ELECTRONIC FUEL INJECTION

Description

The electronic fuel injection system can be divided into two separate systems interconnected only at the injectors.

The systems are:

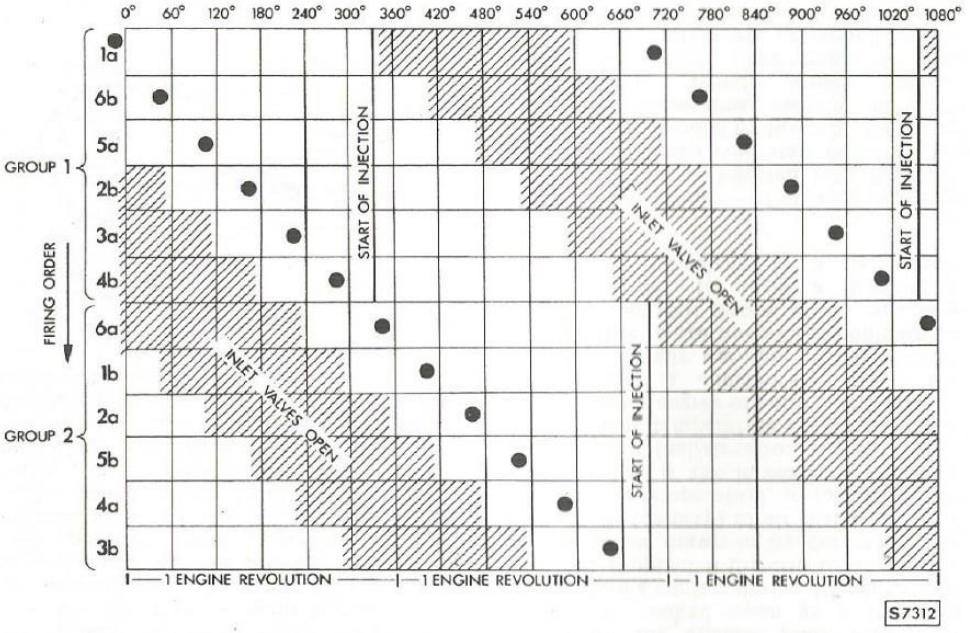
1 A fuel system delivering to the injectors a constant supply of fuel at the correct pressure.

2 An electronic sensing and control system which monitors engine operating conditions of load, speed, temperature (coolant and induction air) and throttle movement. The control system then produces electrical current pulses of appropriate duration to hold open the injector solenoid valves and allow the correct quantity of fuel to flow through the nozzle for each engine cycle.

As the fuel pressure is held constant, varying the electrical pulse duration increases or decreases the amount of fuel passed through the injector to comply precisely with engine requirements.

Pulse duration and therefore fuel quantity, is also modified to provide enrichment during starting and warming up and at closed throttle, full throttle and while the throttle is actually opening.

The injectors are operated by the Electronic Control Unit (ECU) in two groups of six following the engine firing order. Each group is further broken down into two sub-groups of three by a Power Amplifier Unit although each pair of sub-groups is operated simultaneously to make up the two groups of six.

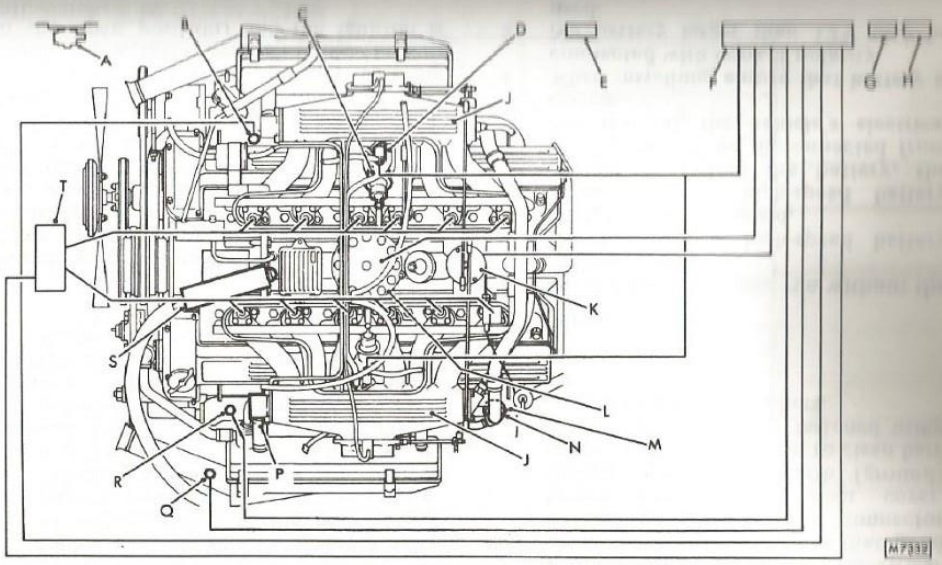


Firing order

A – Right-hand bank B – Left-hand bank
1A 6B 5A 2B 3A 4B 6A 1B 2A 5B 4A 3B
Cylinders numbered from front of engine.

