by bleeding off fuel to the fuel tank.

Control Systems

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As shown in Fig. 5-4, the control-pressure regulator consists of a valve mounted on a bimetal arm. The arm is made up of two different metals of different expansion rates. It bends one way when it is cold and the other way when it is warm, changing control pressure in response to temperature.

When cold, the natural shape of the bimetal arm pulls the diaphragm away from the valve. As a result, the valve:

- increases fuel return to the tank, and
- reduces control pressure

As the regulator warms, the bimetal arm bends the other way. The spring closes the valve, which:

- decreases fuel return to tank, and
- increases control pressure

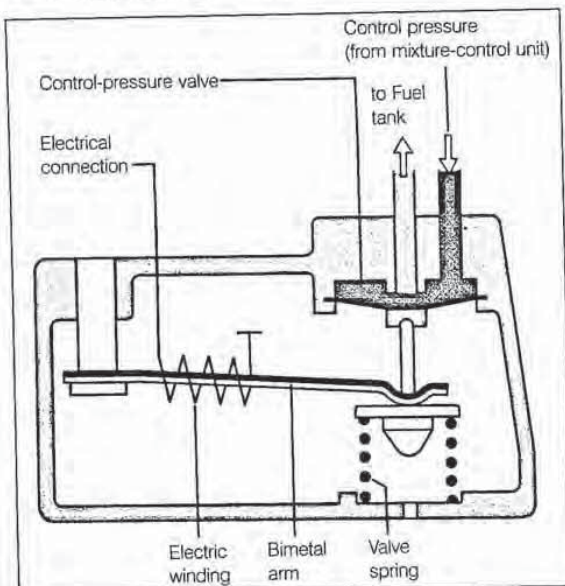


Fig. 5-4. K-basic control-pressure regulator. When cold, bimetal arm bends down. This increases fuel return and lowers control pressure, reducing counterforce on the control plunger. When warm, spring lifts diaphragm to increase control pressure and counterforce on the plunger.

Control Pressure and Mixture Adjustment

Remember that the basic action of the fuel-pressure counterforce on the plunger is to balance the force of the air flow entering the engine, so that the movement of the sensor plate and plunger is opposed. If this counterforce is changed, but the air flow stays the same, the amount that the sensor plate and plunger lift will also change.

The primary action of the control-pressure regulator is to enrich the basic mixture for cold operating conditions by reducing the control-pressure counterforce on the control plunger. As you saw above, when the control-pressure regulator is cold, control-pressure counterforce on the plunger is low. The plunger is able to rise higher for a given air-flow force, uncovering more of the metering slits so more fuel flows for the same amount of air. This enriches the mixture, improving cold driveability.

As the control-pressure regulator and its bimetal arm warm up, control-pressure increases. This increases counterforce on the plunger and it is forced lower for a given air-flow force. This reduces the size of the slits and leans the mixture. The regulator eventually warms to the point where it no longer compensates the mixture for cold conditions; only the basic sensor-plate lift of the control plunger determines the mixture.

A typical control pressure at freezing temperatures might be 1 bar (14.5 psi), and warm control pressure 3.5 bar (51 psi). As you'll see in chapter 6, measuring control pressure is the best way to check the operation of the regulator as pressures change with temperature.

The control-pressure regulator is usually located on the engine block, as shown in Fig. 5-5, so that engine-block temperature can affect the position of the bimetal arm. The regulator is often buried and hard to find. Look for two fuel lines to the fuel distributor: one is the control-pressure line to the regulator, and one returns fuel to the tank. In pre-1978 systems, return fuel flows uncontrolled through a "tee" into the return line from the system-pressure regulator. In 1978 and later, return fuel flow is controlled by the push valve, through the system-pressure regulator and back to the tank. See earlier Fig. 3-7.

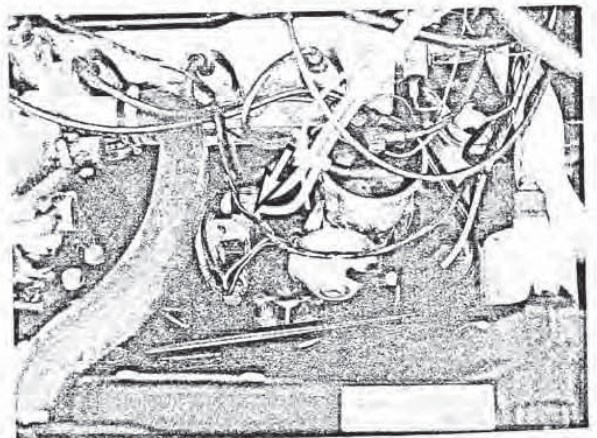


Fig. 5-5. Control-pressure regulator (arrow) is often buried, located on the block to react to engine temperature. Look for two lines from the mixture-control unit.

After a cold start, fuel enrichment needs to be cut back in one or two minutes, but the engine block might take 10 minutes to warm up to the point where it affects the bimetal arm in the control-pressure regulator. To insure that the mixture is not enriched for too long, an electric heating coil warms the arm when the ignition is turned on. Warm-up needs are different for each car model, so do not interchange regulators.

Additional Control-Pressure Compensations

The control-pressure regulator was originally called the warm-up regulator (WUR), because in its early applications, warm-up compensation was its only job. In some cars, control-pressure changes are also used for other reasons; to enrich the mixture during full-load operation or when under boost from a turbocharger, or to lean the mixture for altitude compensation.

For load compensation, the special control-pressure regulator has a second diaphragm which responds to engine load by sensing intake manifold pressure. See Fig. 5-6. High manifold pressure from an open throttle or from turbocharger boost influences the diaphragm and lowers control pressure. Lower control pressure allows greater plunger lift, more open slits, and greater fuel flow for a richer mixture. You can recognize these special control-pressure regulators by the vacuum-hose connection to the intake manifold, and by the extra chamber along the bottom of the regulator.

At part-throttle, when little enrichment is needed, manifold pressure is less than atmospheric pressure in the lower chamber of the diaphragm. This raises the diaphragm to add its spring pressure to the control-pressure valve. Control pressure is high, and there is little additional lift of the control plunger to enrich the mixture.

Altitude compensation is provided by an aneroid chamber at the bottom of the regulator. This chamber expands as the air gets thinner at higher altitudes; this in turn acts on the control-pressure valve to increase control pressure and lean the mixture.

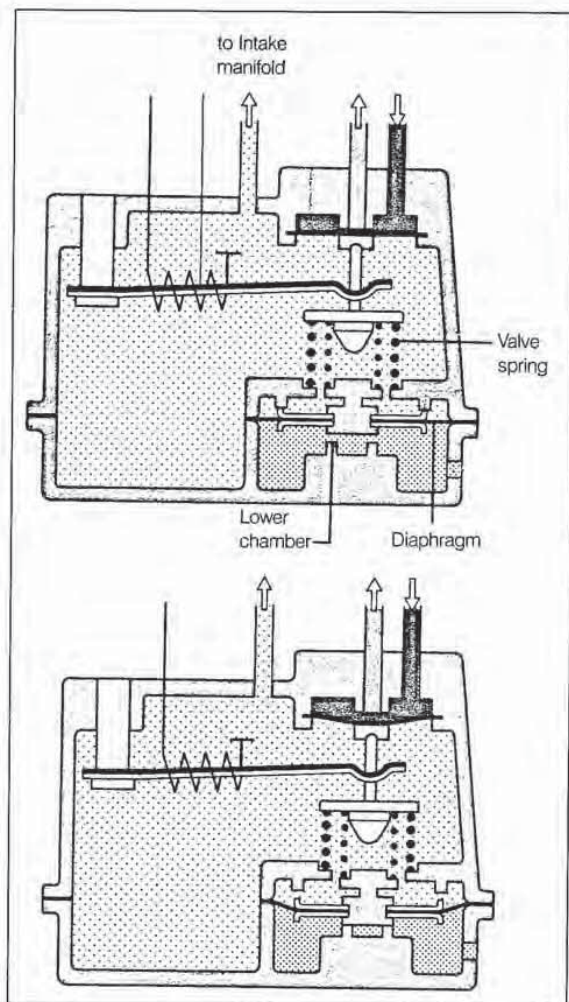


Fig. 5-6. Full-load control-pressure regulator on some K-basic and K-lambda systems has vacuum connection to intake manifold so control pressure is modified according to manifold pressure. Full-load or turbocharger-boosted manifold pressure (**bottom**) presses down on lower diaphragm to reduce control pressure and enrich mixture.

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5.2 K-Lambda — Changing Slit Size and Pressure Drop

K-lambda control systems adjust the basic air-fuel mixture by a combination of two ways. The first is by changing slit size for a given air flow. This is done just as in K-basic, by the control-pressure regulator, primarily for cold running.

The second method of adjusting the basic air-fuel mixture is by changing the pressure drop at the control-plunger slit so that fuel flow changes for a given plunger lift. This is done by manipulating pressures in the differential-pressure valves. Pressure in the valves' lower chambers is controlled by the Lambda Control System, in response to the signals from a lambda sensor in the exhaust system.

K-Lambda Differential-Pressure Valves and Mixture Adjustment

As you saw earlier, the K-basic differential-pressure valves hold the pressure drop constant at the metering slits of the control plunger. The deflection of the valve diaphragm increases with fuel flow for this pressure-drop function. If air flow and plunger lift stay the same but the deflection of the diaphragm is changed for some other reason, the pressure drop, and therefore the amount of fuel flowing through the slits, will also change.

For example, with a given plunger lift and fuel flow through the slits the pressure drop at the slits is a constant. But if the lower-chamber pressure of the differential-pressure valves is lowered, the diaphragm will deflect further. This extra deflection of the diaphragm decreases pressure in the upper chamber and increases the pressure drop at the slits; more fuel flows for the same plunger lift, enriching the mixture.

K-lambda control systems use this method to adjust air-fuel mixture. The lower-chamber pressure of the differential-pressure valves is not system pressure, as in K-basic. The pressure in the lower chambers, and therefore the pressure drop at the slits, is controlled by a separate pressure circuit which is in turn controlled by the lambda control system. Fuel is admitted to the lower chambers through a restrictor, and flows back to the tank through the lambda valve and the fuel return lines. In that way, the pressure of all lower chambers is controlled by the lambda valve.

Lambda Control System

The lambda control system includes a lambda sensor, a lambda electronic control unit, and a lambda control valve. See Fig. 5-7. The lambda valve (sometimes called a frequency valve, or timing valve) looks similar to a pulsed fuel injector, as shown earlier in Fig. 1-5. It opens and closes in a similar manner, but its opening and closing does not meter fuel. Rather, the amount of time the valve is open controls the pressure in the lower-chambers of the differential pressure valves. This in turn changes upper-chamber pressure to change the pressure drop and change enrichment.

Control Systems

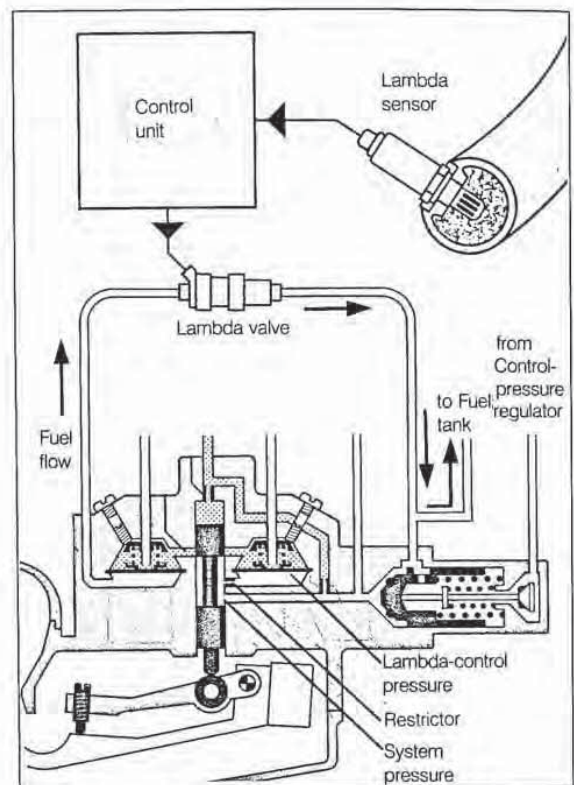


Fig. 5-7. In addition to K-basic control-pressure regulator, K-lambda control adds lambda sensor (or oxygen sensor), control unit, and lambda valve. Note additional fuel connection to pressure regulator.

