CHAPTER

Diagnostic techniques

2.1 Introduction

2.1.1 Logic

Diagnostics or faultf nding is a fundamental part of an automotive technician's work. The subject of diagnostics does not relate to individual areas of the vehicle. If your knowledge of a vehicle system is at a suitable level, then you will use the same logical process for diagnosing the fault, whatever the system.

2.1.2 Information

Information and data relating to vehicles are available for carrying out many forms of diagnostic work. The data may come as a book, online or on CD/DVD. This information is vital and will ensure that you f nd the fault – particularly if you have developed the diagnostic skills to go with it. Faultf nding charts and specif c examples are presented in later chapters. The general type of information available is as follows:

- engine diagnostics, testing and tuning;
- servicing, repairs and times;
- fuel and ignition systems;
- auto electrics data;
- component location;
- body repairs, tracking and tyres.

2.1.3 Where to stop?

This is one of the most diff cult skills to learn. It is also one of the most important. The secret is twofold:

- know your own limitations – it is not possible to be good at everything;
- leave systems alone where you could cause more damage or even injury – for example, air bag circuits.

Often with the best of intentions, a person new to diagnostics will not only fail to f nd the fault but also introduce more faults into the system in the process. I would suggest you learn your own strengths and weaknesses; you may be conf dent and good at dealing with mechanical system problems but less so when electronics is involved. Of course you may be just the opposite of this.

Key fact

Know your own limitations.

Advanced Automotive Fault Diagnosis.

Remember that diagnostic skill is in two parts – the knowledge of the system and the ability to apply diagnostics. If you do not yet fully understand a system, leave it alone until you do.

2.2 Diagnostic process

2.2.1 Six-stage process

A key checklist – the six stages of fault diagnosis – is given in Table 2.1 and Figure 2.1 shows this as a f ow chart.

Here is a very simple example to illustrate the diagnostic process. The reported fault is excessive use of engine oil.

1 Question the customer to f nd out how much oil is being used (is it excessive?).
2 Examine the vehicle for oil leaks and blue smoke from the exhaust. Are there any service bulletins?

Table 2.1 Stages of diagnostics

1. Verify: Is there actually a problem, can you confirm the symptoms
2. Collect: Get further information about the problem, by observation and research
3. Evaluate: Stop and think about the evidence
4. Test: Carry out further tests in a logical sequence
5. Rectify: Fix the problem
6. Check: Make sure all systems now work correctly

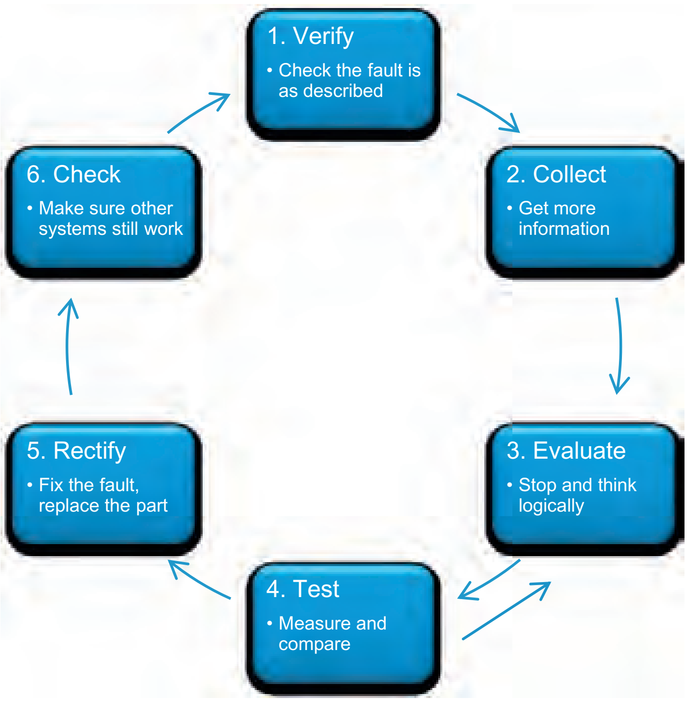


Figure 2.1 Six-stage diagnostic process

3 If leaks are found the engine could still be burning oil but leaks would be a likely cause.
4 A compression test, if the results were acceptable, would indicate a leak to be the most likely fault. Clean down the engine and run for a while. The leak will show up better.
5 Change a gasket or seal, etc.
6 Run through an inspection of the vehicle systems particularly associated with the engine. Double-check that the fault has been rectif ed and that you have not caused any further problems.

The six-stage diagnostic process will be used extensively to illustrate how a logical process can be applied to any situation.

Key fact

The six-stage diagnostic process is recommended but there are others that are similar – the important thing is to follow any 'process' logically:

1. Verify
2. Collect
3. Evaluate
4. Test
5. Rectify
6. Check.

2.2.2 The art of diagnostics

The knowledge needed for accurate diagnostics is in two parts:

1 understanding of the system in which the problem exists;
2 having the ability to apply a logical diagnostic routine.

The knowledge requirement and use of diagnostic skills can be illustrated with a very simple example:

After connecting a hosepipe and turning on the tap, no water comes out of the end. Your knowledge of this system tells you that water should come out providing the tap is on, because the pressure from a tap pushes water through the pipe, and so on. This is where your diagnostic skills become essential. The following stages are now required:

Safety f rst

Don't point any pipes at your eyes.

1 Conf rm that no water is coming out by looking down the end of the pipe.
2 Check if water comes out of the other taps, or did it come out of this tap before you connected the hose?
3 Consider what this information tells you; for example, if the answer is 'Yes' the hose must be blocked or kinked.
4 Walk the length of the pipe looking for a kink.
5 Straighten out the hose.
6 Check that water now comes out and that no other problems have been created.

Much simplif ed I accept, but the procedure you have just followed made the hose work and it is also guaranteed to f nd a fault in any system. It is easy to see how it works in connection with a hosepipe and I'm sure anybody could have found that fault (well most people anyway).

The higher skill is to be able to apply the same logical routine to more complex situations. The routine (Table 2.1) is also represented by Figure 2.1. The loop will continue until the fault is located.

I will now explain each of these steps further in relation to a more realistic automotive workshop situation – not that getting the hose to work is not important! Often electrical faults are considered to be the most diff cult to diagnose – but this is not true. I will use a vehicle cooling system fault as an example here, but electrical systems will be covered in detail in later chapters. Remember that the diagnostic procedure can be applied to any problem – mechanical, electrical or even medical.

However, let us assume that the reported fault with the vehicle is overheating. As is quite common in many workshop situations that's all the information we have to start with. Now work through the six stages:

- Stage 1 – Take a quick look to check for obvious problems such as leaks, broken drive belts or lack of coolant. Run the vehicle and conf rm that the fault exists. It could be the temperature gauge, for example.
- Stage 2 – Is the driver available to give more information? For example, does the engine overheat all the time or just when working hard? Check records, if available, of previous work done to the vehicle.
- Stage 3 – Consider what you now know. Does this allow you to narrow down what the cause of the fault could be? For example, if the vehicle overheats all the time and it had recently had a new cylinder head gasket f tted, would you be suspicious about this? Do not let two and two make f ve, but do let it act as a pointer. Remember that in the science of logical diagnostics, two and two always makes four. However, until you know this for certain then play the best odds to narrow down the fault.
- Stage 4 – The further tests carried out would now be directed by your thinking at stage 3. You do not yet know if the fault is a leaking head gasket, the thermostat stuck closed or some other problem. Playing the odds, a cooling system pressure test would probably be the next test. If the pressure increases when the engine is running, then it is likely to be a head gasket or similar problem. If no pressure increase is noted, then move on to the next test and so on. After each test go back to stage 3 and evaluate what you know, not what you don't know.
- Stage 5 – Let us assume the problem was a thermostat stuck closed – replace it and top up the coolant, etc.
- Stage 6 – Check that the system is now working. Also check that you have not caused any further problems such as leaks or loose wires.

This example is simplif ed a little, but like the hosepipe problem it is the sequence that matters, particularly the 'stop and think' at stage 3. It is often possible to go directly to the cause of the fault at this stage, providing that you have an adequate knowledge of how the system works.

2.2.3 Concern, cause, correction

The three Cs, as concern, cause, correction are sometimes described, is another reminder that following a process for automotive repairs and diagnostics is essential.

It is in a way a simplif ed version of our six-stage process as shown in Table 2.2.

Table 2.2 Repair and diagnostic processes

Six-stage process	CCC
Verify	Concern
Collect Evaluate Test	Cause
Rectify Check	Correction

Table 2.3 is a further example where extra suggestions have been added as a reminder of how important it is to collect further information. It is also recommended that this information and process is included on the jobsheet so the customer is kept informed. Most customer complaints come about because of poor work or poor communication – this may be acceptable in some poor quality establishments but not in any that you and I are involved in – be professional and you will be treated like one (lecture over, sorry).

So, while the concern, cause, correction sequence is quite simple, it is very effective as a means of communication as well as a diagnosis and repair process. An example jobcard/jobsheet is available for download from www.automotive-technology.co.uk that includes the three Cs. It is ideal as a training aid as well as for real use.

Key fact

Most customer complaints are as a result of poor work or poor communication.

2.2.4 Root cause analysis

The phrase 'root cause analysis' (RCA) is used to describe a range of problem-solving methods aimed at identifying the root causes of problems or events. I have included this short section because it helps to reinforce the importance of keeping an open mind when diagnosing faults, and again, stresses the need to

Table 2.3 CCC process

Process outline	Example situation	Notes
Customer Concern:	Battery seems to be discharged and will sometimes not start the car. It seems to be worse when the headlights are used	This should set you thinking that the cause is probably a faulty battery, a charging system fault, a parasitic discharge or a starter motor problem (the symptoms would suggest a charging fault is most likely but keep an open mind)
Vehicle service history information:	Car is five years old, has done 95 000 miles but has a good service history. A new battery was fitted one year ago and the cam belt was replaced two years ago	Battery probably ok and drive belt adjustment likely to be correct (still suspicious of a charging fault)
Related technical service bulletins:	New camshaft drive belt should be fitted every 50 000 miles	Not connected but it would be good to recommend that the belt was changed at this time
Diagnostic procedures performed:	Battery voltage and discharge test – ok Drive belt tension – ok (but a bit worn) Alternator charging voltage – 13 V Checked charging circuit for volt drop – ok	14 V is the expected charging voltage on most systems
Cause:	Alternator not producing correct voltage	An auto electrician may be able to repair the alternator but for warranty reasons a new or reconditioned one is often best (particularly at this mileage)
Correction:	Reconditioned alternator and new drive belt fitted and checked – charging now ok at 14 V	Note how by thinking about this process we had almost diagnosed the problem before doing any tests, also note that following this process will make us confident that we have carried out the correct repair, first time. The customer will appreciate this – and will come back again

Def nition

RCA: Root cause analysis.

work in a logical and structured way. The root cause of a problem is not always obvious; an example will help to illustrate this:

Let us assume the symptom was that one rear light on a car did not work. Using the six-stage process, a connector block was replaced as it had an open circuit fault. The light now works ok but what was missed was that a small leak from the rear screen washer pipe dripped on the connector when the washer was operated. This was the root cause.