Injection in two groups of six

1st group	2nd group
1A 3A 5A 2B 4B 6B	1B 3B 5B 2A 4A 6A



KEY TO LOCATION DIAGRAM

A	Manifold pressure sensor.
B	Thermotime switch
C	Fuel pressure regulator
D	Cold start injector
E	Cold start relay
F	Electronic control unit (ECU)
G	Fuel pump relay
H	Main relay
J	Induction manifolds
K	Throttle switch
L	Trigger unit
M	Auxiliary air valve
N	Idle speed regulating screw
P	Overrun valve
Q	Air temperature sensor
R	Coolant temperature sensor
S	Fuel cooler
T	Power amplifier

The induction system is basically the same as that on a carburetted engine, tuned ram pipes, air cleaners, plenum chambers and induction ports. The air is drawn through paper element cleaners to a single throttle butterfly valve for each bank and to individual ports for each cylinder leading off the plenum chamber. The injectors are positioned at the cylinder head end of each port so that fuel is directed at the back of each inlet valve.

Fuel System

Fuel is drawn from tank at the rear of the car by a fuel pump via expansion tank and passed through a filter to the fuel rails. Fuel is maintained at a constant pressure of 30 lbf/in² (2,1 kgf/cm²) by pressure regulators 'C'. Any fuel in excess of this pressure is returned to the fuel tank via a cooler 'S'.

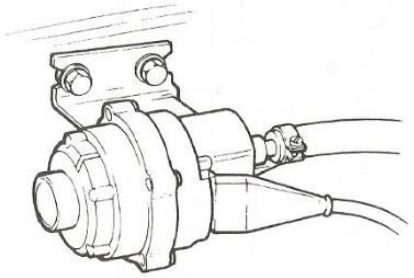
The twelve injectors are connected to the fuel rails. They are solenoid operated and respond to electrical current pulses from the ECU, via a power amplifier, to open and inject fuel into each inlet port. Fuel is also supplied to two cold start injectors 'D' that are operated only during the initial starting of a cold engine.

Electronic System

The main criteria governing the injection of fuel into the engine are manifold depression (engine load) and engine speed.

continued

Engine load sensing – The driver controls engine power output by varying the throttle opening and therefore the flow of air into the engine. The air flow determines the pressure that exists within the plenum chamber, the pressure being a measure of the demand upon the engine. This pressure is used to provide the principle control of fuel quantity being converted by the pressure sensor 'A' into an electrical signal to be passed to the ECU 'F'. The signal varies the duration of the injector operating pulse as appropriate.
The pressure sensor is fitted with a separate diaphragm system that compensates for ambient barometric variations.



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Engine speed sensing – The trigger unit 'L' fitted within the distributor has two reed switches mounted 180° apart so that they are closed alternatively, one each revolution of the crankshaft. Each switch 'triggers' the ECU to produce the timed electrical current pulse to a group of six injectors, although the trigger switch itself has no part in determining the pulse length. In addition to this primary function of initiation of injection, the trigger unit switching is monitored by the ECU for frequency of operation. From this signal an engine speed function is determined that modifies the pulse width, already established by manifold pressure, to take account of engine speed – dependant resonances in induction and exhaust.

Temperature sensors – The temperature of the air being taken into the engine through the inlet manifold and the temperature of the coolant in the cylinder block is constantly monitored. The information is fed directly to the ECU.
The air temperature sensor 'Q' has a small effect on the injector pulse width and should be looked upon as a trimming rather than a control device. It ensures that the fuel supplied is directly related to the weight of air drawn in by the engine. As the weight (density) of air charge increases with falling temperature, so the amount of fuel supplied is also increased to maintain the optimum fuel/air ratio.
The coolant temperature sensor 'R' has a much greater degree of control although its main effect is concentrated while the engine is initially warming up. The coolant temperature sensor operates in conjunction with the cold start system and the auxiliary air valve 'M' to form a completely automatic equivalent to a carburetter choke.