The opening of the lambda valve is controlled by the electronic control unit, which monitors the signal from the lambda sensor (also known as the oxygen sensor.) The lambda sensor sends a signal to the control unit which is based on the oxygen content in the exhaust. The control unit then operates the lambda valve to control lower-chamber pressure.

The lambda valve is a solenoid valve which is either open or closed. The control unit sends on-off voltage pulses to the lambda valve. The frequency of these pulses determines the amount of time the valve is open and, therefore, the amount of fuel that is returned to the fuel tank. The on-off cycle of these pulses is known as the duty cycle. Duty cycle is measured on a scale of 0 to 100%. When the duty cycle is 50%, that means the lambda valve is open 50% of the time and closed the rest of the time.

Duty cycle can also be measured using a dwell meter scale of 0 to 90°. If you read a 50% duty cycle on a dwell meter set to the 4-cylinder scale, it would read 45° (50% of 90°).

Lambda Control and Changing Pressure Drop

When the lambda valve's duty cycle increases so that it is open longer and returning more fuel to the tank, lower-chamber pressure is reduced. The differential-pressure valve diaphragms deflect further, reducing upper-chamber pressure. This increases the pressure drop at each metering slit and more fuel flows through the slits for any given plunger lift. In short, the greater the duty cycle, the richer the mixture.

On the other hand, reduced duty cycle means less fuel bleeds off from the lower chamber; that increases chamber pressure and decreases deflection of the diaphragm. This reduces the pressure drop and fuel flow at the slits. So, less duty cycle means a leaner mixture. See Fig. 5-8.

Lambda Closed-Loop Control

The control of enrichment of the basic mixture by the lambda-control system is closed-loop, based on the signal from the lambda sensor. The control system continuously corrects the air-fuel mixture for a given plunger lift so that the mixture is held near the ideal, stoichiometric ratio necessary for catalytic converter operation.

As exhaust gas passes the lambda sensor, oxygen-content signals are sent to the lambda control unit. The control unit changes the duty cycle of the lambda-control valve to change pressure drop at the slits and adjust the mixture. The resulting change in exhaust-gas oxygen content changes the lambda-sensor signal. The control unit senses the change and continuously changes the duty cycle of the lambda valve. The cycle is continuous. See Fig. 5-9.

The oxygen content of the exhaust is continuously changing, so the lambda-control system averages to achieve the ideal mixture. It tends to correct to either side of the stoichiometric ratio, but always in a very narrow range. For more on closed-loop systems and the operation of the lambda sensor, see chapter 3.

Lambda Thermoswitch

Because lambda sensor operation depends on high temperature, the system operates open-loop before the sensor warms up. This can cause driveability problems and increased exhaust emissions due to imprecise mixture control. To correct this, many cars have a lambda thermoswitch, located in the coolant (or on the cylinder head of air-cooled Porsches) to give the control unit an additional input and insure proper fuel metering during engine warm-up.

When the engine is cold, the thermoswitch is closed. The control unit sends a fixed, slightly-rich duty-cycle signal of 60% to the lambda control valve. When the thermoswitch warms enough to open, the control unit sends a fixed middle signal, 50% duty cycle. When the lambda sensor reaches operating temperature so its signals are valid, the control unit switches to

closed-loop operation. Remember, in closed-loop the duty-cycle signals are constantly changing, cycling back-and-forth between about 45% and 55%, so that the air-fuel ratio is maintained near stoichiometric; lambda (λ) = one.

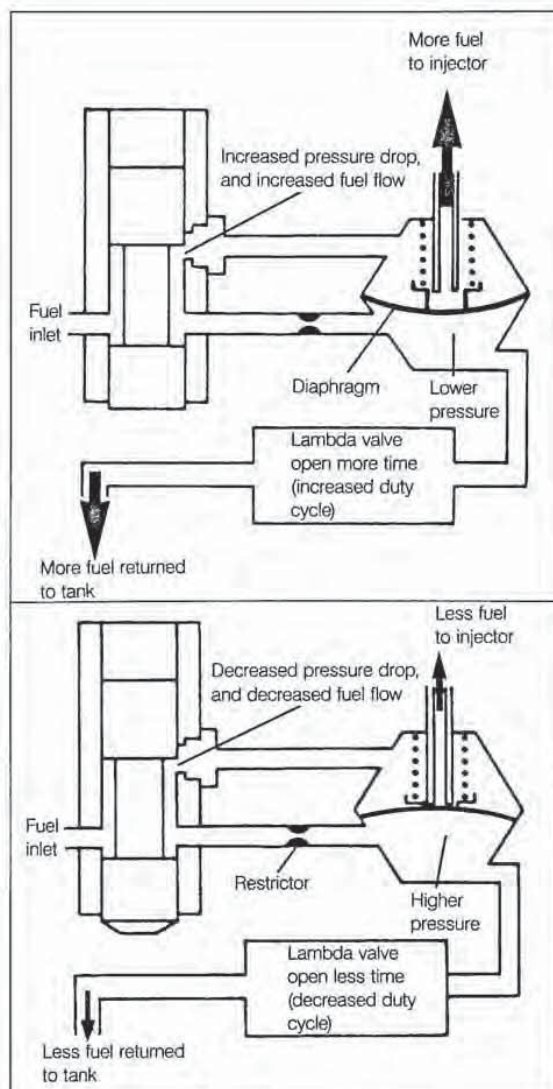


Fig. 5-8. K-lambda valve adjusts mixture by changing pressure drop at the metering slits. **Top:** More open valve returns more fuel, decreases lower and upper chamber pressure, and increases pressure drop and fuel delivery at slits, enriching the mixture. **Bottom:** Decreased opening of valve decreases fuel return, increases lower and upper chamber pressure, and decreases pressure drop and fuel delivery at slits, leaning the mixture.

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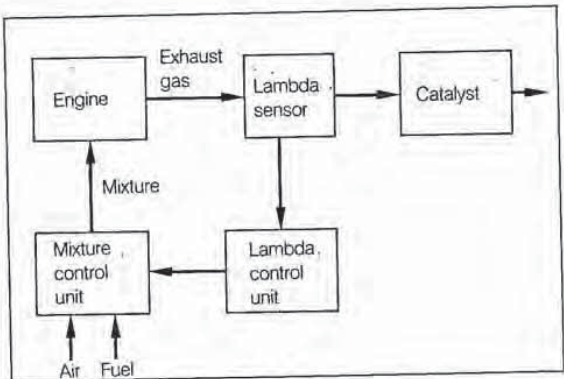


Fig. 5-9. When K-lambda operates closed-loop, the lambda sensor in the exhaust signals oxygen content to the lambda control unit. Signals to the lambda valve on the mixture-control unit change the air-fuel ratio to achieve stoichiometric mixture as burned in the engine.

5.3 KE Systems—Changing Pressure Drop

The KE control system adjusts the basic air-fuel mixture in only one way, by changing pressure drop at the control-plunger slits. KE systems do not have a control-pressure regulator or lambda-control valve. Instead, these controls are replaced by the KE control system—a series of sensors similar to those used in pulsed fuel injection, a control unit to monitor those sensors, and a pressure actuator on the fuel distributor, operated by the control unit.

For any given air flow, slit size in KE systems is governed only by the basic fuel metering—by the lift of the sensor plate. The KE control system changes pressures in the chambers of the differential-pressure valves, and therefore pressure-drop at the slits, to handle all adjustments to the basic air-fuel mixture to compensate for warm-up, emission control demands, and all other operating conditions.

On KE systems, the counterforce on the plunger that balances the air-flow force is system pressure, which is constant. So for any given air flow, plunger lift and slit size is constant. See Fig. 5-10. That's in contrast to K-basic and K-lambda, where reducing control pressure allows the plunger to rise further for a given air flow, increasing slit size to increase fuel delivery.

KE Differential-Pressure Valves and Separate Fuel Flows

In order to achieve more accurate pressure control by the KE control system, there are two fuel flow paths into the chambers of the differential-pressure valves. See Fig. 5-11. In one path, fuel enters the control-plunger barrel at system pressure. It then flows through each slit into each separate upper chamber at reduced pressure, and out to the injectors. I'll call this injector fuel. The basic rate of injector fuel flow is determined by the lift of the control plunger by the air-flow sensor, just as in the other systems.

Control Systems

In the other path, fuel at system pressure first flows to something called the pressure actuator. Fuel then flows at reduced pressure through the lower chambers and a restrictor and back to the fuel tank. I'll call this actuator fuel. The fixed restrictor controls the rate of flow out of the lower chambers. The variable pressure actuator controls the amount of fuel throughflow passing into the lower chambers, and therefore controls lower-chamber pressure and pressure drop at the slits. The operation of this control system is in addition to the basic fuel metering of the control plunger.

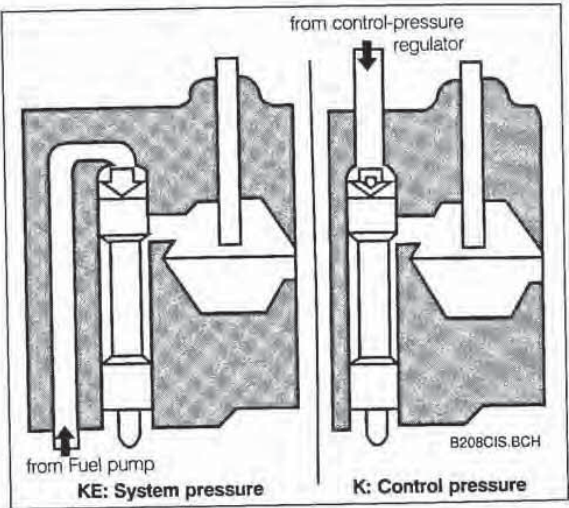


Fig. 5-10. KE meters with constant system pressure on the control plunger, so for any given air flow plunger lift is constant and slit size stays the same.

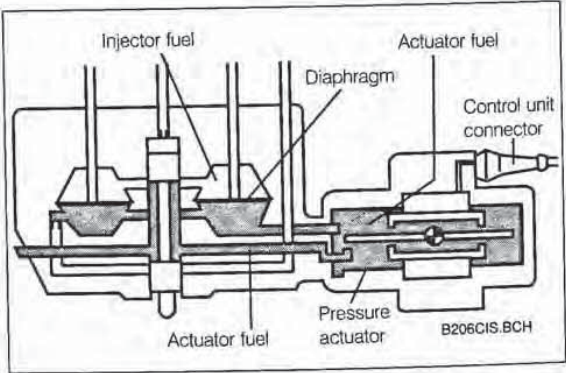


Fig. 5-11. KE injected fuel flow through each upper chamber is separated from actuator fuel flow below the diaphragm, which is spring loaded from below. KE actuator fuel flows continuously through the lower chambers. This throughflow is controlled by the pressure actuator.

KE Differential Pressure and Pressure Drop

In KE systems, the pressure drop at the slits, and therefore adjustment of the basic fuel metering, is controlled by the pressure drop at the entrance to the pressure actuator. This is also known as the Differential Pressure, the difference between actuator fuel pressure in the lower chambers and system pressure entering the pressure actuator.

The differential pressure directly affects the deflection of the differential-pressure valve diaphragms and so controls the pressure drop at the slits. Remember, by changing the pressure drop at the metering slits of the control plunger, fuel flow is changed for a given air flow and slit size.

The differential pressure is controlled by changing the flow of actuator fuel through the lower chambers. This control of throughflow is by the pressure actuator at its inlet. See Fig. 5-12.