The practice of RCA is based, quite rightly, on the belief that problems are best solved by attempting to address, correct or eliminate the root causes, as opposed to just addressing the faults causing observable symptoms. By dealing with root causes, it is more likely that problems will not reoccur. RCA is best considered to be an iterative process because complete prevention of recurrence by one corrective action is not always realistic.

Root causes of a problem can be in many different parts of a process. This is sometimes represented by a ‘f shbone’ diagram. Two examples are presented as Figures 2.2 and 2.3. These show how any one cause on any one branch (or rib) can result in a problem at the end of a more complex process.

RCA is usually used as a reactive method of identifying causes, revealing problems and solving them and it is done after an event has occurred. However,

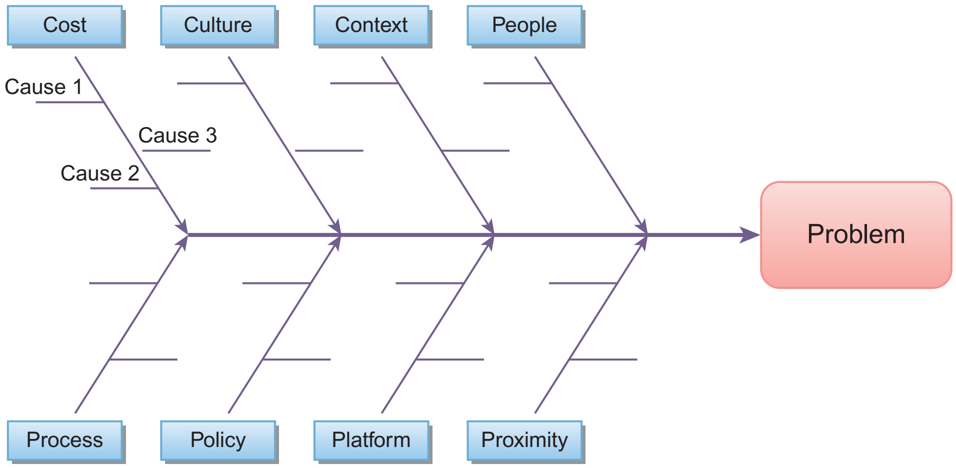


Figure 2.2 Fishbone diagram showing possible root causes of a problem in software development

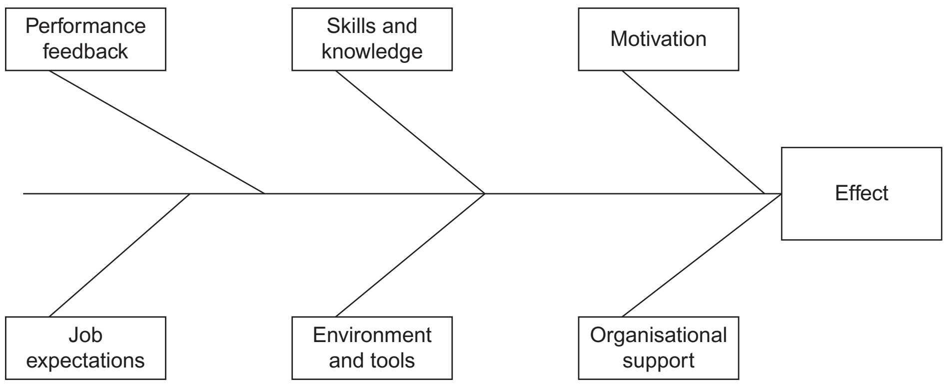


Figure 2.3 Fishbone diagram that could be used to look at diagnostic processes

RCA can be a useful proactive technique because, in some situations, it can be used to forecast or predict probable events.

RCA is not a single def ned methodology. There are a number of different ways of doing the analysis. However, several very broadly def ned methods can be identif ed:

- Safety-based RCA descends from the f elds of accident analysis and occupational safety and health.
- Production-based RCA has its origins in the f eld of quality control for industrial manufacturing.
- Process-based RCA is similar to production-based RCA, but has been expanded to include business processes.
- Failure-based RCA comes from the practice of failure analysis used in engineering and maintenance.

The following list is a much simplif ed representation of a failure-based RCA process. Note that the key steps are numbers 3 and 4. This is because they direct the corrective action at the true root cause of the problem.

1 Def ne the problem.
2 Gather data and evidence.
3 Identify the causes and root causes.
4 Identify corrective action(s).
5 Implement the root cause correction(s).
6 Ensure effectiveness (Figure 2.4).

As an observant reader, you will also note that these steps are very similar to our six-stage faultf nding process.

Key fact

RCA directs the corrective action at the true root cause of the problem.

2.2.5 Summary

I have introduced the six-stage process of diagnostics, not so that it should always be used as a checklist but to illustrate how important it is to follow a

Key fact

Six-stage process:

1. Verify
2. Collect
3. Evaluate
4. Test
5. Rectify
6. Check.

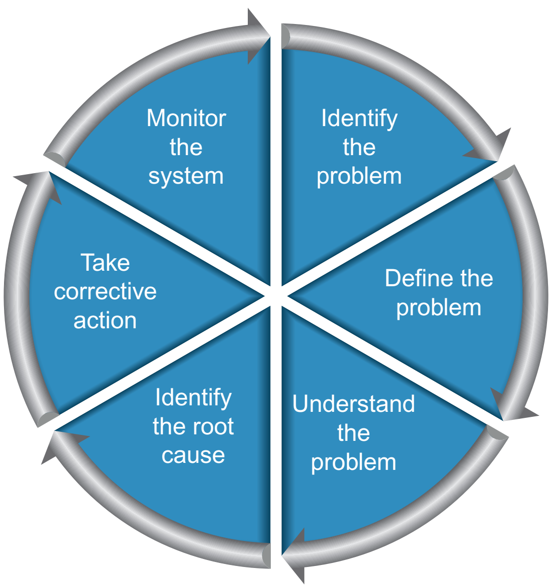


Figure 2.4 RCA process

Def nition

'Logic is the beginning of wisdom not the end'. (Spock to Valeris, *Star Trek II*).

process. Much more detail will be given later, in particular about stages 3 and 4. The purpose of this set process is to ensure that 'we' work in a set, logical way.

2.3 Diagnostics on paper

2.3.1 Introduction

Key fact

Stop and think before pulling the vehicle to pieces.

This section is again a way of changing how you approach problems on a vehicle. The key message is that if you stop and think before 'pulling the vehicle to pieces', it will often save a great deal of time. In other words, some of the diagnostic work can be done 'on paper' before we start on the vehicle. To illustrate this, the next section lists symptoms for three separate faults on a car and for each of these symptoms, three possible faults.

2.3.2 Examples

All the faults are possible in the following example, but in each case see which you think is the 'most likely' option (Table 2.4).

The most likely fault for example A is number 3. It is possible that all the lights have blown but unlikely. It could not be the auxiliary relay because this would affect other systems.

For example B, the best answer would be number 2. It is possible that the pump pressure is low but this would be more likely to affect operation under other conditions. A loose wire on the engine speed sensor could cause the engine to stall but it would almost certainly cause misf re under other conditions.

The symptoms in example C would suggest answer 1. The short circuit suggested as answer 3 would be more likely to cause lights and others to stay on rather than not work, equally the chance of a short between these two circuits is remote if not impossible. If the lighting fusible link were blown then none of the lights would operate.

The technique suggested here relates to stages 1–3 of the 'the six stages of fault diagnosis' process. By applying a little thought before even taking a screwdriver to the car, a lot of time can be saved. If the problems suggested in the previous table were real we would at least now be able to start looking in the right area for the fault.

Table 2.4 Example faults

Symptoms	Possible faults
A: The brake/stoplights are reported as not operating. On checking it is conf rmed that neither of the two bulbs or the row of high-mounted LEDs are operating as the pedal is pressed. All other systems work correctly	1. Two bulbs and 12 LEDs blown 2. Auxiliary systems relay open circuit 3. Brake light switch not closing
B: An engine f tted with full management system tends to stall when running slowly. It runs well under all other conditions and the reported symptom is found to be intermittent	1. Fuel pump output pressure low 2. Idle control valve sticking 3. Engine speed sensor wire loose
C: The off side dip beam headlight not operating. This is conf rmed on examination and also noted that the off side tail lights do not work	1. Two bulbs blown 2. Main lighting fusible link blown 3. Short circuit between off side tail and dip beam lights

2.3.3 How long is a piece of string?

Yes I know, twice the distance from the middle to one end. What I am really getting at here though is the issue about what is a valid reading or measurement and what is not – when compared to data. For example, if the 'data source' says the resistance of the component should be between 60 and 90Ω, what do you do when the measured value is 55Ω? If the measured value was 0Ω or 1000Ω then the answer is easy – the component is faulty. However, when the value is very close you have to make a decision. In this case (55Ω) it is very likely that the component is serviceable.

The decision over this type of issue is diff cult and must, in many cases, be based on experience. As a general guide, however, I would suggest that if the reading is in the right 'order of magnitude', then the component has a good chance of being OK. By this I mean that if the value falls within the correct range of 1s, 10s, 100s or 1000s, etc, then it is probably good.