Cold start system – For cold starting, additional fuel is injected into the inlet manifolds by two cold start injectors 'D'. These are controlled by the cold start relay 'E' and thermotime switch 'B'. The thermotime switch senses coolant temperature and depending on that temperature, interrupts or completes the earth (ground) connection for the relay. When the starter is operated, the cold start relay is energised with its circuit completed via the thermotime switch. The thermotime switch also limits the length of time for which the relay is energised, to a maximum of eight seconds under conditions of extreme cold. This enrichment is in addition to that provided by the coolant temperature sensor. If the coolant temperature is above the rated value of the thermotime switch, the thermotime switch does not operate; no starting enrichment being required.

Cranking enrichment – The ECU provides an increased pulse duration during engine cranking in addition to any enrichment due to the coolant temperature sensor or the cold start injectors. The additional signal reduces slightly when cranking stops but does not fall to normal level for a few seconds. This temporary enrichment sustains the engine during initial running.

Throttle switch – The throttle switch 'K' is a rotary switch directly coupled to the throttle pulley. It contains sets of contacts that provide information for the ECU regarding the position and movement of the throttle butterfly valves. The operation of these contacts is as follows.

1 **Throttle closed (idle) contacts**
These contacts establish a specific, slightly richer, level of fuelling while the throttle is completely closed and the engine is running at idling revolutions. While the throttle is in this position, the exhaust CO level can be varied using the idle mixture control knob on the ECU. This knob **MUST NOT** be moved unless correct test equipment and skilled personnel are in attendance to monitor changes made.

2 **Throttle movement contacts**
Immediately the throttle is opened a series of 20 make-and-break contacts are put into circuit. If the throttle butterfly is opened quickly a slight delay occurs before the pressure sensor reacts to the change in manifold pressure. This period of delay is overcome by the throttle switch contacts which transmit a series of voltage spikes to the ECU. These signals produce an increased pulse duration while the throttle is moving.

On certain cars full load enrichment is provided by revising the response curve of the manifold pressure sensor. In these instances the full throttle enrichment contacts necessary for cars to USA Federal specifications are not used.

Flooding Protection System
When the ignition is on but the engine not cranking, the fuel pump will run for one to two seconds to raise the pressure in the fuel rail; it is then automatically switched off by the ECU. Only after cranking has started is the pump switched on again. Switching control is built into the ECU circuitry. This system prevents flooding should any injectors become faulty (remain in the open position) and the ignition is left switched on.

Auxiliary Air Valve
The auxiliary air valve 'M' is controlled by coolant temperature. To prevent stalling at cold start and cold idle conditions due to the increased drag of the engine, the valve opens to allow air to by-pass the throttles and so increase engine speed. In addition to the main coolant temperature regulated air passage, the auxiliary air valve has a by-pass controlled by an adjusting screw 'N'. This screw controls the idle speed by regulating the air flow.

GOOD PRACTICE

The following instructions must be strictly observed.

1 Always disconnect the battery before removing any components.
2 Always depressurise the fuel system before disconnecting any fuel pipes.
3 When removing fuelling components always clamp fuel pipes approximately 1.5 in (38 mm) from the unit being removed. Do not overtighten clamps.
4 Ensure rags are available to absorb any spillage that may occur.
5 When re-connecting electrical components always ensure that good contact is made by the connector before fitting the rubber cover. Always ensure that earth (ground) connections are made on to clean bare metal, and are tightly fastened using correct screws and washers.

WARNING

1 **Do not let the engine run without the battery connected.**
2 **Do not use a high-speed battery charger as a starting aid.**
3 **When using a high-speed battery charger to charge the battery, the battery MUST be disconnected from the rest of the vehicle's electrical system.**
4 **When installing, ensure that battery is connected with correct polarity.**
5 **No battery larger than 12V may be used.**

MAINTENANCE

There is no routine maintenance procedure laid down for the Electronic Fuel Injection System other than that at 12,000 mile (20,000 km) intervals the fuel filter must be discarded and a replacement component fitted. At all service intervals, the electrical connectors must be checked for security.

Fault finding

The fault finding procedures are divided into two sections. The first section considers initial roadside diagnosis and rectification, while the second section gives a complete test layout and usage procedure for the Lucas 'EPITEST' equipment.

Initial diagnosis

Fault conditions in this section can be further divided into three types as follows:

1 Faults that prevent the engine from starting.
2 Faults that allow the engine to start, but stop it either immediately or after a short delay.
3 Faults that allow starting and continued running, but cause incorrect fuelling at some stage of a driving cycle.