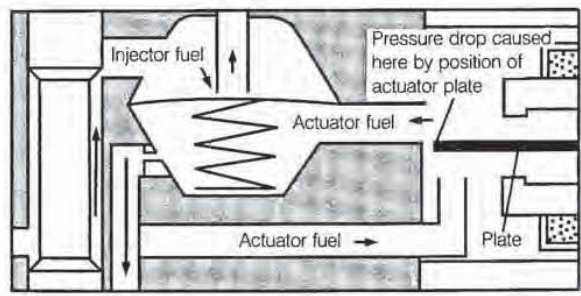


Fig. 5-12. In KE systems, pressure drop at the slits is related through the diaphragm to pressure in the lower chamber. The differential pressure—the difference between system pressure and lower-chamber pressure—determines the pressure drop.

Pressure Actuator

The pressure actuator is part of the mixture-control unit that controls actuator fuel flow through the lower chambers. For any given air flow and its related control-plunger slit opening, the actuator compensates the mixture by changing actuator fuel flow to change the differential pressure. The actuator is shown mounted on the fuel distributor in Fig. 5-13.

The key to the operation of the pressure actuator is the small plate valve that controls fuel throughflow. See Fig. 5-14. A small electromagnet causes the plate to move closer to or farther away from the fuel inlet to the actuator. For example, fuel flows to the actuator inlet at system pressure. Increased current flow through the electromagnet increases the magnetic force and

pulls the plate closer to the inlet. This reduces the flow and pressure of the actuator fuel in the lower chambers, changing the differential pressure. The actuator plate valve is controlled by the electronic control unit, as you'll see later. The valve is very small so that it can move rapidly in response to changing engine conditions.

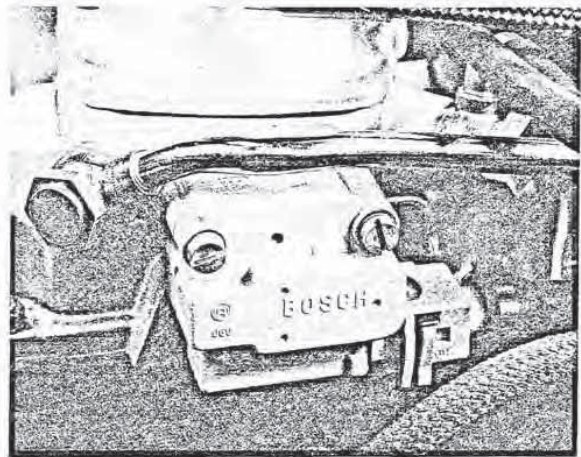


Fig. 5-13. KE pressure actuator controls mixture by controlling flow of actuator fuel through the lower chambers.

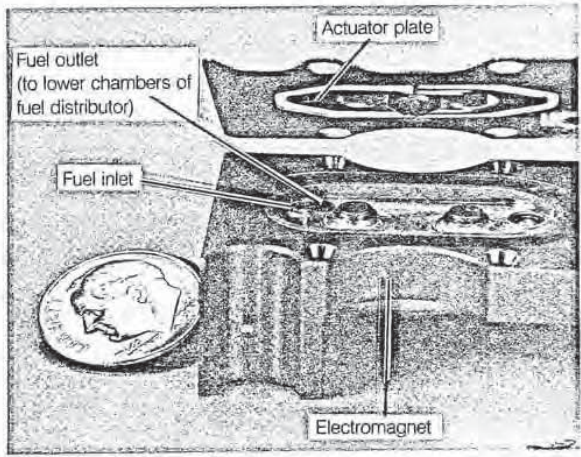


Fig. 5-14. KE pressure-actuator plate valve controls fuel flow through pressure actuator.

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Pressure Actuator and Mixture Adjustment

Fig. 5-15 shows the relationship of differential pressure and pressure drop at the metering slits and how it affects basic fuel metering. When the plate is closer to the actuator inlet it restricts the flow of actuator fuel. Differential pressure increases and the diaphragms deflect further. This increases the pressure drop at the control-plunger slits and increases the flow of injector fuel for a given plunger lift. When the plate is further away from the inlet the differential pressure is less so the diaphragms deflect less. This decreases pressure drop at the slits and reduces the flow of injector fuel for a given plunger lift.

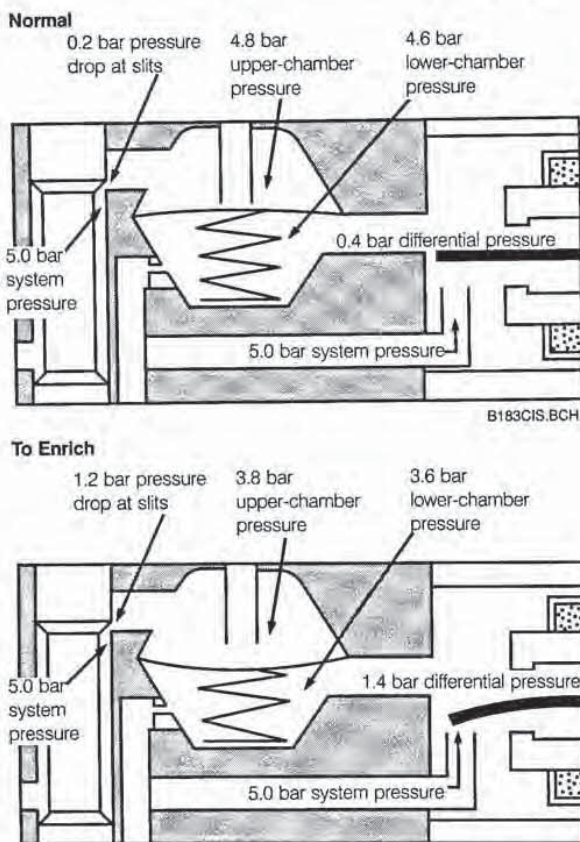


Fig. 5-15. Pressures in the KE differential-pressure valve chambers compared to differential pressure. **Top:** With little deflection of actuator plate differential pressure is low. Actuator fuel flow increases to increase upper-chamber pressure. Pressure drop at the slits drops, restricting the flow of injector fuel. **Bottom:** On the other hand, increased magnetic force increases differential pressure, increases pressure drop at slits, and increases fuel flow.

You can think of the pressure function of the actuator this way: Pressure drop at the metering slits is equal to system pressure minus upper-chamber pressure. Upper-chamber pressure is equal to system pressure plus the 0.2 bar spring pressure, minus the differential pressure. See Fig. 5-16. Remember, differential pressure is the difference between system pressure and pressure in the lower chambers controlled by the pressure actuator. As you'll see in chapter 6, you can't test differential pressure directly. You have to first measure system pressure and then subtract measured lower-chamber pressure to get the differential.

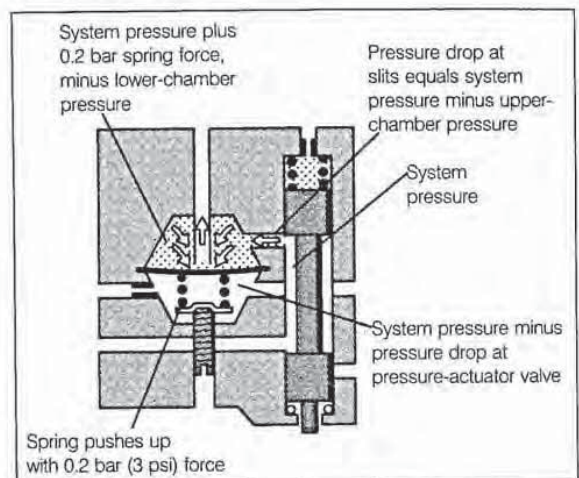


Fig. 5-16. Relationship of pressures in KE differential-pressure valves.

Control Unit and Sensors

The amount of current supplied to the pressure-actuator electromagnet for mixture control is determined by the KE control unit. To determine the correct current, the control unit depends on inputs from sensors much like those used on pulsed systems. See Fig. 5-17. These inputs include those from the ignition circuit for engine-speed, the lambda sensor, the engine-temperature sensor, the intake-air temperature sensor (on Mercedes-Benz, beginning 1986), the sensor-plate potentiometer for acceleration, and the throttle switch for closed and wide-open throttle indications. Control-unit outputs include the pressure-actuator signal and, on some models, signals to an idle-speed stabilizer.

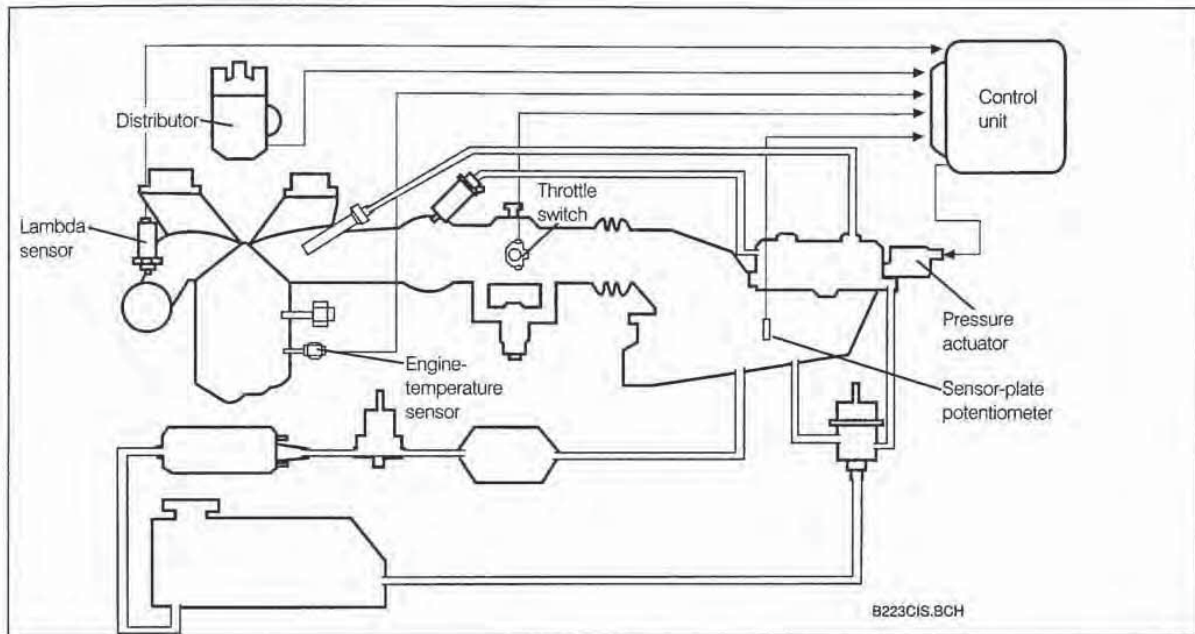


Fig. 5-17. Most KE inputs to control unit are similar to those of pulsed systems. Sensor-plate potentiometer is unique to KE, operating something like a throttle-position sensor. For more information see 6. **Functions and Compensation.**

Actuator Current, Pressures, and Air-Fuel Ratios

When troubleshooting, a digital meter can be used to measure the control-unit actuator current. It's very small, measured in milliamps (mA), so be aware that small milliamp currents are affected by oxidation on connectors. The connectors must remain clean and must not be bent by probes inserted to read small currents. The following are some examples of how the control current relates to pressure-actuator mixture adjustment.

For typical warm-engine operation, current flow is about 10 mA. If you remember the discussion above, this causes a small deflection of the plate valve for a small difference between system pressure and lower-chamber pressure. The differential on a fuel gauge would be about 0.4 bar. Pressure drop and injector fuel flow at the slits is normal.

To lean the mixture, the plate is allowed to move away as the current is reduced, to perhaps only 1 mA. The differential pressure falls to only 0.2 bar, so injector fuel decreases.

To enrich the mixture, as in engine warm-up, the plate is pulled closer with more current, say 70 mA. Differential pressure increases to 1 bar, so injector fuel increases. More actuator current means more differential pressure, more deflection

of the differential-pressure valve diaphragms, and more pressure drop at the metering slits, so more fuel is injected. When you've got that, you've got the basic idea of the KE-Jetronic control system's adjustment of the basic fuel mixture.

The graph shown in Fig. 5-18 looks complicated, but a moment of study will give you a good summary of actuator current as it affects the air-fuel ratio. This typical curve does not apply to any specific car.