Do notice that I have ensured that words or phrases such as 'probably', 'good chance' and 'very likely' have been used here. This is not just to make sure I have a get out clause; it is also to illustrate that diagnostic work can involve 'playing the best odds' – as long as this is within a logical process.

Def nition

Order of magnitude:

- A degree in a continuum of size or quantity;
- A number assigned to the ratio of two quantities;
- Two quantities are of the same order of magnitude if one is less than 10 times as large as the other;
- The number of magnitudes that the quantities differ is speci ed to within a power of 10.

2.4 Mechanical diagnostic techniques

2.4.1 Check the obvious f rst

Start all hands-on diagnostic routines with 'hand and eye checks'. In other words, look over the vehicle for obvious faults. For example, if automatic transmission f uid is leaking on to the f oor then put this right before carrying out complicated stall tests. Here are some further suggestions that will at some point save you a lot of time.

- If the engine is blowing blue smoke out of the exhaust – consider the worth of tracing the cause of a tapping noise in the engine.
- When an engine will not start – check that there is fuel in the tank (Figure 2.5).

Key fact

All diagnostic routines should include 'hand and eye checks'.

2.4.2 Noise, vibration and harshness

Noise, vibration and harshness (NVH) concerns have become more important as drivers have become more sensitive to these issues. Drivers have higher expectations of comfort levels. NVH issues are more noticeable due to reduced engine noise and better insulation in general. The main areas of the vehicle that produce NVH are:

- tyres;
- engine accessories;
- suspension;
- driveline.

It is necessary to isolate the NVH into its specif c area(s) to allow more detailed diagnosis. A road test, as outlined later, is often the best method.

The f ve most common sources of non-axle noise are exhaust, tyres, roof racks, trim and mouldings, and transmission. Ensure that none of the following

Def nition

NVH: Noise, vibration and harshness.

Key fact

The fve most common sources of non-axle noise are exhaust, tyres, roof racks, trim and mouldings, and transmission.

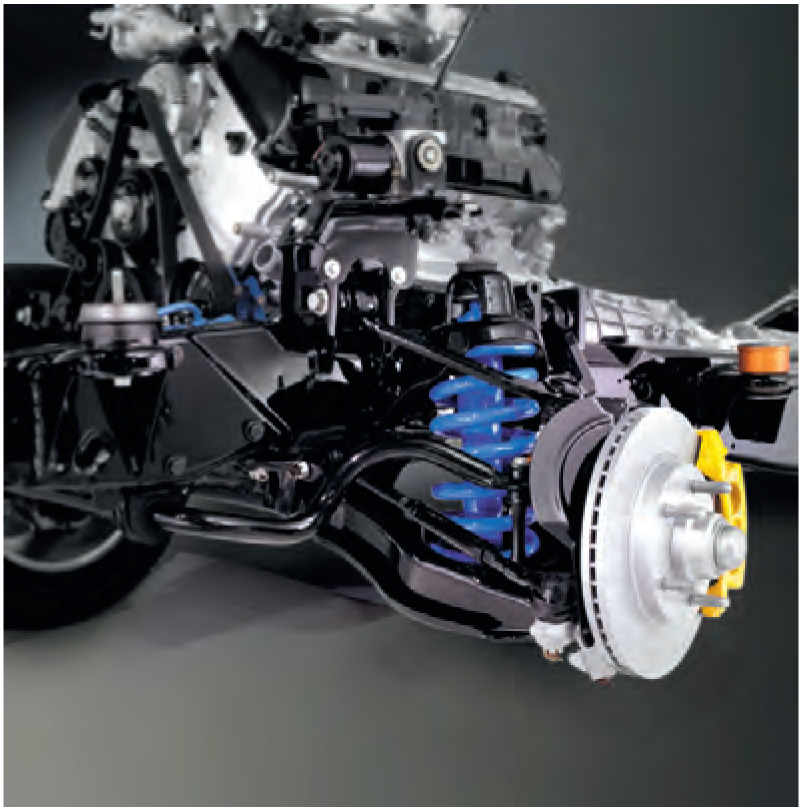


Figure 2.5 Mechanical systems

conditions is the cause of the noise before proceeding with a driveline strip down and diagnosis.

1 In certain conditions, the pitch of the exhaust may sound like gear noise or under other conditions like a wheel bearing rumble.
2 Tyres can produce a high-pitched tread whine or roar, similar to gear noise. This is particularly the case for non-standard tyres.
3 Trim and mouldings can cause whistling or whining noises.
4 Clunk may occur when the throttle is applied or released due to backlash somewhere in the driveline.
5 Bearing rumble sounds like marbles being tumbled.

2.4.3 Noise conditions

Noise is very diff cult to describe. However, the following are useful terms and are accompanied by suggestions as to when they are most likely to occur.

- Gear noise is typically a howling or whining due to gear damage or incorrect bearing preload. It can occur at various speeds and driving conditions or it can be continuous.
- 'Chuckle' is a rattling noise that sounds like a stick held against the spokes of a spinning bicycle wheel. It usually occurs while decelerating.
- Knock is very similar to chuckle though it may be louder and occurs on acceleration or deceleration.

Check and rule out tyres, exhaust and trim items before any disassembly to diagnose and correct gear noise.

2.4.4 Vibration conditions

Clicking, popping or grinding noises may be noticeable at low speeds and be caused by the following:

- inner or outer CV joints worn (often due to lack of lubrication, so check for split gaiters);
- loose drive shaft;
- another component contacting a drive shaft;
- damaged or incorrectly installed wheel bearing, brake or suspension component.

The following may cause vibration at normal road speeds:

- out-of-balance wheels;
- out-of-round tyres.

The following may cause shudder or vibration during acceleration:

- damaged powertrain/drivetrain mounts;
- excessively worn or damaged out-board or in-board CV joints.

The cause of noise can often be traced by f rst looking for leaks. A dry bearing or joint will produce signif cant noise.

1. Inspect the CV joint gaiters (boots) for cracks, tears or splits.
2. Inspect the underbody for any indication of grease splatter near the front wheel half shaft joint boots.
3. Inspect the in-board CV joint stub shaft bearing housing seal for leakage at the bearing housing.
4. Check the torque on the front axle wheel hub retainer.

2.4.5 Road test

A vehicle will produce a certain amount of noise. Some noise is acceptable and may be audible at certain speeds or under various driving conditions such as on a new road.

Carry out a thorough visual inspection of the vehicle before carrying out the road test. Keep in mind anything that is unusual. A key point is to not repair or adjust anything until the road test is carried out. Of course this does not apply if the condition could be dangerous or the vehicle will not start.

Establish a route that will be used for all diagnostic road tests. This allows you to get to know what is normal and what is not. The roads selected should have sections that are reasonably smooth, level and free of undulations as well as lesser quality sections needed to diagnose faults that only occur under particular conditions. A road that allows driving over a range of speeds is best. Gravel, dirt or bumpy roads are unsuitable because of the additional noise they produce.

> **Key fact**
>
> Establish a standard route that will be used for all diagnostic road tests so you know what to expect.

If a customer's concern is a noise or vibration on a particular road and only on a particular road, the source of the concern may be the road surface. Test the vehicle on the same type of road. Make a visual inspection as part of the preliminary diagnosis routine prior to the road test; note anything that does not look right. For example,

1. tyre pressures, but do not adjust them yet;
2. leaking f uids;
3. loose nuts and bolts;

4 bright spots where components may be rubbing against each other;
5 check the luggage compartment for unusual loads.

Road test the vehicle and def ne the condition by reproducing it several times during the road test. During the road test recreate the following conditions:

1 Normal driving speeds of 20–80 km/h (15–50 mph) with light acceleration – a moaning noise may be heard and possibly a vibration is felt in the front f oor pan. It may get worse at a certain engine speed or load.
2 Acceleration/deceleration with slow acceleration and deceleration – a shake is sometimes noticed through the steering wheel seats, front f oor pan, front door trim panels, etc.
3 High speed – a vibration may be felt in the front f oor pan or seats with no visible shake, but with an accompanying sound or rumble, buzz, hum, drone or booming noise. Coast with the clutch pedal down or gear lever in neutral and engine idling. If vibration is still evident, it may be related to wheels, tyres, front brake discs, wheel hubs or wheel bearings.
4 Engine rpm sensitive – a vibration may be felt whenever the engine reaches a particular speed. It may disappear in neutral coasts. Operating the engine at the problem speed while the vehicle is stationary can duplicate the vibration. It can be caused by any component, from the accessory drive belt to the clutch or torque converter, which turns at engine speed when the vehicle is stopped.
5 Noise and vibration while turning – clicking, popping or grinding noises may be due to the following: damaged CV joint; loose front wheel half shaft joint boot clamps; another component contacting the half shaft; worn, damaged or incorrectly installed wheel bearing; damaged powertrain/drivetrain mounts.

After a road test, it is often useful to do a similar test on a hoist or lift. When carrying out a 'shake and vibration' diagnosis or 'engine accessory vibration' diagnosis on a lift, observe the following precautions:

- If only one drive wheel is allowed to rotate, speed must be limited to 55 km/h (35 mph) indicated on the speedometer. This is because the actual wheel speed will be twice that indicated on the speedometer.
- The suspension should not be allowed to hang free. If a CV joint were run at a high angle, extra vibration as well as damage to the seals and joints could occur.

Support the front suspension lower arm as far out-board as possible. This will ensure that the vehicle is at its correct ride height. The procedure is outlined by the following steps:

1 Raise and support the vehicle.
2 Explore the speed range of interest using the road test checks as previously discussed.
3 Carry out a coast down (overrun) in neutral. If the vehicle is free of vibration when operating at a steady indicated speed and behaves very differently in drive and coast, a transmission concern is likely.

A test on the lift may produce different vibrations and noises than a road test because of the effect of the lift. It is not unusual to f nd a vibration on the lift that was not noticed during the road test. If the condition found on the road can be duplicated on the lift, carrying out experiments on the lift may save a great deal of time.

2.4.6 Engine noises

How do you tell a constant tapping from a rattle? Worse still, how do you describe a noise in a book? I'll do my best. Try the following table as a non-def nitive guide to the source or cause of engine or engine ancillary noises (Table 2.5).