Examples of all three classes of fault are given in the 'Symptoms' column of the Initial Diagnosis and Rectification chart, together with a list of possible causes in the order in which they should be checked. This is followed by Procedures for Rectification which details the effect that each possible failure will have upon the engine and its remedy. It is assumed that the vehicle has sufficient fuel in the tanks, and that purely engine functions, e.g. ignition timing, valve timing, and the ignition system as a whole are operating satisfactorily. If necessary, these functions must be checked by following the relevant procedures in the Repair Operations Manual before the fuel injection system is suspected.

INITIAL DIAGNOSIS AND RECTIFICATION

POSSIBLE CAUSES IN ORDER OF CHECKING

	Will not start*	Difficult cold start	Difficult hot start	Starts but will not run	Misfires and cuts out	Runs rough	Idle speed too fast	Hunting at idle	Low power and top speed	High fuel consumption
Battery	A	A	A							
Connections	B	B	B	A	A	A			A	A
Ignition system	C	C	C	B	B	B	B		C	B
Fuel system	D	E	E	D	C	C			D	D
Trigger unit	E	F								
Pressure sensor	F	G	F	E	D	D		B	B	C
Cold start system	G	D	D	C	E	F				F
ECU/amplifier	H	J	H	G	G	H		D		H
Air leaks		G					A			
Temperature sensors		H	G	F	F	G			G	G
Auxiliary air valve			F	E	D					
Throttle switch						E			F	E
Throttle butterfly							C			
Overrun valve							D			
Compression								A	E	
Idle fuel control setting								C		
Air filters									B	
Throttle linkage									F	

* Before proceeding with checks, hold throttle fully open and attempt a start. If the engine then starts and continues to run, no further action is necessary.

PROCEDURES FOR RECTIFICATION OF CAUSES SHOWN IN TABLE

Battery: Battery depleted, giving insufficient cranking speed or inadequate spark. Check battery condition with hydrometer; Recharge, clean and secure terminals, or renew as necessary.

Connections: Ensure all connector plugs are securely attached. Pull back rubber boot and ensure plug is fully home. While replacing boot press cable towards socket. Ensure Electronic Control Unit (ECU) multi-pin connector is fully made. Ensure all ground connections are clean and tight.

Ignition System: Check ignition system as detailed in electrical section.

Fuel System: Check for fuel pipe failure (strong smell of fuel). Check inertia switch closed. If necessary, clear fuel tank vents or supply pipe.

Trigger Unit: Check operation of reed switches; engine will not run unless both reed switches are satisfactory.

Pressure Sensor: Ensure manifold pressure reference pipe is attached to sensor and is not twisted, kinked or disconnected elsewhere. Engine may start but will run badly.

Cold Start System: Fault conditions could cause cold start system to be inoperative on a cold engine, or operative on a hot engine. If engine is either very hot, or cold, these particular faults will cause the engine to run very rich. Check cold start system, see 19.22.32.

ECU/Amplifier: If either of these components is faulty it is possible that various groups of injectors will be inoperative. This will range from barely detectable, one group, to very rough or no start, two, three or four groups. The ECU may also be responsible for any degree of incorrect fuelling. Before suspecting the ECU for fuelling problems, however, all other likely components should be proved good.

Air Leaks: Ensure all hose and pipe connections are secure. Engine is, however, likely to start more easily with air leaks if cold, as air leaking augments that through the auxiliary air valve. A leak, or failed air valve is shown up, however, by a very high idle speed when engine is warm and air valve main passage should be closed.

Temperature Sensors: If either sensor is short-circuited, starting improves with higher engine temperature. Engine will run very weak, improving as temperature rises, but still significantly weak when fully hot. If a sensor is open circuit, or disconnected, engine will run very rich, becoming worse as temperature rises. Engine may not run when fully hot, and will almost certainly not re-start if stalled. Effect of air temperature sensor will be less marked than coolant temperature sensor.

Auxiliary Air Valve: Check opening throttle. If engine immediately starts, unscrew idle speed adjustment, and re-check start with closed throttle. Re-set idle speed when engine hot. Check cold start. Check throttle return springs and linkage for sticking or maladjustment as a sticking throttle may have enforced incorrect idle speed adjustment on a previous occasion.

Throttle Switch: Check operation of throttle switch. Incorrect function or sequence of switching will give this fault.

Throttle Butterfly: Check adjustment of both throttle butterfly valves, ensure return springs correctly fitted, and throttle not sticking open.