On the baseline, read the pressure-actuator current in milliamps (mA). On the left, one vertical scale shows the pressure drop at the slit: the difference between system pressure and upper-chamber pressure. The other vertical scale shows the specified differential-pressure, the difference between system pressure and lower-chamber pressure. These numbers are 0.2 bar higher than corresponding pressure drop numbers, the result of the 0.2 bar pressure from the spring in the lower chamber.

The right column shows the corresponding air-fuel ratios. Follow the curved line to see how changing pressure-actuator current changes the air-fuel ratio.

Control Systems

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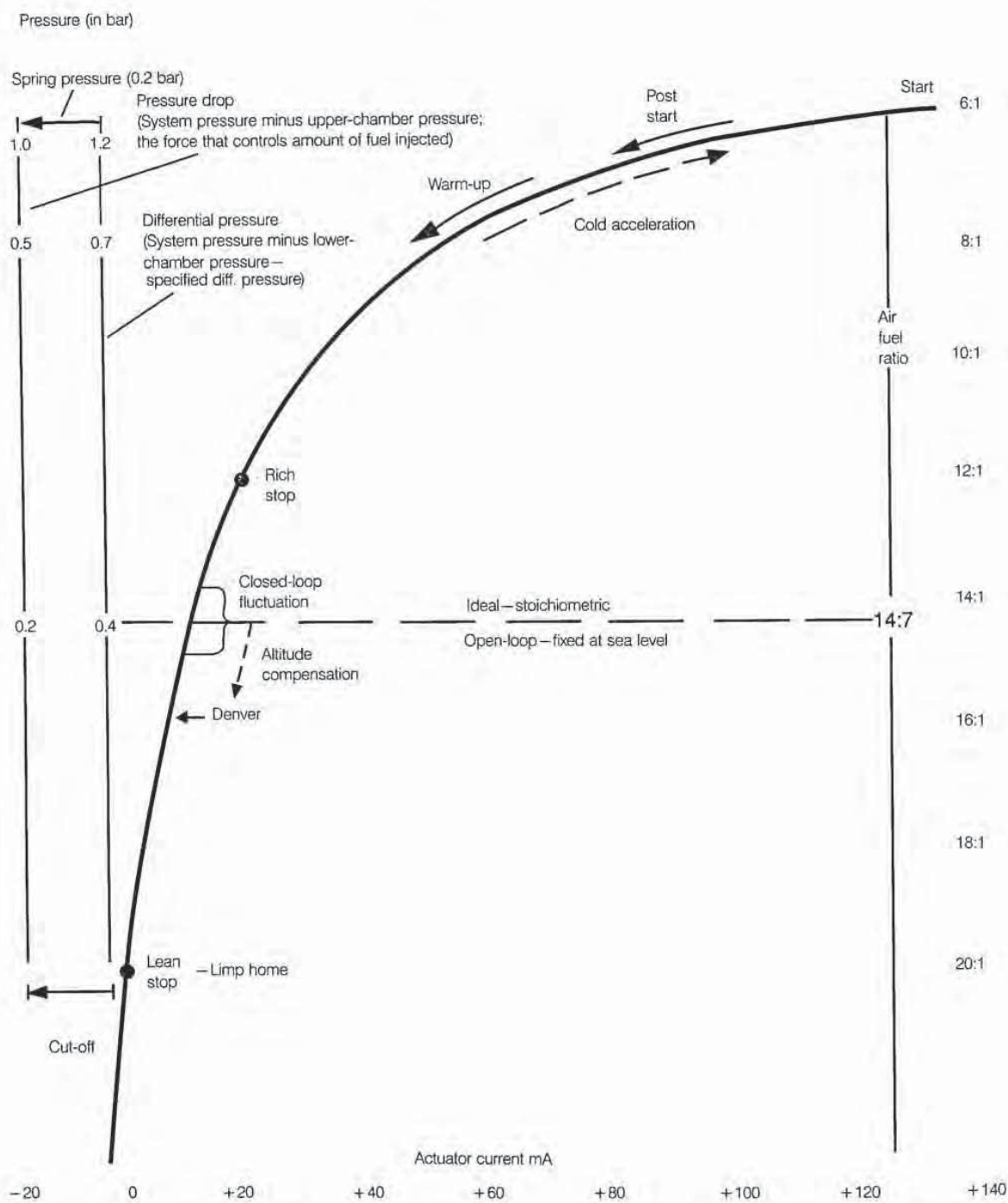


Fig. 5-18. KE actuator current changes typical pressure drop at the slits, and therefore the differential pressure (system pressure minus lower-chamber pressure) and the air-fuel ratio. Notice small closed-loop fluctuation around stoichiometric air-fuel ratio at 8–12 mA, and the limp-home setting at lean stop. These values do not apply to any specific car.

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Limp-Home Mode

The actuator plate is designed to rest at a "limp-home" position if the control-unit current is interrupted. The engine will continue to run, but slightly leaner than normal since the actuator current is not fine-tuning the mixture. In this circumstance, mixture is determined solely by the basic mechanical metering of the air-flow sensor and control plunger. The uncontrolled plate in the pressure actuator allows just enough pressure drop at the slits to keep a warm engine running. The engine may not start, but if it's running, it will get you home. You can simulate the limp-home condition on a running warm engine by disconnecting the pressure-actuator connector.

Logic Circuits

Beginning in 1986, some KE systems have logic circuits in the control unit which help it to recognize and ignore erroneous signals. The computer recognizes rapid changes in input from some sensors as improper and switches to pre-programmed outputs. For example, the coolant temperature signal does not normally change rapidly. If it does, the computer interprets this as a short or an open circuit, and switches to a predetermined value associated with a warm engine. Because this capability is so new and so vehicle-specific, refer to your car service manual for more information.

5.4 Summary of Control Systems: K-Basic, K-Lambda, KE

Now that I've discussed how the control systems of the three types of continuous fuel injection fine-tune the basic fuel

metering of the air-flow sensor and control plunger, I'll summarize these systems according to the two important factors: changing control-plunger slit size for a given air flow, and changing pressure drop at the slits for a given plunger lift. In all cases, pressure drop at the slits is the difference between system pressure inside the slit and upper-chamber pressure in the differential-pressure valves.

In all three types of continuous systems, the air-flow sensor and the control plunger meter the basic amount of proportional fuel to match the air flow. The control systems then manipulate pressures in the system to adjust the basic air-fuel mixture to compensate for different operating conditions. Refer to Fig. 5-19 on the next page for comparison of the manipulation of pressures in the differential-pressure valves of the three systems. Note that the following control descriptions are not for any specific air flow or operating condition.

Table b illustrates these comparisons with numbers. The table uses the same system pressure of 5.0 bar (73 psi) for clarity, but be aware that system pressures do vary.

K-Basic

K-basic systems increase fuel delivery to enrich the mixture for a given air flow by reducing counterforce on the plunger, allowing it to rise higher. When the engine is cold, the control-pressure regulator opens more and increases return flow from the control-pressure circuit. This reduces control-pressure counterforce and the plunger rises higher for the same air-flow force. A larger portion of the plunger slit is exposed and fuel flow to the injectors increases.

Table b. CIS Upper-Chamber and Lower-Chamber Pressures

System	System pressure	Lower-chamber pressure	Upper-chamber pressure	Pressure drop at slit (system pressure minus upper-chamber pressure)	Enrichment method
K-Basic	5.0 bar (73 psi)	5.0 bar (73 psi)	4.9 bar (71.5 psi) (lower-chamber pressure minus 0.1 bar (1.5 psi) spring pressure)	0.1 bar (1.5 psi)	Increase slit size (by control pressure)
K-Lambda	5.0 bar (73 psi)	5.0 bar (73 psi) minus reduction caused by return of fuel at lambda valve	Lower-chamber pressure minus 0.1 bar (1.5 psi) spring pressure	Varies: 0.1 bar (1.5 psi) plus the change in lower-chamber pressure	Increase slit size (by control pressure), increase pressure drop (by lambda valve)
KE	5.0 bar (73 psi)	5.0 bar (73 psi) minus reduction caused by pressure actuator	5.0 bar (73 psi) plus 0.2 bar (3 psi) spring pressure, minus differential pressure (difference between system pressure and lower-chamber pressure)	Varies: differential pressure plus 0.2 bar (3 psi) lower spring force	Increase pressure drop (by pressure actuator)

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Pressure drop at the metering slits of the control plunger is a constant 0.1 bar (1.5 psi), maintained by the spring in the upper chamber pressing down on the diaphragm of the differential-pressure valve. Each flexible diaphragm of the differential-pressure valves moves with a change in fuel flow, so upper-chamber pressure is always 0.1 bar less than lower-chamber pressure.

K-Lambda

K-lambda systems use control pressure to change the mixture, just as in K-basic. They also have an additional control system. K-lambda changes the pressure drop at the slit by changing the lower-chamber pressure in the differential-pressure valve.

Fuel pressure in the lower chambers is controlled by the lambda control system. To enrich as a result of lean signal from the lambda sensor, the control unit increases the duty cycle of the lambda-control valve. More fuel is returned from the lambda-control circuit so lower-chamber pressure drops. Through the movement of the differential-pressure valve diaphragm, this decreases upper-chamber pressure and increases the pressure drop at the slits. More fuel flows for a given plunger lift and slit size.

With the spring in the upper chamber pressing down, each diaphragm moves so the pressure drop at the slit is always 0.1 bar (1.5 psi) less than lower-chamber pressure. Upper-chamber pressure is always 0.1 bar less than lower-chamber pressure as lower-chamber pressure varies according to action of the lambda control valve.

KE Systems

KE systems adjust the basic mixture only by changing the pressure drop at the slit. KE slit size does not vary for a given air-flow force because the counterforce on the plunger is system pressure, which is constant. The fuel flow through the lower chambers, and therefore lower-chamber pressure, is controlled by the pressure actuator. This KE control system compensates for all operating conditions, as well as maintaining a stoichiometric air-fuel ratio for emission control.

To enrich, increased current from the control unit pulls down the pressure-actuator plate valve to reduce lower-chamber pressure. This increases differential pressure—the difference between system pressure and pressure in the lower chambers. For any given air flow, this increases diaphragm deflection in the differential-pressure valves. The pressure drop at the slits increases, increasing fuel delivery to the injectors.

With a spring pushing up on each differential-pressure valve, upper-chamber pressure is 0.2 bar (3 psi) higher than lower-chamber pressure. Lower-chamber pressure is system pressure minus differential pressure. Vehicle specifications will list differential pressures for corresponding actuator currents in milliamperes (mA).

Control Systems

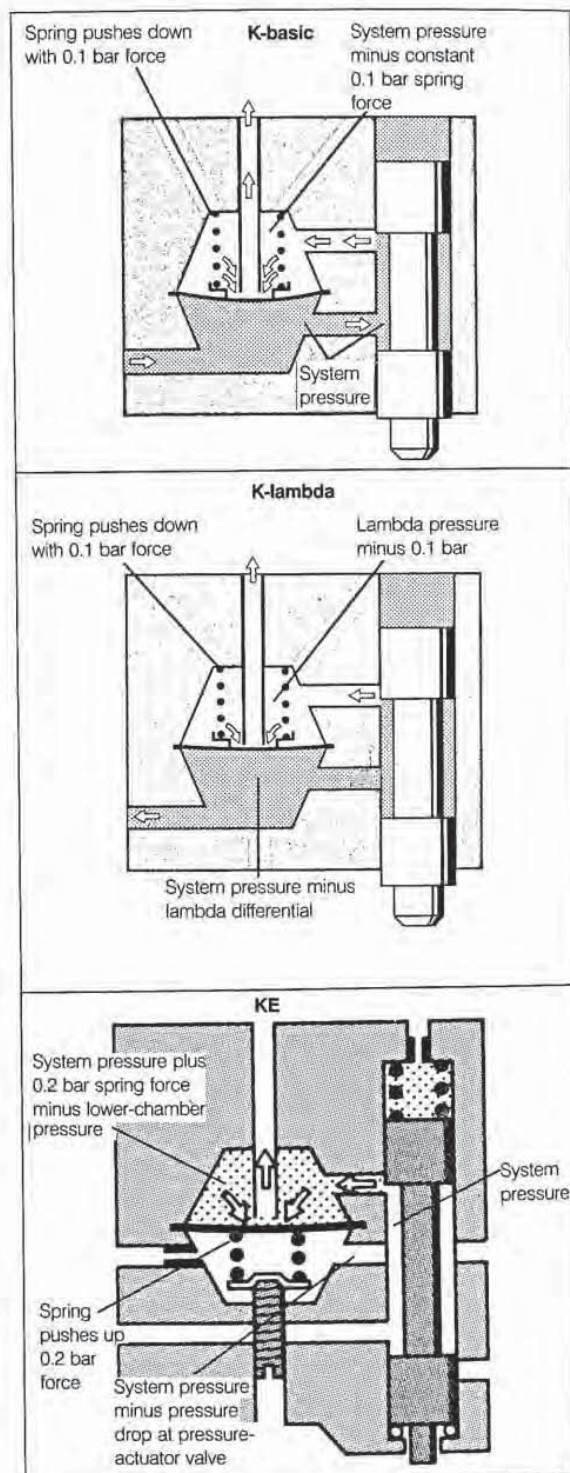


Fig. 5-19. Comparison of differential-pressure valve pressures in continuous systems. Lift of plunger by air flow determines basic fuel quantity. Control systems then manipulate pressure to change mixture. All three have system pressure inside the control-plunger slit.