Table 2.5 Noise diagnostics

Noise description	Possible source
Tap	Valve clearances out of adjustment, cam followers or cam lobes worn
Rattle	A loose component, broken piston ring or component
Light knock	Small-end bearings worn, cam or cam follower
Deep knock or thud	Big-end bearings worn
Rumble	Main bearings worn
Slap	Worn pistons or bores
Vibration	Loose or out-of-balance components
Clatter	Broken rocker shaft or broken piston rings
Hiss	Leak from inlet or exhaust manifolds or connections
Roar	Air intake noise, air filter missing, exhaust blowing or a seized viscous fan drive
Clunk	Loose flywheel, worm thrust bearings or a loose front pulley/damper
Whine	Power steering pump or alternator bearing
Shriek	Dry bearing in an ancillary component
Squeal	Slipping drive belt

Table 2.6 Engine noises

Sources of engine noise	Possible cause	Required action
Misfiring/backfiring	Fuel in tank has wrong octane/cetane number or is wrong type of fuel Ignition system faulty Engine temperature too high Carbon deposits in the combustion chamber start to glow and cause misfiring Timing incorrect, which causes misfiring in the intake/exhaust system	Determine which type of fuel was last put in the tank Check the ignition system Check the engine cooling system Remove the carbon deposits by using fuel additives and driving the vehicle carefully Check the timing
Valve train faulty	Valve clearance too large due to faulty bucket tappets or incorrect adjustment of valve clearance Valve timing incorrectly adjusted valves and pistons are touching Timing belt broken or damaged	Adjust valve clearance if possible and renew faulty bucket tappets – check cam condition Check the valve timing and adjust if necessary Check timing belt and check pistons and valves for damage – renew any faulty parts
Engine components faulty	Pistons Piston rings Cylinder head gasket Big-end and/or main bearing journals	Disassemble the engine and check components
Ancillary components	Engine components or ancillary components loose or broken	Check that all components are secure, tighten/adjust as required. Renew if broken

2.4.7 Sources of engine noise

The above table is a further guide to engine noise. Possible causes are listed together with the necessary repair or further diagnosis action as appropriate (Table 2.6).

2.5 Electrical diagnostic techniques

2.5.1 Check the obvious f rst

Start all hands-on diagnostic routines with ‘hand and eye checks’. In other words, look over the vehicle for obvious faults. For example, if the battery terminals are loose or corroded then put this right before carrying out complicated voltage readings. Here are some further suggestions that will at some point save you a lot of time.

- A misf re may be caused by a loose plug lead – it is easier to look for this than interpret the ignition waveforms on a scope.
- If the ABS warning light stays on – look to see if the wheel speed sensor(s) are covered in mud or oil (Figure 2.6).

Key fact

Start all hands-on diagnostic routines with ‘hand and eye checks’.

2.5.2 Test lights and analogue meters – warning

A test lamp is ideal for tracing faults in say a lighting circuit because it will cause a current to f ow, which tests out high-resistance connections. However, it is this same property that will damage delicate electronic circuits – so don’t use it for any circuit that contains an electronic control unit (ECU).

Safety f rst

A test lamp will cause a current to f ow, which can damage delicate electronic circuits.

Even an analogue voltmeter can cause enough current to f ow to at best give you a false reading and at worst damage an ECU – so do not use it.

A digital multimeter is ideal for all forms of testing, most have an internal resistance in excess of 10 MΩ, which means that the current they draw is almost insignif cant. An LED test lamp or a logic probe is also acceptable.

Key fact

A digital multimeter is ideal for all forms of electrical testing.

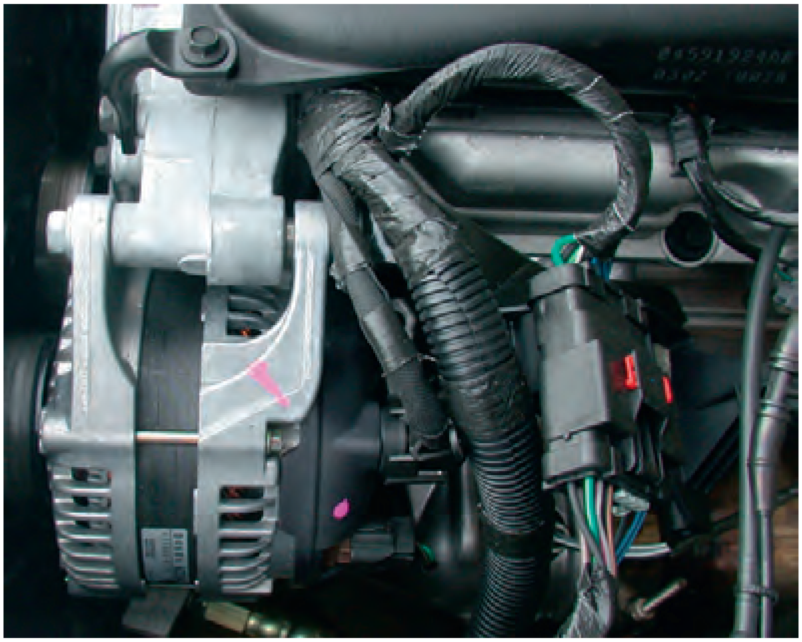


Figure 2.6 Electrical system

2.5.3 Generic electrical testing procedure

The following procedure is very generic but with little adaptation can be applied to any electrical system. Refer to manufacturer's recommendations if in any doubt. The process of checking any system circuit is represented by Figure 2.7.

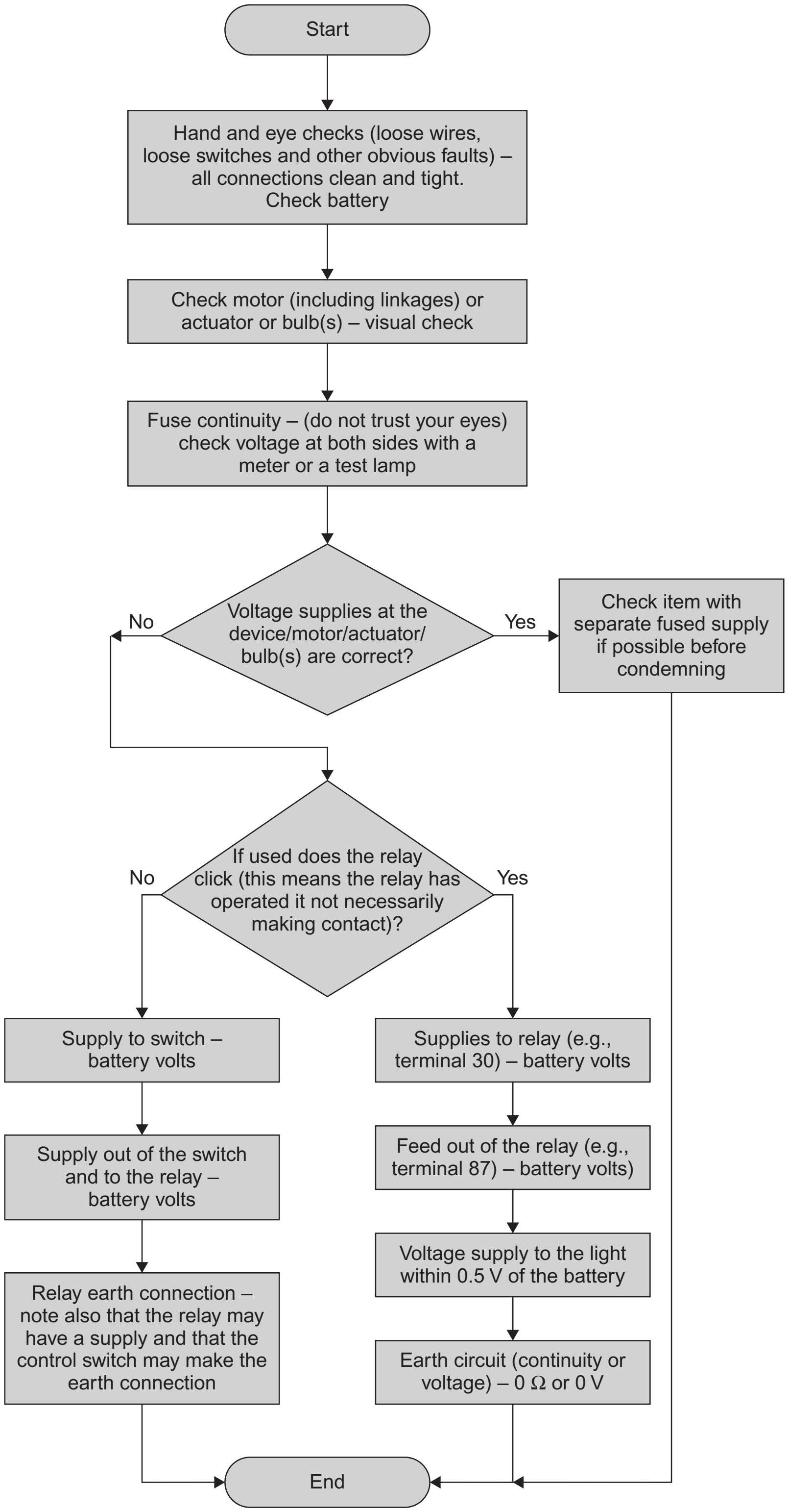


Figure 2.7 Generic electrical diagnostics chart

2.5.4 Volt drop testing

Volt drop is a term used to describe the difference between two points in a circuit. In this way we can talk about a voltage drop across a battery (normally about 12.6 V) or the voltage drop across a closed switch (ideally 0 V but may be 0.1 or 0.2 V).

The f rst secret to volt drop testing is to remember a basic rule about a series electrical circuit:

Key fact

The sum of all volt drops around a circuit always add up to the supply

'The sum of all volt drops around a circuit always add up to the supply'.

The second secret is to ensure the circuit is switched on and operating – or at least the circuit should be 'trying to operate'.

In Figure 2.8 this means that, if the circuit is operating correctly, $V_1 + V_2 + V_3 = V_s$. When electrical testing therefore, and if the battery voltage is measured as say 12 V, a reading of less than 12 V at V_2 would indicate a volt drop between the terminals of V_1 and/or V_3. Likewise the correct operation of the switch, that is, it closes and makes a good connection, would be conf rmed by a very low reading on V_1.