Overrun valve: Check operation of overrun valve—19.20.21.

Compression: Low compressions; a general lack of engine tune could cause this fault. Check engine timing, ignition timing, and function of ignition system complete. If necessary, check valve condition.

Idle Fuel Control Setting: Set butterfly valve (see 19.20.11). Set idle speed adjustment screw — 19.20.16/17/18 to obtain 750 rev/min with engine fully warm. Remove cap from air injection diverter valve to interrupt air injection. Run engine at 2,000 rev/min for 15 seconds and return to idle speed. Adjust idle potentiometer (see CAUTION) on electronic control unit to obtain required CO reading (1—2%) at sampling point in the end of each air injection rail. Refit cap to diverter valve and reset idle speed if necessary.

CAUTION: This knob MUST NOT be moved unless correct test equipment and skilled personnel are in attendance to monitor changes made.

Air Filters: Remove air filters and check for choked filter element.

Throttle Linkage: Check throttle linkage adjustment and ensure that throttle butterfly valves can be fully operated.

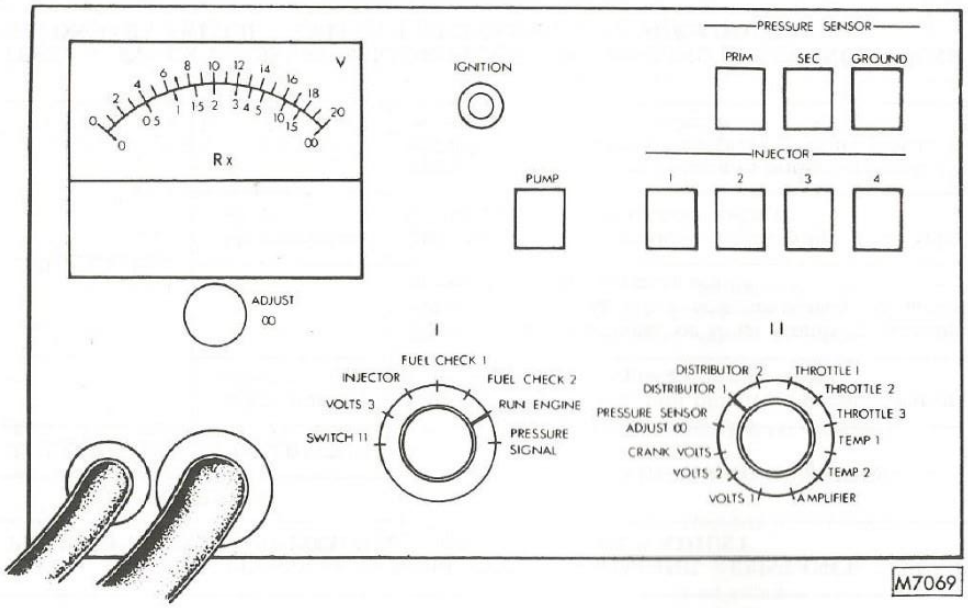
PREPARATION

Ensure all connections are clean and tight, particularly battery connections and engine to chassis bonding strap. Check battery condition and ensure ignition system satisfactory.

If engine still refuses to run, carry out the following test procedure commencing with Part A.

Operating Instructions for 'EPITEST' Test Box

CAUTION: Ensure ignition is switched off at all times when making or breaking main wiring connections.



Part A

1 Disconnect harness multi-plug from ECU.
2 Connect test box 25-way multi-plug adaptor to vehicle harness multi-plug.
3 Select 'Switch II' on switch I.
4 Select 'Volts 1' on switch II.
5 Switch on vehicle ignition and leave on for all tests in Part A. Warning lamp on test box should illuminate, otherwise check ignition supply, multi-plug, etc.
6 Continue testing until end of Part A, moving to new position on switch II, and using push switches when indicated on test chart.
7 Rectify any faults found before continuing with further tests.
8 Switch off ignition on completion of tests in Part A.

TEST 1 – CHECK VOLTAGE SUPPLIES TO ECU – SWITCH II AT 'VOLTS 1'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
11–12.5V	No reading	(a) Open circuit or poor connections between pin 16 of ECU and terminal 87 of main relay. (b) Main relay not energised; check voltage at terminal 86 of main relay. If 0V, check feed from ignition switch. If satisfactory, check relay (terminal 85) and its ground connections. (c) Check voltage at terminal 30 of relay. If 0V, check battery supply.
	Low–below 11V	Battery flat, or high resistance in cable to pins 11 and 16 of ECU, or across relay contacts.