6. FUNCTIONS AND COMPENSATIONS

You've seen how each control system adjusts the basic air-fuel mixture. Now you'll see how that control is applied for all operating conditions, and you'll also see how other components add additional enrichment as necessary.

6.1 Starting

When the key is turned to start, the fuel pump is turned on through the safety circuit to build system pressure; if the engine stops turning for more than one second (as when the engine will not start) the pump shuts off, even with the ignition key on. For starting enrichment, extra fuel is delivered to the port injectors. In K-basic and K-lambda, reduced control pressure allows more plunger lift, increasing slit size to deliver more fuel. In KE systems, the control unit sends more current to the pressure actuator for start enrichment, lasting about one second. The current is high for maximum pressure drop at the metering slits, enriching the mixture delivered to the port injectors.

Cold Starting

For cold starting, in addition to enrichment at the port injectors, continuous systems enrich the mixture with a cold-start injector system, similar to that used on pulsed systems. Also, an auxiliary-air valve or idle-speed stabilizer adds air, bypassing the throttle plate to increase idle rpm. See chapter 3 for more information. Beginning about 1985, some KE systems ground the start injector through the control unit, so the thermo-time switch is eliminated.

Hot-Start Pulse Relay

Some cars—notably VWs beginning about 1985—have a special hot-start pulse relay. See Fig. 6-1. The relay bypasses the thermo-time switch and grounds the cold-start injector in short pulses when a warm engine is started, spraying fuel into the manifold. This provides additional fuel in the intake manifold to aid starting when the port injectors are delivering less fuel because of high temperatures and vapor in the lines.

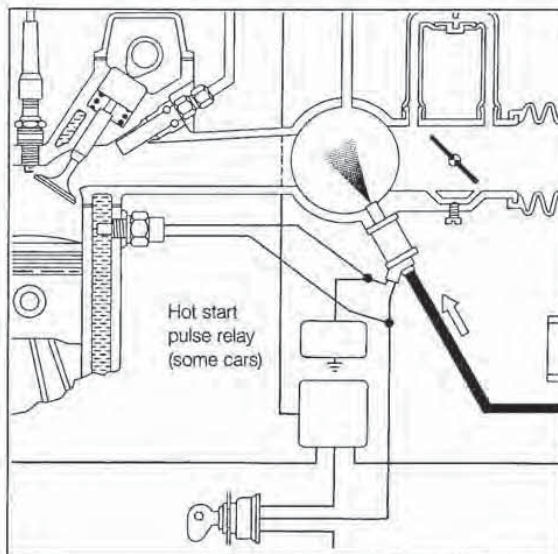


Fig. 6-1. In some VWs and Audis, hot-start pulse relay adds fuel by energizing cold-start injector during hot-engine cranking.

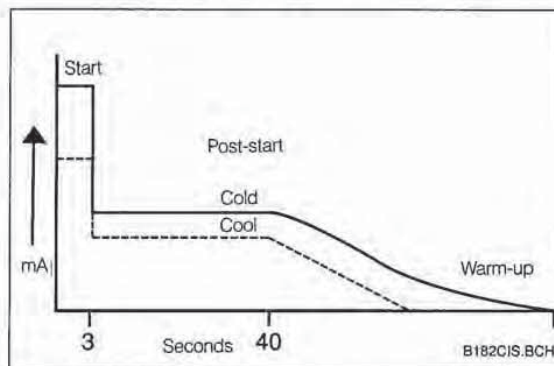


Fig. 6-2. KE enrichment at start and post-start depends on temperature. Warm-up enrichment also depends on time since starting.

6.2 Post-Start/Warm-Up

When the key is released to run, enrichment changes from engine-crank needs to engine-run needs. On K-basic and K-lambda, the control-pressure regulator warms up, gradually increasing control pressure on the plunger. This cuts back the enrichment factor in a few minutes.

KE post-start enrichment is determined by the control unit based on input from the engine temperature sensor. Increased actuator current keeps the engine running, right after starting. Then enrichment tapers off during warm-up, depending on engine temperature. See Fig. 6-2.

6.3 Acceleration

In all systems, rapid opening of the throttle increases air flow and causes the air-flow sensor plate to overreact, in a manner similar to that of pulsed systems vane-type air-flow sensor flaps. Overswing of the sensor plate allows the plunger to momentarily rise higher and enriches the mixture enough to prevent lean-mixture flat-spots and hesitation. See Fig. 6-3.

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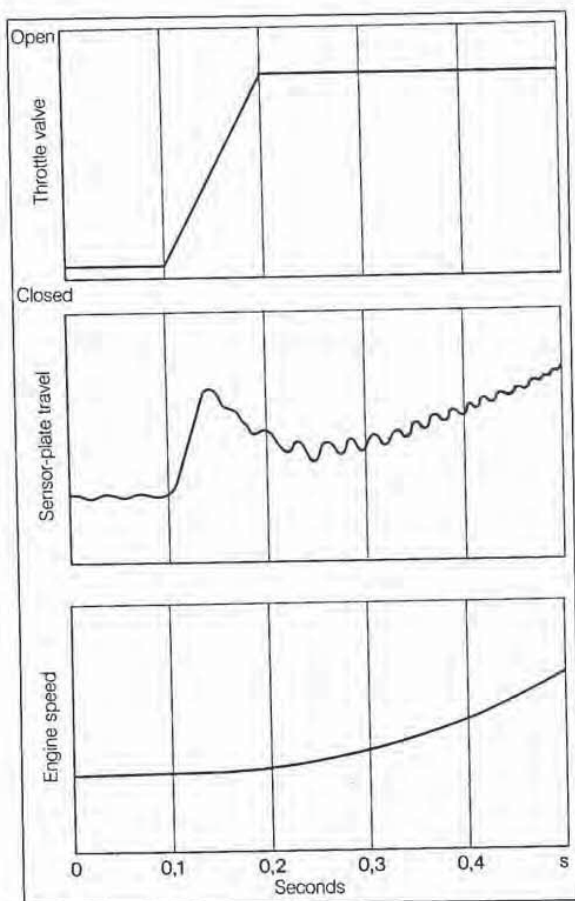


Fig. 6-3. Sudden opening of throttle causes overswing of sensor plate, adding acceleration enrichment for K-basic and K-lambda.

Part-Throttle Acceleration

In K-basic and K-lambda, cold-engine overswing is greater than that of a warm engine because reduced control pressure on the plunger allows more lift. In addition, some control-pressure regulators sense manifold pressure to further reduce control pressure and add acceleration enrichment.

KE systems use an additional sensor, the sensor-plate potentiometer (also called the air-flow sensor position indicator), to signal the need for extra enrichment during cold-engine part-throttle acceleration. The potentiometer signals how fast and how far the sensor plate moves as air flow increases. See Fig. 6-4.

The potentiometer has an arm with sliding contacts that is connected to the sensor-plate pivot. As the arm moves, it changes a voltage signal. See Fig. 6-5. From this input, the control unit sends a compensation output to the pressure actuator. For about one second, pressure-actuator current

increases, depending on sensor plate movement and on engine temperature and rpm. The greatest enrichment is when the engine is cold; middle enrichment when the engine is cool; no enrichment when engine temperature is above 175°F (80°C). Mercedes-Benz has added an Intake Air Temperature Sensor to further compensate acceleration-enrichment for cold air, a refinement for better driveability.

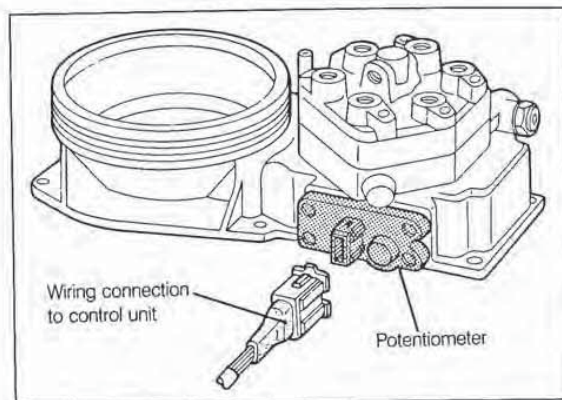


Fig. 6-4. Location of potentiometer on KE mixture-control unit.

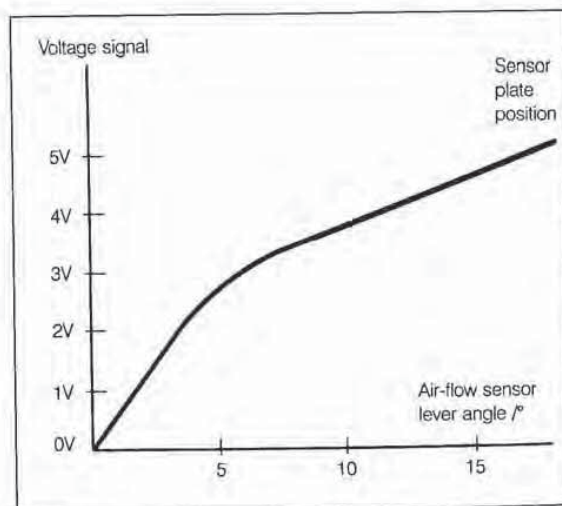


Fig. 6-5. KE adds signal from sensor-plate potentiometer to enrichment from sensor-plate overswing. The more the lever angle changes, the greater the voltage signal to the control unit.

Full-Throttle Acceleration

On K-basic and K-lambda, enrichment is supplied only on systems with control-pressure regulators linked to manifold pressure.

Functions and Compensations

KE enrichment usually continues as long as the throttle switch signals a full-load condition, adding enrichment by control of the pressure actuator. Some engines, particularly VW, need full-throttle enrichment only during limited rpm ranges, so the control unit is programmed accordingly. The control unit adds about 3 mA to the actuator current to compensate the mixture for full-load acceleration, depending on the full-load signal, on rpm and on engine temperature.

6.4 Lambda Control

K-lambda closed-loop operation is described under 5. Control Systems. Note that closed-loop operation switches to open-loop under these conditions:

- lambda sensor cool, not ready to send valid signals
- engine cool, usually below about 105°F (40°C)
- WOT, full-load
- coasting cut-off
- acceleration enrichment (some cars)

KE systems also operate closed-loop with a lambda sensor. The lambda-sensor signals are processed with the other inputs to determine pressure-actuator current. The plate valve is always moving; either slightly toward the inlet or slightly away from it, the result of constantly changing pressure actuator current. With the engine warm, and the lambda sensor hot, look for actuator current to change back and forth in a narrow range, typically from 8 to 12 mA. This fluctuation during closed-loop operation is normal; the system is adjusting to maintain the ideal air-fuel ratio. During open-loop operation, with the lambda sensor disconnected and the engine warm, actuator current should be about in the middle of the fluctuations, according to engine specifications. When you see no change in actuator current, you know the system is running open-loop.