What is often described as a 'bad earth' (when what is meant is a high resistance to earth) could equally be determined by the reading on V_3. To further narrow the cause of a volt drop down, simply measure across a smaller area. The voltmeter V_4, for example, would only assess the condition of the switch contacts.

2.5.5 Testing for short circuits to earth

This fault will normally blow a fuse – or burn out the wiring completely. To trace a short circuit is very different to looking for a high-resistance connection or an open circuit. The volt drop testing above will trace an open circuit or a high-resistance connection.

My preferred method of tracing a short, after looking for the obvious signs of trapped wires, is to connect a bulb or test lamp across the blown fuse and switch on the circuit. The bulb will light because on one side it is connected to the supply for the fuse and on the other side it is connected to earth via the short circuit fault.

Now disconnect small sections of the circuit one at a time until the test lamp goes out. This will indicate the particular circuit section that has shorted out.

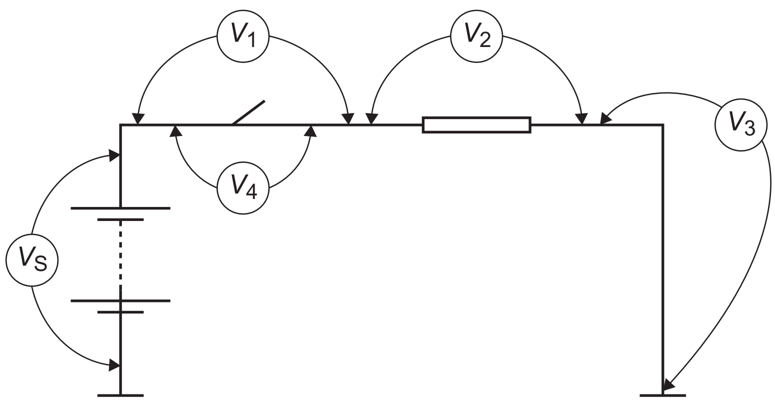


Figure 2.8 Volt drop testing

2.5.6 On and off load tests

On load means that a circuit is drawing a current; off load means it is not. One example where this may be an issue is when testing a starter circuit. Battery voltage may be 12 V (well 12.6 V) off load, but may be as low as 9 V when on load (cranking a cold engine perhaps).

A second example is the supply voltage to the positive terminal of an ignition coil via a high-resistance connection (corroded switch terminal for example). With the ignition on and the vehicle not running, the reading will almost certainly be battery voltage because the ignition ECU switches off the primary circuit and no volt drop will show up. However, if the circuit were switched on (with a fused jumper lead if necessary) a lower reading would result showing up the fault.

2.5.7 Black box technique

The technique outlined here is known as 'black box faultf nding'. This is an excellent technique and can be applied to many vehicle systems from engine management and ABS to cruise control and instrumentation.

As most systems now revolve around an ECU, the ECU is considered to be a 'black box'; in other words, we know what it should do but the exact details of how it does it are less important.

Figure 2.9 shows a block diagram that could be used to represent any number of automobile electrical or electronic systems. In reality the arrows from the 'inputs' to the ECU and from the ECU to the 'outputs' are wires. Treating the ECU as a 'black box' allows us to ignore its complexity. The theory is that if all the sensors and associated wiring to the 'black box' are OK, all the output actuators and their wiring are OK and the supply/earth (ground) connections are OK, then the fault must be the 'black box'. Most ECUs are very reliable however and it is far more likely that the fault will be found in the inputs or outputs.

Normal faultf nding or testing techniques can be applied to the sensors and actuators. For example, if an ABS system uses four inductive-type wheel speed sensors, then an easy test is to measure their resistance. Even if the correct value were not known, it would be very unlikely for all four to be wrong at the same time so a comparison can be made. If the same resistance reading is obtained on the end of the sensor wires at the ECU then almost all of the 'inputs' have been tested with just a few ohmmeter readings.

Key fact

Most vehicle systems involve an ECU.

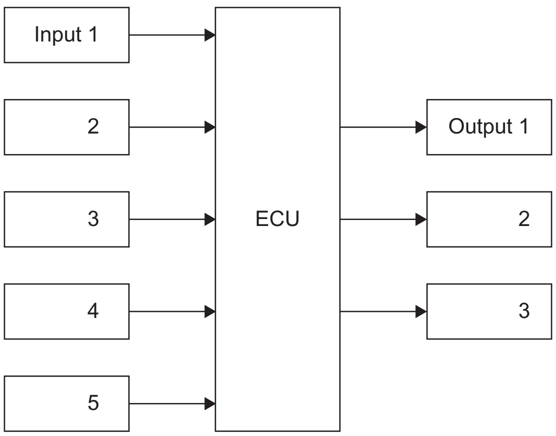


Figure 2.9 System block diagram

Key fact

If the resistance of all similar items connected to an ECU is the same, then it is reasonable to assume the f gure is almost certainly correct.

The same technique will often work with 'outputs'. If the resistance of all the operating windings in say a hydraulic modulator were the same, then it would be reasonable to assume the f gure was correct.

Sometimes, however, it is almost an advantage not to know the manufacturer's recommended readings. If the 'book' says the value should be between 800 and 900 Ω, what do you do when your ohmmeter reads 905 Ω? Answers on a postcard please… (or see Section 2.3.3).

Finally, don't forget that no matter how complex the electronics in an ECU, they will not work without a good power supply and an earth.

2.5.8 Sensor to ECU method

This technique is simple but very useful. Figure 2.10 shows a resistance test being carried out on a component. Ω_1 is a direct measure of its resistance, whereas Ω_2 includes the condition of the circuit. If the second reading is the same as the f rst then the circuit must be in good order.

Warning: The circuit supply must always be off when carrying out ohmmeter tests.

2.5.9 Flight recorder tests

It is said that the best place to sit in an aeroplane is on the black box f ight recorder. Personally, I would prefer to be in 'f rst class'! Also – apart from the black box usually being painted bright orange so it can be found after a crash – my reason for mentioning it is to consider how the f ight recorder principle can be applied to automotive diagnostics.

Key fact

Most digital oscilloscopes have f ight record facilities.

Most digital oscilloscopes have f ight record facilities. This means that they will save the signal from any probe connection in memory for later playback. The time duration will vary depending on the available memory and the sample speed but this is a very useful feature.

As an example, consider an engine with an intermittent misf re that only occurs under load. If a connection is made to the suspected component (coil HT output

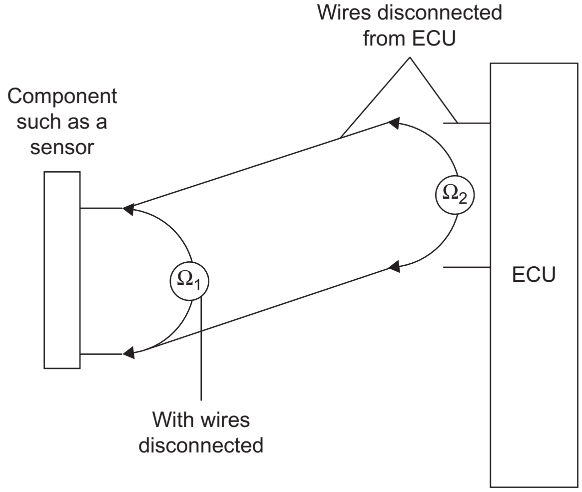


Figure 2.10 Ohmmeter testing

for example), and the vehicle road tested, the waveforms produced can be examined afterwards.

Many engine (and other system) ECUs have built-in f ight recorders in the form of self-diagnostic circuits. If a wire breaks loose causing a misf re but then reconnects, the faulty circuit will be ‘remembered’ by the ECU.

2.5.10 Faultf nding by luck – or is it logic?

Actually, what this section considers is the benef t of playing the odds which, while sometimes you get lucky, is still a logical process.

If four electric windows stopped working at the same time, it would be very unlikely that all four motors had burnt out. On the other hand if just one electric window stopped working, then it may be reasonable to suspect the motor. It is this type of reasoning that is necessary during faultf nding. However, be warned that it is theoretically possible for four motors to apparently burn out all at the same time.

Using this ‘playing the odds’ technique can save time when tracing a fault in a vehicle system. For example, if both stop lights do not work and everything else on the vehicle was OK, I would suspect the switch (stages 1–3 of the six-stage process). At this stage though, the fault could be anywhere – even two or three blown bulbs. Nonetheless a quick test at the switch with a voltmeter would prove the point. Now, let’s assume the switch is OK and it produces an output when the brake pedal is pushed down. Testing the length of wire from the front to the back of the vehicle further illustrates how ‘luck’ comes into play.

Figure 2.11 represents the main supply wire from the brake switch to the point where the wire ‘divides’ to each individual stop light (the odds say the fault must be in this wire). For the purpose of this illustration we will assume the open circuit is just before point ‘I’. The procedure continues in one of the two following ways:

One

- Guess that the fault is in the f rst half and test at point F.
- We were wrong. Guess that the fault is in the f rst half of the second half and test at point I.
- We were right. Check at H and we have the fault … In only 3 tests

Two

- Test from A to K in a logical sequence of tests.

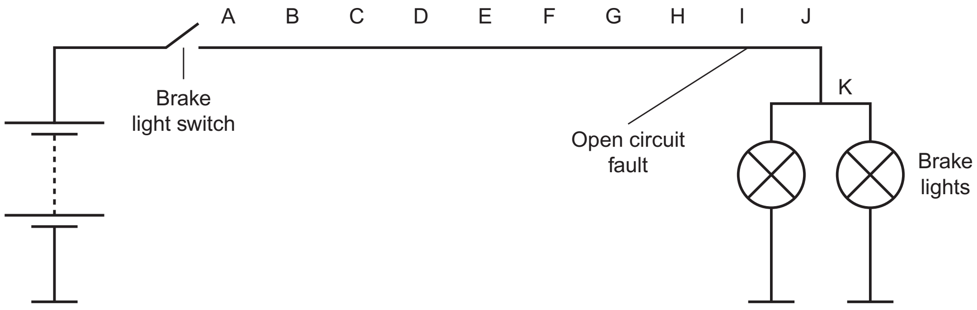


Figure 2.11 Faultf nding by playing the odds – sometimes you get lucky

- We would f nd the fault … In 9 tests

You may choose which method you prefer.