TEST 2 – CHECK VOLTAGE SUPPLIES TO ECU – SWITCH II AT 'VOLTS 2'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
11–12.5V	No reading	As test 1, but check for open circuit or poor connections between pin 24 of ECU and terminal 87 of main relay.

TEST 3 – CHECK VOLTAGE AT START FEED TO ECU (TERMINAL 18) – CRANK ENGINE WITH STARTER MOTOR – SWITCH II AT 'CRANK VOLTS'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
9.0–12V while cranking	No reading, starter operates	Open circuit between starter relay terminal C4 and ECU (check cable to terminal 18 on ECU). Also check operation of starter relay.
	No reading, starter does not operate	Check ignition/start switch, starter relay, solenoid, all connections and associated wiring.
	Below 9.0V	Battery flat, or excessive voltage drop. Check all cables and connections including ignition/start switch, and starter relay circuit (check cable with voltmeter).

TEST CHART – PART A

CALIBRATE METER CIRCUITS TO BATTERY VOLTAGE/CHECK BATTERY VOLTAGE – SET METER TO '00' WITH 'ADJUST 00' CONTROL – SWITCH II AT 'PRESSURE SENSOR ADJUST 00'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
'∞'	Other than '00'	Battery voltage too low, replace with charged unit.

TEST 4 – CHECK PRESSURE SENSOR PRIMARY WINDING RESISTANCE – PUSH 'PRIMARY SWITCH' – SWITCH II AT 'PRESSURE SENSOR ADJUST'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
00.8–1.2 ohms	Below nominal value	Damage to insulation; pull plug from pressure sensor. If meter shows '∞' replace pressure sensor.
	'0'	Short circuit to ground, or short circuit in primary winding. Pull plug from pressure sensor. If meter shows '∞', replace pressure sensor.
	Above nominal value	High resistance connections; check plugs and cables for poor connections or open circuits.
	'∞'	Open circuit; disconnect plug and bridge terminals 15 and 17. If meter shows '0', replace pressure sensor. If '∞' is indicated, check cables.

TEST 5 – CHECK PRESSURE SENSOR SECONDARY WINDING RESISTANCE – PUSH 'SECONDARY SWITCH' – SWITCH II AT 'PRESSURE SENSOR ADJUST'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
3–4 ohms	As test 4 except '∞'	Open circuit, disconnect plug and bridge terminals 10 and 8. If meter shows '0', replace pressure sensor. If '∞' is indicated, check cables.

TEST 6 – CHECK PRESSURE SENSOR WINDINGS FOR SHORT CIRCUIT TO GROUND – PUSH 'GROUND' SWITCH – SWITCH II AT 'PRESSURE SENSOR ADJUST'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
'∞'	'0'	Short circuit to ground in cables or at pressure sensor. Pull plug from pressure sensor, if meter shows '00' replace pressure sensor. If meter remains at '0', check cables between plug and terminals 7, 8, 10 and 15 at ECU for short circuit.
	Below '∞' but not '0'	Damage to insulation either in sensor or cables as above.

TEST 7 – CHECK TRIGGER CONTACTS IN DISTRIBUTOR – ROTATE DISTRIBUTOR BY CRANKING ENGINE – SWITCH II AT 'DISTRIBUTOR 1'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
Alternating between '∞' and '1'	Constant at '∞' or '1'	Check terminals 12, 21 and 22 at trigger. Check for faulty in-line cable connector. If terminals and cable satisfactory, replace trigger unit.

TEST 8 – CHECK TRIGGER CONTACTS IN DISTRIBUTOR – ROTATE DISTRIBUTOR BY CRANKING ENGINE – SWITCH II AT 'DISTRIBUTOR 2'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
Alternating between '∞' and '1'	Constant at '∞' or '1'	Check terminals 12, 21 and 22 at trigger. Check for faulty in-line cable connector. If terminals and cable satisfactory, replace trigger unit.

TEST 9 – CHECK TEMPORARY ENRICHMENT DEVICE – OPEN THROTTLE SLOWLY – SWITCH II AT 'THROTTLE 1'

METER READING		POSSIBLE FAULTS AND REMEDIES
CORRECT	INCORRECT	
Needle should swing between '1' and '∞' approx. 20 times	See next column	As the fully open throttle is released, the meter needle must remain at '∞'. If '1' is shown the throttle switch is faulty and must be replaced. If some of the swings are missed as the throttle is opened, re-check. If still not satisfactory, replace throttle switch.