6.5 Cut-off

(KE only)

In KE, to cut off fuel injection, such as during coasting or for rpm limitation, actuator current is reversed to move the plate valve completely away from the inlet. With no limit to the amount of actuator fuel flowing through the lower chamber, both chambers rise to system pressure. Each spring pushes its diaphragm up, as shown in Fig. 6-6, closing the outlet and cutting off injector fuel. On some cars, such as Mercedes, rpm limitation is also handled by cutting power to the fuel-pump relay. On most cars, coasting cut-off is inhibited during cruise-control operation.

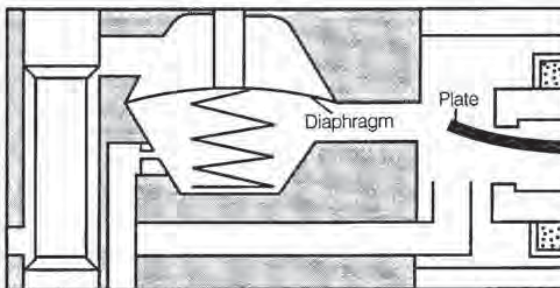


Fig. 6-6. To cut off fuel in KE systems, pressure actuator current is reversed (to approximately -40 mA), pushing plate away from inlet. Zero differential pressure causes lower-chamber spring to raise diaphragm, shutting off fuel to injectors.

6.6. Altitude

On some K-basic and K-lambda systems, altitude compensation is built into the control-pressure regulator, as described in 5. Control Systems.

In KE systems on higher-priced cars, an altitude sensor signals the control unit to reduce pressure-actuator current to reduce fuel delivery when the air is thinner. The decrease is about 1 mA actuator current for each thousand feet above sea level. KE-Motronic systems with adaptive air-fuel mixture control "learn" to adjust themselves and therefore need no altitude sensor.

7. KE3-JETRONIC AND KE-MOTRONIC

KE3-Jetronic and KE-Motronic systems combine the control of KE-type fuel injection with the control of ignition timing. The difference between the two systems is that KE3-Jetronic has two separate control units—one for fuel injection, one for ignition timing—and operates with standard KE-Jetronic fuel injection. KE-Motronic is a true "Motronic" system; it has both fuel injection and ignition control combined into one control unit, and has a special data-point map in the control unit that determines actuator current for all operating conditions. Ignition-timing control for both KE3-Jetronic and KE-Motronic also uses maps. For more information on timing control, Motronic systems, and control-unit maps, see the Motronic section of chapter 3.

The first application of KE3-Jetronic is on some 1987 Audi 5000s, and all 1988 5-cylinder Audis. Audi calls this system CIS-E III. The first use of KE-Motronic is on the 1988 4-cylinder Audi 80; Audi calls this system CIS-Motronic.

In the two system diagrams, shown in Fig. 7-1 and Fig. 7-2, you can see the ignition timing input (the Hall-effect sender in the Ignition distributor) that makes these systems different from KE-Jetronic. The ignition outputs to the ignition coil with power stage are: 1) close-circuit to begin charging the coil and 2) open circuit to fire the spark plug.

KE3-Jetronic and KE-Motronic

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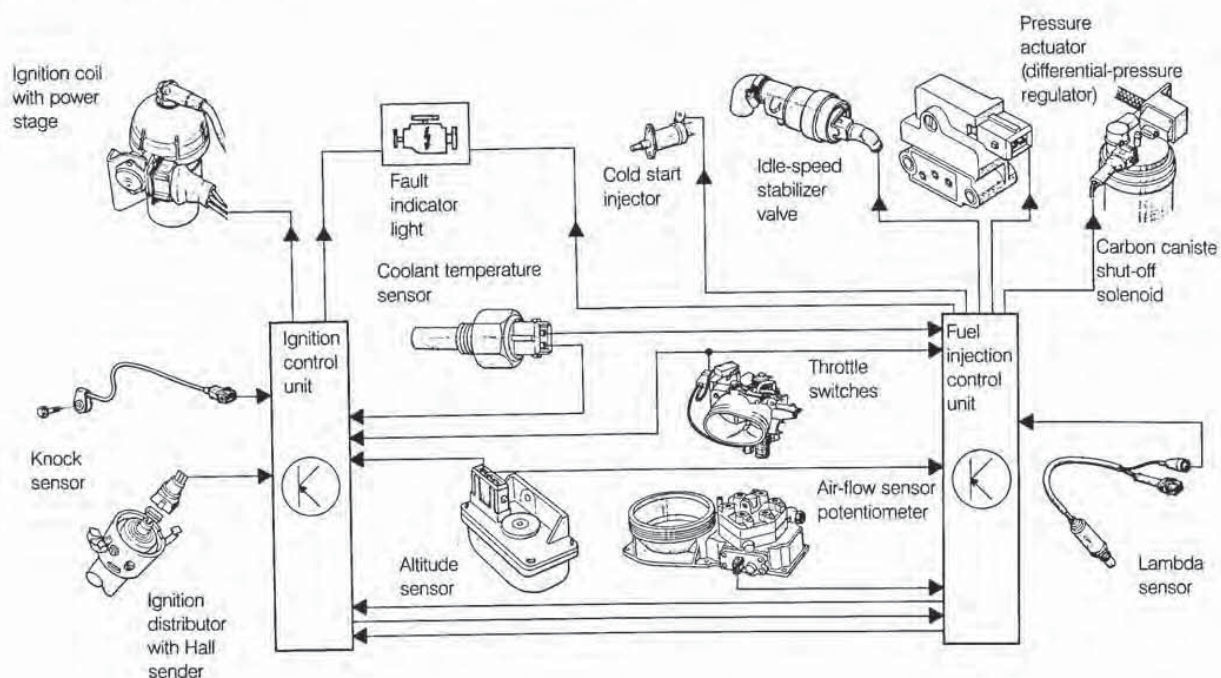


Fig. 7-1. KE3-Jetronic system used in recent Audi and Mercedes includes diagnostics, but controls fuel injection with normal Jetronic control unit. Ignition is controlled by separate control unit.

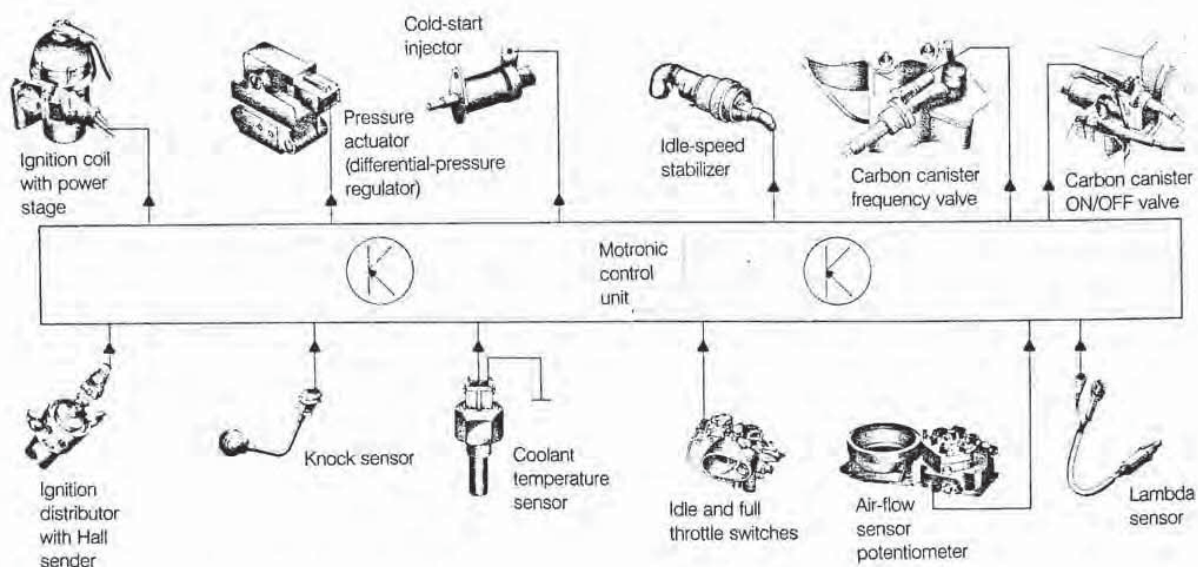


Fig. 7-2. KE-Motronic has special Motronic control unit with special internal data maps to determine operating points for actuator current and other functions. Inputs include Hall sender in distributor, and knock sensor. Outputs include ignition coil for ignition timing control.

KE3-Jetronic and KE-Motronic

The other KE3-Jetronic and KE-Motronic inputs are the same as KE-Jetronic: knock sensor, coolant temperature sensor, closed throttle (idle) and full-throttle switches, air-sensor potentiometer, and lambda sensor. Most of these inputs are used to control ignition timing as well as fuel injection.

The outputs are also the same: pressure actuator (called a differential-pressure regulator by VW/Audi) current, and idle-speed stabilizer control. In addition, the control unit manages the vapor-canister frequency valve and the canister on-off valve; parts of the evaporative emission control system.

Actuator Current

Both systems have a different range of control-unit current for the pressure actuator. For KE3-Jetronic, a typical rich limit is +10 mA, with a lean limit of -10 mA. The nominal adjustment point is 0 mA, to provide for the widest range of adaptation.

For KE-Motronic, a typical rich limit is +23 mA, with a lean limit of -16 mA. This provides for the operation of the adaptive circuitry. The system can compensate for broader changes beyond just lambda control, including all engine operating conditions, altitude, intake leaks and other variations. A typical actuator current for a new engine running open-loop (lambda sensor disconnected) might be 2 mA. As the engine ages, perhaps with minor intake air leaks, typical open-loop actuator current might be 7 mA. See Fig. 7-3.

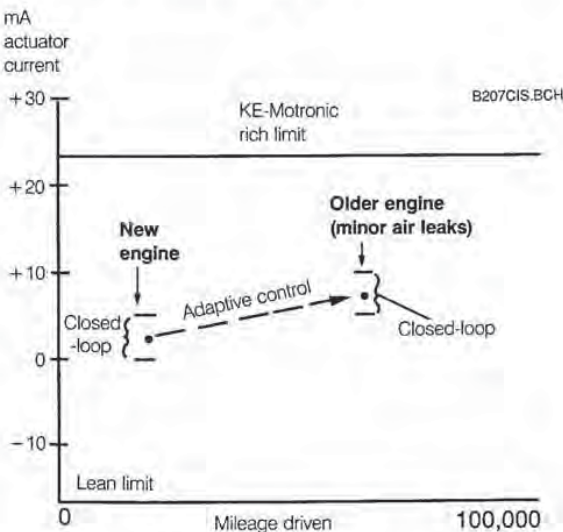


Fig. 7-3. KE-Motronic adaptive control can adjust actuator current to match changing conditions. Older engine may need greater actuator current for enrichment to counter minor air leaks.

KE-Motronic Adaptive Control

Adaptive control means that the control unit “learns” to make automatic mixture adjustment. The control-unit circuitry senses nominal warm-engine cruise values. It stores those values as the normal open-loop operation, and then uses those values as a basis for both closed-loop and open-loop actuator current. The control unit continually “relearns” the compensations necessary for changes in engine condition, or even intake air leaks.

The air-fuel ratio values are stored in the control unit’s volatile memory, so they are lost any time the battery is disconnected. If the engine runs differently after service, even if that service was as seemingly unrelated as the installation of a radio or theft alarm, be ready to drive the car normally for about 10 minutes to re-store the nominal air-fuel mixture values in the volatile memory of the KE-Motronic control unit.

Fault Memory (Diagnostic Codes)

Diagnostic codes (fault memories) are stored in the control unit. The control unit continually checks all systems for incorrect signals. If one is found, the fault is stored in the control-unit fault memory as a series of electrical pulses. On KE3-Jetronic systems you can read these fault-memory pulses at the indicator light on the dash panel as shown in Fig. 7-4. On KE-Motronic systems, you connect a test light between the battery and the test lead next to the fuel distributor on the engine. See Fig. 7-5. The fault codes are read out by inserting a spare fuse into the top of the fuel-pump relay.