2.5.11 Colour codes and terminal numbers

It is useful to become familiar with a few key wire colours and terminal numbers when diagnosing electrical faults. As seems to be the case for any standardisation a number of colour code systems are in operation.

A system used by a number of manufacturers is based broadly on the information in Table 2.7. After some practice with the use of colour codes the job of the technician is made a lot easier when faultf nding an electrical circuit.

A system now in use almost universally is the terminal designation system in accordance with DIN 72 552. This system is to enable easy and correct connections to be made on the vehicle, particularly in after-sales repairs. Note that the designations are not to identify individual wires but are to def ne the terminals of a device. Listed below are some of the most popular numbers (Table 2.8).

Ford motor company, and many others, now uses a circuit numbering and wire identif cation system. This is in use worldwide and is known as Function-System-Connection (FSC). The system was developed to assist in vehicle development

Table 2.7 Colour codes in use in Europe and elsewhere

Colour	Symbol	Destination/Use
Red	Rt	Main battery feed
White/Black	Ws/Sw	Headlight switch to dip switch
White	Ws	Headlight main beam
Yellow	Ge	Headlight dip beam
Grey	Gr	Sidelight main feed
Grey/Black	Gr/Sw	Left-hand sidelights
Grey/Red	Gr/Rt	Right-hand sidelights
Black/Yellow	Sw/Ge	Fuel injection
Black/Green	Sw/Gn	Ignition controlled supply
Black/White/Green	Sw/Ws/Gn	Indicator switch
Black/White	Sw/Ws	Left-side indicators
Black/Green	Sw/Gn	Right-side indicators
Light Green	LGn	Coil negative
Brown	Br	Earth
Brown/White	Br/Ws	Earth connections
Pink/White	KW	Ballast resistor wire
Black	Sw	Reverse
Black/Red	Sw/Rt	Stop lights
Green/Black	Gn/Sw	Rear fog light

and production processes. However, it is also very useful to help the technician with faultf nding. Many of the function codes are based on the DIN system. Note that earth wires are now black.

The system works as follows: 31S-AC3A || 1.5 BK/RD

Function:
- 31 = ground/earth
- S = additionally switched circuit

System:
- AC = headlamp levelling

Connection:
- 3 = switch connection
- A = branch

Size:
- 1.5 = 1.5 mm^2

Key fact

Further reference should always be made to manufacturer's information for specifc details.

Table 2.8 DIN Terminal numbers (examples)

1	Ignition coil negative
4	Ignition coil high tension
15	Switched positive (ignition switch output)
30	Input from battey positive
31	Earth connection
49	Input to fasher unit
49a	Output from fasher unit
50	Starter control (solenoid terminal)
53	Wiper motor input
54	Stop lamps
55	Fog lamps
56	Headlamps
56a	Main beam
56b	Dip beam
58L	Left-hand sidelights
58R	Right-hand sidelights
61	Charge warning light
85	Relay winding out
86	Relay winding input
87	Relay contact input (change over relay)
87a	Relay contact output (break)
87b	Relay contact output (make)
L	Left side indicators
R	Right side indicators
C	Indicator warning light (vehicle)

Table 2.9 Colour codes table

Code	Colour
BK	Black
BN	Brown
BU	Blue
GN	Green
GY	Grey
LG	Light Green
OG	Orange
PK	Pink
RD	Red
SR	Silver
VT	Violet
WH	White
YE	Yellow

Table 2.10 Ford system codes

Letter	Main system	Examples
D	Distribution systems	DE = earth
A	Actuated systems	AK = wiper/washer
B	Basic systems	BA = charging BB= starting
C	Control systems	CE = power steering
G	Gauge systems	GA = level/pressure/temperature
H	Heated systems	HC = heated seats
L	Lighting systems	LE = headlights
M	Miscellaneous systems	MA = air bags
P	Powertrain control systems	PA = engine control
W	Indicator systems ('indications' not turn signals)	WC = bulb failure
X	Temporary for future features	XS = could mean too much?

Colour:

BK = Black (determined by function 31)

RD = Red stripe (Tables 2.9 and 2.10)

It should be noted that the colour codes and terminal designations given in this section are for illustration only.

2.5.12 Back probing connectors

If you are testing for a supply, for example, at an ECU, then use the probes of your digital meter with care. Connect to the back of the terminals, as this will not

Figure 2.12 Test the voltage by back probing a connector with care

damage the connecting surfaces as long as you do not apply excessive force. Sometimes a pin clamped in the test lead's crocodile/alligator clip is ideal for connecting 'through' the insulation of a wire without having to disconnect it. Figure 2.12 shows this technique.

2.6 Fault codes

2.6.1 Fast and slow

Most modern vehicle management systems carry out self-diagnostic checks on the sensors and actuators that connect to the vehicle ECU(s). A fault in one of the components or its associated circuit causes a code to be stored in the ECU memory. These codes may be described as fast or slow. Some ECUs produce both types.

Most fast codes are now read, or scanned, by a code reader or scanner. However, some earlier systems with fault memory were able to output slow codes as a series of pulses.

An LED, dash warning light, scope or even an analogue voltmeter can be used to read slow codes. Normally, slow codes are output as a series of f ashes that must then be interpreted by looking up the code in a table. The slow codes are normally initiated by shorting two connections on the diagnostic plug and then switching the ignition on. Refer to detailed data before shorting any pins out.

Modern ECUs only use fast codes. This really means that, in the same way we accept that a good digital multimeter is an essential piece of test equipment, it is now necessary to consider a fault code reader in the same way.

If a code reader is attached to the serial port on the vehicle harness, fast and slow codes can be read out from the vehicle computer. These are either displayed in the form of a two-, three- or four-digit output code or if software is used the display is in text format.

Key fact

An LED, dash warning light, scope or even an analogue voltmeter can be used to read slow codes.

Key fact

Modern ECUs only use fast codes.

Definition

DLC: Data link connector
DTC: Diagnostic trouble code.
OBD: On-board diagnostics.
EOBD: European on-board diagnostics.

Most connections for this information are now made to the standard data link connector (DLC), which is a mandatory on-board diagnostics (OBD) item. More on this later.

2.6.2 Fault code examples

A number of codes and descriptions are reproduced here as an example of the detailed information that is available from an OBD2 system (Table 2.11).

Table 2.11 OBD2 DTCs

Code	Description
P0000	SAE Reserved – Usage not allowed except as padding in DTC response message
P0001	Fuel volume regulator control circuit/Open
P0002	Fuel volume regulator control range/Performance
P0003	Fuel volume regulator control circuit low
P0004	Fuel volume regulator control circuit high
P0005	Fuel shutoff valve 'A' control circuit/Open
P0006	Fuel shutoff valve 'A' control circuit low
P0007	Fuel shutoff valve 'A' control circuit high
P0008	Engine position system performance (Bank 1)
P0009	Engine position system performance (Bank 2)
P000A	Intake (A) Camshaft position slow response (Bank 1)
P000B	Exhaust (B) Camshaft position slow response (Bank 1)
P000C	Intake (A) Camshaft position slow response (Bank 2)
P000D	Exhaust (B) Camshaft position slow response (Bank 2)
P000E	Fuel volume regulator control exceeded learning limit
P000F	Fuel system over pressure relief valve activated
P0010	Intake (A) Camshaft position actuator circuit/Open (Bank 1)
P0011	Intake (A) Camshaft position timing – Over advanced (Bank 1)
P0012	Intake (A) Camshaft position timing – Over retarded (Bank 1)
P0013	Exhaust (B) Camshaft position actuator circuit/Open (Bank 1)
P0014	Exhaust (B) Camshaft position timing – Over advanced (Bank 1)
P0015	Exhaust (B) Camshaft position timing – Over retarded (Bank 1)
P0016	Crankshaft position – Camshaft position correlation (Bank 1 Sensor A)
P0017	Crankshaft position – Camshaft position correlation (Bank 1 Sensor B)
P0018	Crankshaft position – Camshaft position correlation (Bank 2 Sensor A)
P0019	Crankshaft position – Camshaft position correlation (Bank 2 Sensor B)
P001A	Intake (A) Cam profile control circuit/Open (Bank 1)
P001B	Intake (A) Cam profile control circuit Low (Bank 1)

(Continued)

Table 2.11 (Continued)

Code	Description
P001C	Intake (A) Cam profile control circuit High (Bank 1)
P001D	Intake (A) Cam profile control circuit/Open (Bank 2)
P001E	Intake (A) Cam profile control circuit Low (Bank 2)
P001F	Intake (A) Cam profile control circuit High (Bank 2)
P0020	Intake (A) Camshaft position actuator circuit/Open (Bank 2)
P0021	Intake (A) Camshaft position timing – Over-advanced (Bank 2)
P0022	Intake (A) Camshaft position timing – Over-retarded (Bank 2)
P0023	Exhaust (B) Camshaft position actuator circuit/Open (Bank 2)
P0024	Exhaust (B) Camshaft position timing – Over-advanced (Bank 2)
P0025	Exhaust (B) Camshaft position timing – Over-retarded (Bank 2)
P0026	Intake valve control solenoid circuit range/Performance (Bank 1)
P0027	Exhaust valve control solenoid circuit range/Performance (Bank 1)
P0028	Intake valve control solenoid circuit range/Performance (Bank 2)
P0029	Exhaust valve control solenoid circuit range/Performance (Bank 2)
P002A	Exhaust(B) Cam profile control circuit/Open (Bank 1)
P002B	Exhaust (B) Cam profile control circuit Low (Bank 1)
P002C	Exhaust (B) Cam profile control circuit High (Bank 1)
P002D	Exhaust (B) Cam profile control circuit/Open (Bank 2)
P002E	Exhaust (B) Cam profile control circuit Low (Bank 2)
P002F	Exhaust (B) Cam profile control circuit High (Bank 2)
P0030	HO2S Heater control circuit (Bank 1 Sensor 1)
P0031	HO2S Heater control circuit Low (Bank 1 Sensor 1)
P0032	HO2S Heater control circuit High (Bank 1 Sensor 1)
P0033	Turbocharger/Supercharger bypass valve 'A' control circuit/Open
P0034	Turbocharger/Supercharger bypass valve 'A' control circuit low
P0035	Turbocharger/Supercharger bypass valve 'A' control circuit high
P0036	HO2S Heater control circuit (Bank 1 Sensor 2)
P0037	HO2S Heater control circuit low (Bank 1 Sensor 2)
P0038	HO2S Heater control circuit high (Bank 1 Sensor 2)

2.6.3 Clearing

Fault codes can be cleared from the ECU memory in two ways:

1. Using the facilities of a fault code reader (scanner) to clear the memory;
2. Disconnecting the battery earth lead for about two minutes (on some systems this does not work).