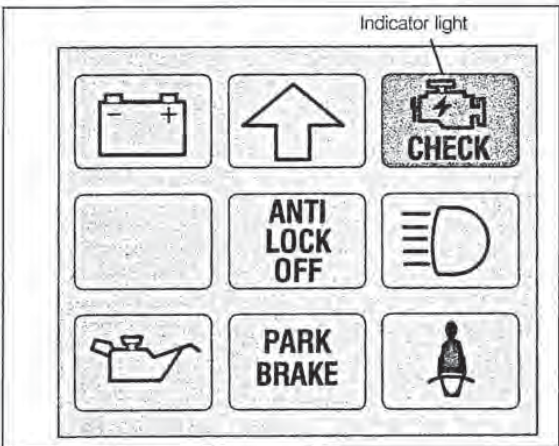


Fig. 7-4. On KE3-Jetronic, diagnostic codes from the control unit fault memory are read out at the dashboard.

KE3-Jetronic and KE-Motronic

36 CONTINUOUS INJECTION — THEORY

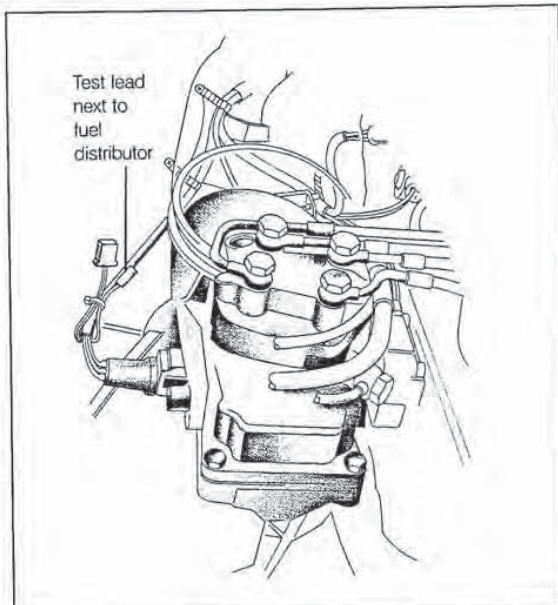


Fig. 7-5. On KE-Motronic, diagnostic read-out of fault memory is by voltage pulses at test lead near mixture-control unit.

KE3-Jetronic codes in all cars except California are erased when the ignition is turned off. Fault codes are restored by driving for 5 minutes (at at least 3,000 rpm, and once at full-throttle) or by cranking the engine for 6 seconds. If the fault is emission related, the indicator light on California cars remains on as long as the fault is present; in all other cars the code is stored, but will not come on until the fuse is inserted. When you activate the fault memory, injection faults read out first, and then ignition faults.

In KE-Motronic, if the fault is emission related, all cars except California will store the fault in memory until it is erased. California cars flash the fault light as long as a fault is present. This helps in finding intermittent faults. For non-emission related faults, all cars store the fault until the engine is restarted. Troubleshooting can be done before engine is shut off, or with ignition OFF. Fault codes can be restored by driving for 5 minutes (at at least 3,000 rpm, and at least once at full throttle), or by cranking for 6 seconds. For more information on the fault memory and reading trouble codes, see chapter 6.

KE3-Jetronic and KE-Motronic

Electronic Acknowledgement Receipt	
EFS ID:	38057221
Application Number:	10014286
International Application Number:	
Confirmation Number:	3146
Title of Invention:	METHOD OF CALCULATING A VALVE TIMING COMMAND FOR AN ENGINE
First Named Inventor/Applicant Name:	Lawrence A. Mianzo
Customer Number:	24939
Filer:	Timothy Devlin/Pat Mathews
Filer Authorized By:	Timothy Devlin
Attorney Docket Number:	10541-070
Receipt Date:	17-DEC-2019
Filing Date:	11-DEC-2001
Time Stamp:	15:03:36
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no
------------------------	----

File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Power of Attorney	2019-12-17-USPN6557540-MMT-Transmittal-POA-as-filed.pdf	309420	no	2
			c64a345fa3dd74383b6cd7f148da4729551fc518		

Warnings:

Information:					
2	Assignee showing of ownership per 37 CFR 3.73	2019-12-17-USPN6557540-MMT-373c-Statement.pdf	124146	no	3
			bb176997b12121c42e1aac8974033f5a3a56a4d7		
Warnings:					
Information:					
Total Files Size (in bytes):			433566		
<p>This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.</p> <p><u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.</p> <p><u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.</p> <p><u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.</p>					

TRANSMITTAL FOR POWER OF ATTORNEY TO ONE OR MORE REGISTERED PRACTITIONERS

NOTE: This form is to be submitted with the Power of Attorney by Applicant form (PTO/AIA/82B) to identify the application to which the Power of Attorney is directed, in accordance with 37 CFR 1.5, unless the application number and filing date are identified in the Power of Attorney by Applicant form. If neither form PTO/AIA/82A nor form PTO/AIA82B identifies the application to which the Power of Attorney is directed, the Power of Attorney will not be recognized in the application.

Application Number	10/014,286
Filing Date	December 11, 2001
First Named Inventor	Lawrence A. Mianzo
Title	METHOD OF CALCULATING A VALVE TIMING COMMAND FOR AN ENGINE
Art Unit	3747
Examiner Name	Solis, Erick R.
Attorney Docket Number	

SIGNATURE of Applicant or Patent Practitioner			
Signature	/Timothy Devlin/	Date (Optional)	2019-12-17
Name	Timothy Devlin	Registration Number	41706
Title (if Applicant is a juristic entity)	Attorney for Applicant		
Applicant Name (if Applicant is a juristic entity)	Michigan Motor Technologies LLC		

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.

☒ *Total of 1 forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:

☒ Practitioners associated with Customer Number: 163393

OR

☐ Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name	Registration Number

Name	Registration Number

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignment documents attached to this form in accordance with 37 CFR 3.73(c).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(c) to:

☒ The address associated with Customer Number: 163393

OR

☐

Firm or individual name

Address

City

State

Zip

Country

Telephone

Email

Assignee name and address: MICHIGAN MOTOR TECHNOLOGIES LLC
2380 ORCHARD LAKE ROAD, SUITE 100
SYLVAN LAKE, MICHIGAN 48320

A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/AIA/96 or equivalent) is required to be filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of the practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee.

Signature *KC Brady*

Date 8/5/2019

Name Kevin Brady

Telephone 215 298 3164

Title Managing Member

This collection of information is required by 37 CFR 1.31, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public, which is to update (and by the USPTO to process) the file of a patent or reexamination proceeding. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 18 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.
If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: Michigan Motor Technologies LLC

Application No./Patent No.: Patent No.: 6,557,540 Filed/Issue Date: Issued: May 6, 2003

Titled: METHOD OF CALCULATING A VALVE TIMING COMMAND FOR AN ENGINE

Michigan Motor Technologies LLC, a limited liability company

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of options 1, 2, 3 or 4 below):

1. ☒ The assignee of the entire right, title, and interest.
2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

☐ The extent (by percentage) of its ownership interest is % . Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (e.g., bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose one of options A or B below):

- A. ☐ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel , Frame , or for which a copy thereof is attached.
- B. ☒ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: Lawrence A. Mianzo, Brett D. Collins, Ibrahim Haskara To: Visteon Global Technologies, Inc.

The document was recorded in the United States Patent and Trademark Office at Reel 012382 , Frame 0565 , or for which a copy thereof is attached.

2. From: Visteon Global Technologies, Inc. To: Godo Kaisha IP Bridge 1

The document was recorded in the United States Patent and Trademark Office at Reel 035421 , Frame 0739 , or for which a copy thereof is attached.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: Godo Kaisha IP Bridge To: Mobile Automotive Technologies, LLC

The document was recorded in the United States Patent and Trademark Office at
Reel 043463, Frame 0223, or for which a copy thereof is attached.

4. From: Godo Kaisha IP Bridge To: Mobile Automotive Technologies, LLC

The document was recorded in the United States Patent and Trademark Office at
Reel 043843, Frame 0821, or for which a copy thereof is attached.

5. From: Mobile Automotive Technologies, LLC To: Michigan Motor Technologies LLC

The document was recorded in the United States Patent and Trademark Office at
Reel 043463, Frame 0881, or for which a copy thereof is attached.

6. From: To:

The document was recorded in the United States Patent and Trademark Office at
Reel, Frame, or for which a copy thereof is attached.

Additional documents in the chain of title are listed on a supplemental sheet(s).

As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.
[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Timothy Devlin/
Signature
Timothy Devlin
Printed or Typed Name

2019-12-17
Date
Reg. No. 41706
Title or Registration Number

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Trials@uspto.gov
571-272-7822

Paper No. 4

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

VOLKSWAGEN GROUP OF AMERICA, INC.,
Petitioner,

v.

MICHIGAN MOTOR TECHNOLOGIES, LLC,
Patent Owner.

Case IPR2020-00160
Patent 6,557,540

Mailed: December 9, 2019

Before Amy Kattula, *Trial Paralegal*

NOTICE OF FILING DATE ACCORDED TO PETITION
AND
TIME FOR FILING PATENT OWNER PRELIMINARY RESPONSE

The petition for *inter partes* review filed in the above proceeding has been accorded the filing date of November 25, 2019.

Patent Owner may file a preliminary response to the petition no later than three months from the date of this notice. The preliminary response is limited to setting forth the reasons why the requested review should not be

Case IPR2020-00160
Patent 6,557,540

instituted. Patent Owner may also file an election to waive the preliminary response to expedite the proceeding. For more information, please consult the Office Patent Trial Practice Guide, 77 Fed. Reg. 48756 (Aug. 14, 2012), which is available on the Board Web site at <http://www.uspto.gov/PTAB>.

Patent Owner is advised of the requirement to submit mandatory notice information under 37 C.F.R. § 42.8(a)(2) within 21 days of service of the petition.

The parties are encouraged to use the heading on the first page of this Notice for all future filings in the proceeding.

The parties are advised that under 37 C.F.R. § 42.10(c), recognition of counsel *pro hac vice* requires a showing of good cause. The parties are authorized to file motions for *pro hac vice* admission under 37 C.F.R. § 42.10(c). Such motions shall be filed in accordance with the “Order -- Authorizing Motion *for Pro Hac Vice* Admission” in Case IPR2013-00639, Paper 7, a copy of which is available on the Board Web site under “Representative Orders, Decisions, and Notices.”

The parties are reminded that unless otherwise permitted by 37 C.F.R. § 42.6(b)(2), all filings in this proceeding must be made electronically in Patent Trial and Appeal Board End to End (PTAB E2E), accessible from the Board Web site at <http://www.uspto.gov/PTAB>. To file documents, users must register with PTAB E2E. Information regarding how to register with and use PTAB E2E is available at the Board Web site.

If there are any questions pertaining to this notice, please contact Amy Kattula at 571-272-5826 or the Patent Trial and Appeal Board at 571-272-7822.

Case IPR2020-00160
Patent 6,557,540

PETITIONER:

Michael Specht
Mspecht-ptab@sternekessler.com

Jason Fitzsimmons
Jfitzsimmons-ptab@sternekessler.com

Daniel Yonan
Dyonan-ptab@sternekessler.com

Christopher O'Brien
Cobrien-ptab@sternekessler.com

PATENT OWNER:

Visteon Global Technologies Inc.
Intellectual Property Department
One Village Center Drive
Van Buren Township, MI 48111

NOTICE CONCERNING ALTERNATIVE DISPUTE RESOLUTION
(ADR)

The Patent Trial and Appeal Board (PTAB) strongly encourages parties who are considering settlement to consider alternative dispute resolution as a means of settling the issues that may be raised in an AIA trial proceeding. Many AIA trials are settled prior to a Final Written Decision. Those considering settlement may wish to consider alternative dispute resolution techniques early in a proceeding to produce a quicker, mutually agreeable resolution of a dispute or to at least narrow the scope of matters in dispute. Alternative dispute resolution has the potential to save parties time and money.

Many non-profit organizations, both inside and outside the intellectual property field, offer alternative dispute resolution services. Listed below are the names and addresses of several such organizations. The listings are provided for the convenience of parties involved in cases before the PTAB; the PTAB does not sponsor or endorse any particular organization’s alternative dispute resolution services. In addition, consideration may be given to utilizing independent alternative dispute resolution firms. Such firms may be located through a standard keyword Internet search.