The f rst method is clearly recommended because disconnecting the battery will also ‘reset’ many other functions such as the radio code, the clock and even the learnt or adaptive functions in the ECUs.

2.7 Systems

2.7.1 What is a system?

Def nition

System: From the Latin *systēma*, in turn from Greek *σύστημα systēma*, system is a set of interacting or interdependent system components forming an integrated whole.

System is a word used to describe a collection of related components, which interact as a whole. A motorway system, the education system or computer systems are three varied examples. A large system is often made up of many smaller systems which in turn can each be made up of smaller systems and so on. Figure 2.13 shows how this can be represented in a visual form. One further def nition: ‘A group of devices serving a common purpose’.

Using the systems approach helps to split extremely complex technical entities into more manageable parts. It is important to note, however, that the links between the smaller parts and the boundaries around them are also very important. System boundaries will overlap in many cases.

The modern motor vehicle is a complex system and in itself forms just a small part of a larger transport system. It is the ability for the motor vehicle to be split into systems on many levels which aids both in its design and construction. The systems approach helps in particular with understanding of how something works and further how to go about repairing it when it doesn’t.

2.7.2 Vehicle systems

Splitting the vehicle into systems is not an easy task because it can be done in many different ways. A split between mechanical systems and electrical systems would seem a good start. However, this division can cause as many problems as it solves. For example, in which half do we put anti-lock brakes, mechanical or electrical? The answer is of course both. Nonetheless, it still makes it easier to be able to just consider one area of the vehicle and not have to try to comprehend the whole.

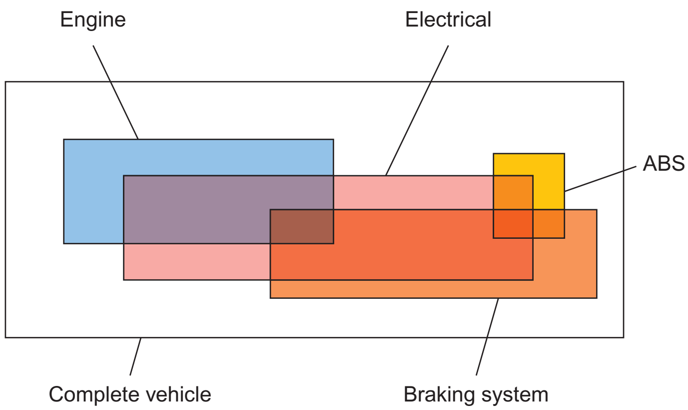


Figure 2.13 Systems in systems representation

Once a complex set of interacting parts such as a motor vehicle has been 'systemised', the function or performance of each part can be examined in more detail. In other words, what each part of the system should do in turn helps to determine how each part actually works. It is again important to stress that the links and interactions between various sub-systems are a very important consideration. Examples of this would be how the power demands of the vehicle lighting system will have an effect on the charging system operation, or in the case of a fault, how an air leak from a brake servo could cause a weak air/fuel ratio.

To further analyse a system whatever way it has been sub-divided from the whole, consideration should be given to the inputs and the outputs of the system. Many of the complex electronic systems on a vehicle lend themselves to this form of analysis. Considering the ECU of the system as the control element and looking at its inputs and outputs is the recommended approach.

2.7.3 Open-loop systems

An open-loop system is designed to give the required output whenever a given input is applied. A good example of an open-loop vehicle system would be the headlights. With the given input is the switch being operated, the output required is that the headlights will be illuminated.

This can be taken further by saying that an input is also required from the battery and a further input from, say, the dip switch. The feature, which determines that a system is open loop, is that no feedback is required for it to operate. Figure 2.14 shows this example in block diagram form.

2.7.4 Closed-loop systems

A closed-loop system is identif ed by a feedback loop. It can be described as a system where there is a possibility of applying corrective measures if the output is not quite what is wanted. A good example of this in a vehicle is an automatic temperature control system. The interior temperature of the vehicle is determined by the output from the heater which is switched on or off in response to a signal from a temperature sensor inside the cabin. The feedback loop is the fact that the output from the system, temperature, is also an input to the system. This is represented by Figure 2.15.

The feedback loop in any closed-loop system can be in many forms. The driver of a car with a conventional heating system can form a feedback loop by turning

Figure 2.14 Open-loop system

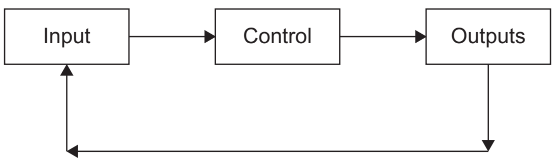


Figure 2.15 Closed-loop system

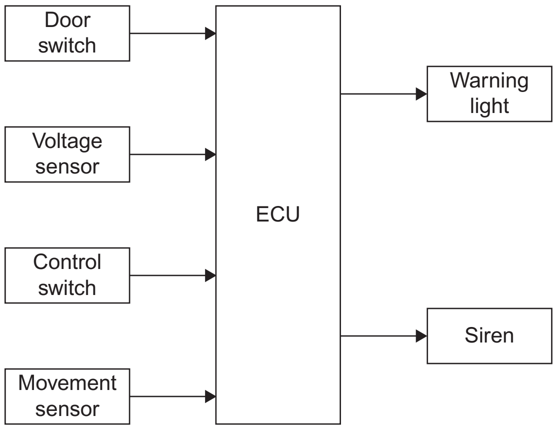


Figure 2.16 Block diagram

Key fact

A closed-loop system always has a feedback loop that may be negative or positive.

the heater down when he or she is too hot and turning it back up when cold. The feedback on an ABS system is a signal that the wheel is locking, where the system reacts by reducing the braking force – until it stops locking, when braking force can be increased again – and so on to maintain a steady state.

2.7.5 Block diagrams

Another secret to good diagnostics is the 'block diagram' approach. Most systems can be considered as consisting of 'inputs to a control which has outputs'. This technique means that complex systems can be considered in manageable 'chunks'. It is similar to the black box method but just a different approach.

Many complex vehicle electronic systems can be represented as block diagrams. In this way several inputs can be shown supplying information to an ECU that in turn controls the system outputs. As an example of this, consider the operation of a vehicle alarm system (Figure 2.16). In its simplest form the inputs would be the 'sensors' (such as door switches) and the 'outputs' the actuators (such as the siren). The 'control' section is the alarm ECU.

The diagnostic approach is that if all the sensors are providing the correct information to the control and the actuators respond when tested, then the fault must be the control unit. If a sensor does not produce the required information then the fault is equally evident.

2.8 Data sources

2.8.1 Introduction

Key fact

The best source of data is the manufacturer but other companies are now able to supply vergood information.

Data is available from a number of sources; clearly the best being direct from the manufacturer. However, for most 'general' repair workshops other sources have to be found. Most sources are now either online or supplied on CD/DVD. However, some useful 'data books' are still available (Figure 2.17).

Examples of the type of data necessary for diagnostic and other work are as follows:

- Component specif cation (resistance, voltage output, etc.)
- Diagnostics charts