CPR INSTITUTE FOR DISPUTE RESOLUTION	AMERICAN INTELLECTUAL PROPERTY LAW ASSOCIATION (AIPLA)	AMERICAN ARBITRATION ASSOCIATION (AAA)	WORLD INTELLECTUAL PROPERTY ORGANIZATION (WIPO)	AMERICAN BAR ASSOCIATION (ABA)
Telephone: (212) 949-6490	Telephone: (703) 415-0780	Telephone: (212) 484-3266	Telephone: 41 22 338 9111	Telephone : (202) 662-1000
Fax: (212) 949-8859	Fax: (703) 415-0786	Fax: (212) 307-4387	Fax: 41 22 733 5428	N/A
575 Lexington Ave	241 18th Street, South, Suite 700	140 West 51st Street	34, chemin des Colombettes	1050 Connecticut Ave, NW
New York, NY 10022	Arlington, VA 22202	New York, NY 10020	CH-1211 Geneva 20, Switzerland	Washington D.C. 20036
www.cpradr.org	www.aipla.org	www.adr.org	www.wipo.int	www.americanbar.org

If parties to an AIA trial proceeding consider using alternative dispute resolution, the PTAB would like to know whether the parties ultimately decided to engage in alternative dispute resolution and the reasons why or why not. If the parties actually engage in alternative dispute resolution, the PTAB would be interested to learn what mechanism (e.g., arbitration,

Case IPR2020-00160
Patent 6,557,540

mediation, etc.) was used and the general result. Such a statement from the parties is not required but would be helpful to the PTAB in assessing the value of alternative dispute resolution to parties involved in AIA trial proceedings. To report an experience with ADR, please forward a summary of the particulars to the following email address:
PTAB_ADR_Comments@uspto.gov

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

VOLKSWAGEN GROUP OF AMERICA, INC.,
Petitioner,

v.

MICHIGAN MOTOR TECHNOLOGIES LLC,
Patent Owner

IPR2020-00160
Patent 6,557,540

PATENT OWNER'S MANDATORY NOTICES

Mail Stop PATENT BOARD
Patent Trial and Appeal Board
US Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450

Through the undersigned Counsel, Patent Owner, Michigan Motor Technologies LLC, is submitting the following Mandatory Notice pursuant to 37 C.F.R. § 42.9(a)(2).

REAL PARTY-IN-INTEREST

Michigan Motor Technologies LLC certifies that it is the real party-in-interest as it is the owner of the Patent No. 6,557,540.

RELATED MATTERS:

The Patent Owner identifies the following judicial and/or administrative matters that may affect, or may be affected by, a decision in the *Inter Partes* Review:

Michigan Motor Technologies LLC v. Volkswagen AG, Case No. 2:19-cv-10485 (E.D. Mich.), filed February 18, 2019.

LEAD COUNSEL:

Pursuant to 37 C.F.R. §§ 42.8(b)(3) and 42.01(a), Michigan Motor Technologies LLC designates the following:

Lead Counsel:

Timothy Devlin, Reg. No. 41706
Devlin Law Firm LLC
1526 Gilpin Ave.
Wilmington, DE 19806
Phone: (302) 449-9010
Fax: (302) 353-4251
tdevlin@devlinlawfirm.com

SERVICE INFORMATION:

Service information is as follows: DEVLIN LAW FIRM LLC, 1526 Gilpin Ave., Wilmington, DE 19806; Phone: (302) 449-9010; Fax: (302) 353-4251; Michigan Motor Technologies LLC consents to service by electronic mail at TD-PTAB@devlinlawfirm.com; tdevlin@devlinlawfirm.com; rwilliams@devlinlawfirm.com, mmcclain@devlinlawfirm.com and fxu@devlinlawfirm.com.

Michigan Motor Technologies LLC believes this submission fulfills the requirements of 37 C.F.R. § 42.8. If additional information is required, please contact the undersigned counsel at the address shown below.

Should the Board require any further information, the Board is encouraged to contact the Patent Owner's undersigned representative at the telephone number listed below.

Respectfully submitted,

Dated: December 18, 2019

DEVLIN LAW FIRM LLC

By: /s/ Timothy Devlin
Timothy Devlin
Reg. No. 41706
1526 Gilpin Ave.
Wilmington, DE 19806
Phone: (302) 449-9010
tdevlin@devlinlawfirm.com

Attorney for Patent Owner

CERTIFICATE OF SERVICE

I hereby certify that on December 18, 2019, I caused a true and correct copy of this Mandatory Notice to be served via electronic mail on Counsel for

Petitioner:

Sterne, Kessler, Goldstein & Fox P.L.L.C.
mspecht-PTAB@sternekessler.com;
jfitzsimmons-PTAB@sternekessler.com;
dyonan-PTAB@sternekessler.com;
gphero-PTAB@sternekessler.com;
PTAB@sternekessler.com.

/s/ Timothy Devlin
Timothy Devlin

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

VOLKSWAGEN GROUP OF AMERICA, INC.,

Petitioner,

v.

MICHIGAN MOTOR TECHNOLOGIES LLC,

Patent Owner

IPR2020-00160
Patent 6,557,540

PATENT OWNER'S POWER OF ATTORNEY AND CHANGE OF
CORRESPONDENCE ADDRESS FOR INTER PARTES REVIEW

Mail Stop PATENT BOARD
Patent Trial and Appeal Board
US Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450

I. Designation of Power of Attorney

I hereby appoint Practitioner(s) associated with Customer Number 163393 as my attorney(s) to prosecute the aforementioned proceeding, and to transact all business in the United States Patent and Trademark Office connected therewith, including the appointment of lead counsel.

II. Change of Correspondence Address

Please recognize the correspondence address (including any electronic mail address) for the above-identified Inter Partes Review proceeding number to be the address associated with the appointed lead counsel.

III. Authorization for Power of Attorney and Change of Correspondence Address

I am the patent owner, having filed a Power of Attorney by Applicant and a Statement under 37 CFR 3.73(c) in connection with this proceeding (attached as Exhibits A and B).

Respectfully submitted,

Dated: 8/5/2019

By: KCBrady
Kevin Brady
Managing Member
Michigan Motor Technologies LLC
Telephone: 215 298 3164

TRANSMITTAL FOR POWER OF ATTORNEY TO ONE OR MORE
REGISTERED PRACTITIONERS

NOTE: This form is to be submitted with the Power of Attorney by Applicant form (PTO/AIA/82B) to identify the application to which the Power of Attorney is directed, in accordance with 37 CFR 1.5, unless the application number and filing date are identified in the Power of Attorney by Applicant form. If neither form PTO/AIA/82A nor form PTO/AIA82B identifies the application to which the Power of Attorney is directed, the Power of Attorney will not be recognized in the application.

Application Number	10/014,286
Filing Date	December 11, 2001
First Named Inventor	Lawrence A. Mianzo
Title	METHOD OF CALCULATING A VALVE TIMING COMMAND FOR AN ENGINE
Art Unit	3747
Examiner Name	Solis, Erick R.
Attorney Docket Number	

SIGNATURE of Applicant or Patent Practitioner			
Signature	/Timothy Devlin/	Date (Optional)	2019-12-17
Name	Timothy Devlin	Registration Number	41706
Title (if Applicant is a juristic entity)	Attorney for Applicant		
Applicant Name (if Applicant is a juristic entity)		Michigan Motor Technologies LLC	
NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.			
☒ *Total of 1 forms are submitted.			

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:



Practitioners associated with Customer Number:

163393

OR



Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name	Registration Number

Name	Registration Number

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignment documents attached to this form in accordance with 37 CFR 3.73(c).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(c) to:



The address associated with Customer Number:

163393

OR



Firm or individual name

Address

City

State

Zip

Country

Telephone

Email

Assignee name and address:
MICHIGAN MOTOR TECHNOLOGIES LLC
2360 ORCHARD LAKE ROAD, SUITE 100
SYLVAN LAKE, MICHIGAN 48320

A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/AIA/96 or equivalent) is required to be filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of the practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee.

Signature *KC Brady*

Date 8/5/2019

Name Kevin Brady

Telephone 215 298 3164

Title Managing Member

This collection of information is required by 37 CFR 1.31, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public, which is to update (and by the USPTO to process) the file of a patent or reexamination proceeding. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 18 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**
If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

EXHIBIT A

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: Michigan Motor Technologies LLC

Application No./Patent No.: Patent No.: 6,557,540 Filed/Issue Date: Issued: May 6, 2003

Titled: METHOD OF CALCULATING A VALVE TIMING COMMAND FOR AN ENGINE

Michigan Motor Technologies LLC, a limited liability company

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of options 1, 2, 3 or 4 below):

1. ☒ The assignee of the entire right, title, and interest.
2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

☐ The extent (by percentage) of its ownership interest is % . Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (e.g., bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.
- The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose one of options A or B below):

- A. ☐ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel , Frame , or for which a copy thereof is attached.
- B. ☒ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: Lawrence A. Mianzo, Brett D. Collins, Ibrahim Haskara To: Visteon Global Technologies, Inc.

The document was recorded in the United States Patent and Trademark Office at Reel 012382 , Frame 0565 , or for which a copy thereof is attached.

2. From: Visteon Global Technologies, Inc. To: Godo Kaisha IP Bridge 1

The document was recorded in the United States Patent and Trademark Office at Reel 035421 , Frame 0739 , or for which a copy thereof is attached.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: Godo Kaisha IP Bridge To: Mobile Automotive Technologies, LLC

The document was recorded in the United States Patent and Trademark Office at
Reel 043463, Frame 0223, or for which a copy thereof is attached.

4. From: Godo Kaisha IP Bridge To: Mobile Automotive Technologies, LLC

The document was recorded in the United States Patent and Trademark Office at
Reel 043843, Frame 0821, or for which a copy thereof is attached.

5. From: Mobile Automotive Technologies, LLC To: Michigan Motor Technologies LLC

The document was recorded in the United States Patent and Trademark Office at
Reel 043463, Frame 0881, or for which a copy thereof is attached.

6. From: To:

The document was recorded in the United States Patent and Trademark Office at
Reel, Frame, or for which a copy thereof is attached.

Additional documents in the chain of title are listed on a supplemental sheet(s).

As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.
[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Timothy Devlin/
Signature
Timothy Devlin
Printed or Typed Name

2019-12-17
Date
Reg. No. 41706
Title or Registration Number

Electronic Acknowledgement Receipt	
EFS ID:	38057221
Application Number:	10014286
International Application Number:	
Confirmation Number:	3146
Title of Invention:	METHOD OF CALCULATING A VALVE TIMING COMMAND FOR AN ENGINE
First Named Inventor/Applicant Name:	Lawrence A. Mianzo
Customer Number:	24939
Filer:	Timothy Devlin/Pat Mathews
Filer Authorized By:	Timothy Devlin
Attorney Docket Number:	10541-070
Receipt Date:	17-DEC-2019
Filing Date:	11-DEC-2001
Time Stamp:	15:03:36
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no
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File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Power of Attorney	2019-12-17-USPN6557540-MMT-Transmittal-POA-as-filed.pdf	309420	no	2
			c64a345fa3dd74383b6cd7f148da4729551fc518		

Warnings:

EXHIBIT B

Information:					
2	Assignee showing of ownership per 37 CFR 3.73	2019-12-17-USPN6557540-MMT-373c-Statement.pdf	124146	no	3
			bb176997b12121c42e1aac8974033f5a3a56a4d7		
Warnings:					
Information:					
Total Files Size (in bytes):			433566		
<p>This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.</p> <p><u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.</p> <p><u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.</p> <p><u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.</p>					

CERTIFICATE OF SERVICE

I hereby certify that on December 18, 2019 I caused a true and correct copy of Patent Owner's Power of Attorney and Change of Correspondence Address for Inter Partes Review, with Exhibits A and B, to be served via electronic mail on the following counsel for Petitioner:

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Dated: December 18, 2019

Respectfully submitted,

DEVLIN LAW FIRM LLC

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