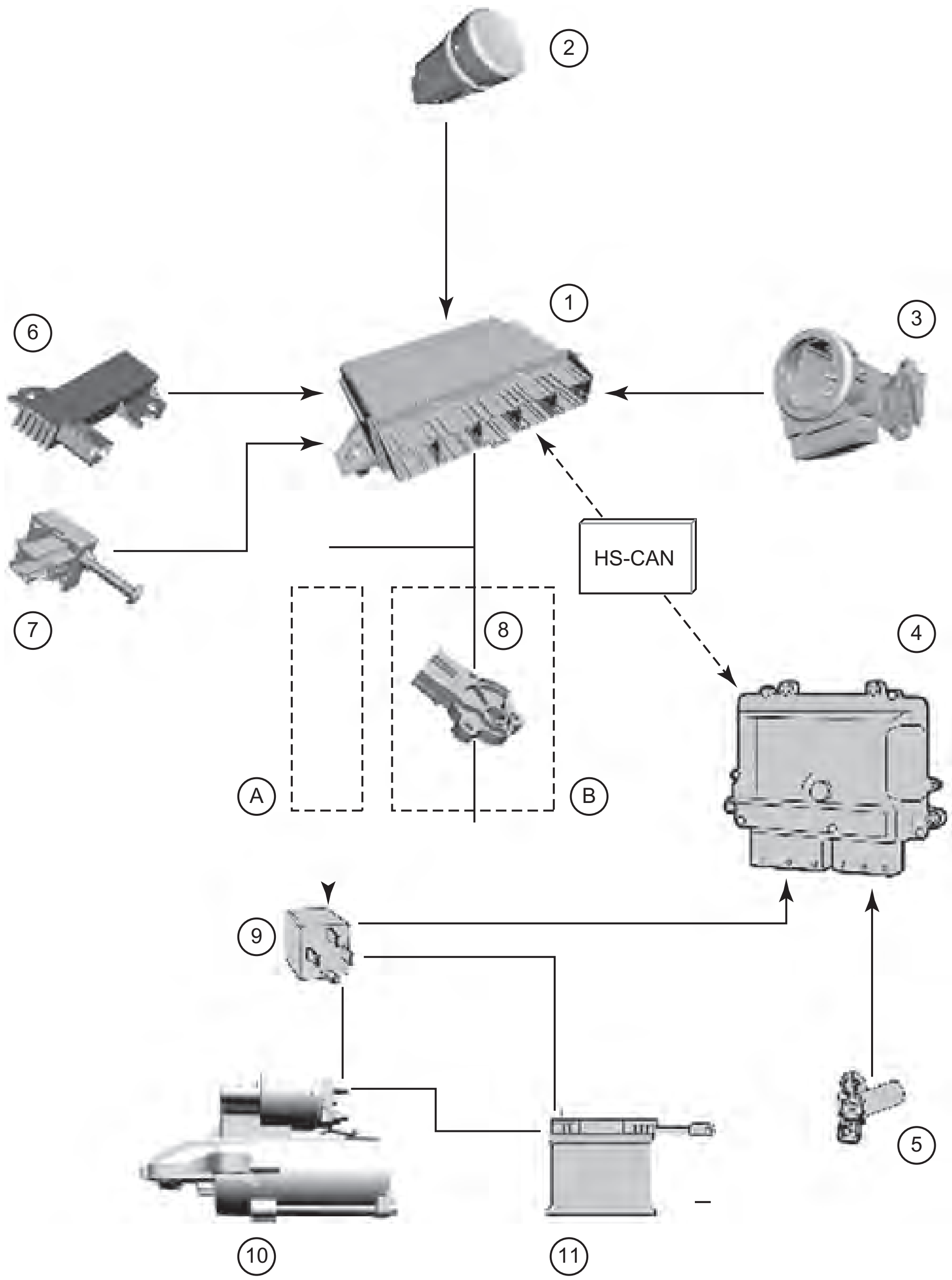


Figure 2.17 Example of a manufacturer's data (Ford): Keyless starting system: 1 – keyless vehicle module; 2 – Start/Stop button; 3 – electronic steering lock; 4 – powertrain control module; 5 – crank sensor; 6 – keyless vehicle antenna; 7 – vehicles with manual transmission: clutch pedal position switch/vehicles with automatic transmission: stoplamp switch; 8 – the TR sensor; 9 – starter relay; 10 – starter motor; 11 – battery (Source: Ford Motor Company)

- Circuit diagrams
- Adjustment data
- Timing belt fitting data
- Component location
- Repair times
- Service schedules

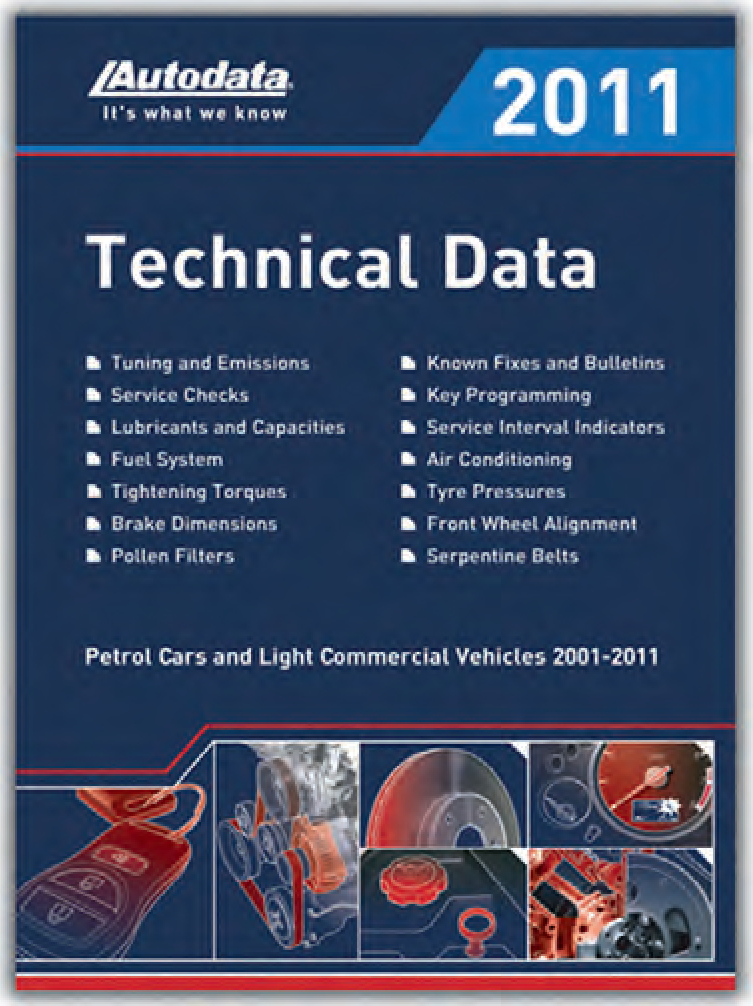


Figure 2.18 Standard data book (Source: Autodata)

2.8.2 Autodata

One of the best known companies for supplying automotive data is Autodata, both in the United Kingdom, United States and elsewhere. This information, presented as books, on the Web and on CDs, is well known and well respected (Figure 2.18).

Very comprehensive information is available ranging from the standard 'data book' to full vehicle circuit diagrams and engine management (and other systems) diagnostic test routines. The online system is particularly useful. Visit www.autodata.ltd.uk for more information.

Information about testing procedures is available as shown in Figure 2.19. These sheets include test data as well as test procedures related to specif c vehicles or systems (Figure 2.20).

2.8.3 Bosch ESItronic

There are already over 30 million registered cars in the United Kingdom and over 240 million in the United States. Of course this includes older vehicles but all of

			1	2	3	4	5
	PORSCHE	Technical Data					Autodata
1	Vehicle Identification	list No.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	Model		944S	944 Turbo	944 S2	928 GT	928 S4
3							
4							
5	Engine specially tuned for			R-Cat	R-Cat	R-Cat	R-Cat
6	Year		1986-89	1989-93	1989-93	1989-92	1989-94
7	Engine	Code	M44/04	M44/52	M44/41	M28/47	M28/41/42
8	No. of cylinders/Type		4/OHC	4/OHC	4/OHC	8/OHC	8/OHC
9	Capacity	cm^3	2479	2479	2990	4957	4957
10	Output	kW (DIN hp) rpm	140 (190) 6000	184 (250) 6000	155 (211) 5800	243 (330) 6200	235 (320) 6000
11	Minimum octane rating	RON	95	95	95	95	95
12	Ignition system	Description	Map-h	Map-h	Map-h	Map-i	Map-i
13		Trigger location	Crankshaft	Crankshaft	Crankshaft	Crankshaft	Crankshaft
14	Fuel system	Make	Bosch	Bosch	Bosch	Bosch	Bosch
15		Type	Motronic	Motronic	Motronic	LH-Jetronic	LH-Jetronic
16		Description	MFI-i	MFI-i	MFI-i	MFI-i	MFI-i
17	Air metering	Type	Flow	Flow	Flow	Mass	Mass
18	Combined ignition and fuel ECU		Yes	Yes	Yes	No	No
19	Diagnostic socket		Yes	Yes	Yes	Yes	Yes
20	Tuning and emissions				■		■
21	Ignition coil supply voltage	V	12.0	12.0	12.0	11.0	12.0
22	Primary resistance	Ω	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6
23	Secondary resistance	Ω	5000-7200	5000-7200	5000-7200	5000-7000	5000-7200
24	Firing order		1-3-4-2	1-3-4-2	1-3-4-2	1-3-7-2-6-5-4-8	1-3-7-2-6-5-4-8
25	Ignition distributor (ECU)	no.	(0 261 200 080)	(0 261 200 088)	(0 261 200 195)	(0 227 400 164)	(0 227 400 034)
26	Ignition timing BTDC	°Engine/rpm	10±3/840	5±3/840	10±3/840	10±2/775	10±2/675
27	alternative	°Engine/rpm	–	–	–	–	–
28		o without + with vacuum	o	–	–	–	o
29	Ignition advance checks	°Engine/rpm	ECU controlled	ECU controlled	ECU controlled	ECU controlled	ECU controlled
30	a – without vacuum and base timing b – without vacuum with base timing	°Engine/rpm	–	–	–	–	–
31	c – with vacuum and base timing	°Engine/rpm	–	–	–	–	–
32	Vacuum advance range	°Engine	–	–	–	–	–
33	Idle speed	rpm	840±40	840±40	840±40	775±25	675±25
34	alternative	rpm	–	–	–	–	–
35	Oil temperature for CO test	°C	90	90	90	90	90
36	CO content at idle - tail pipe	Vol.%	1.0±0.5	0.5 Max	0.5 Max	0.5 Max	0.5 Max
37	- sample pipe	Vol.%	–	0.4-0.8	0.4-0.8	0.4-1.2	0.4-1.2
38	CO_2/O_2 content at idle speed	Vol.%	13-16/0.5-2.0	14.5-16/0.1-0.5	14.5-16/0.1-0.5	14.5-16/0.1-0.5	14.5-16/0.1-0.5
39	HC content at idle speed	ppm	300	100	100	100	100
40	Increased idle speed for CO test	rpm	–	2500-2800	2500-2800	2500-2800	2500-2800
41	CO content at increased idle speed	Vol.%	–	0.3	0.3	0.3	0.3
42	Lambda at increased idle speed	λ	–	0.97-1.03	0.97-1.03	0.97-1.03	0.97-1.03
43	Service checks and adjustments						
44	Spark plugs	Make	Bosch	Bosch	Bosch	Bosch	Bosch
45	(also see Spark Plugs list)	Type	WR5DC	WR7DC	WR5DC	WR7DC	WR7DC
46	Electrode gap	mm	0.7	0.7	0.7	0.7	0.6-0.8
47	Valve clearances - inlet	mm	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
48	- exhaust	mm	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
49	Compression pressure	bar	–	–	–	–	–
50	Oil pressure	bar / rpm	3.5/6000	3.5/6000	3.5/6000	5/4000	5/5000
51	Lubricants and capacities						
52	Engine oil grade	SAE (API)	15W/40 (SF)	15W/40 (SF)	15W/40 (SF)	15W/40 (SF)	15W/40 (SF)
53	Engine with filter	litres	6.5	7.0	7.0	7.5	7.5
54	Gearbox oil grade	SAE	75W/90	75W/90	75W/90	75W/90	75W/90
55	4/5 speed	litres	2.0	2.0	7.0	4.5	4.5
56	Automatic transmission fluid	Type	Dexron II D	–	–	–	Dexron II D
57	refill	litres	6.0	–	–	–	7.3
58	Differential oil grade	SAE	90W	–	–	–	90W
59	front/rear	litres	1.0 (AT)	–	–	–	3.0 (AT)
	POR 3	■ = refer to technical information at end of this manufacturer					Λ = setting not adjustable

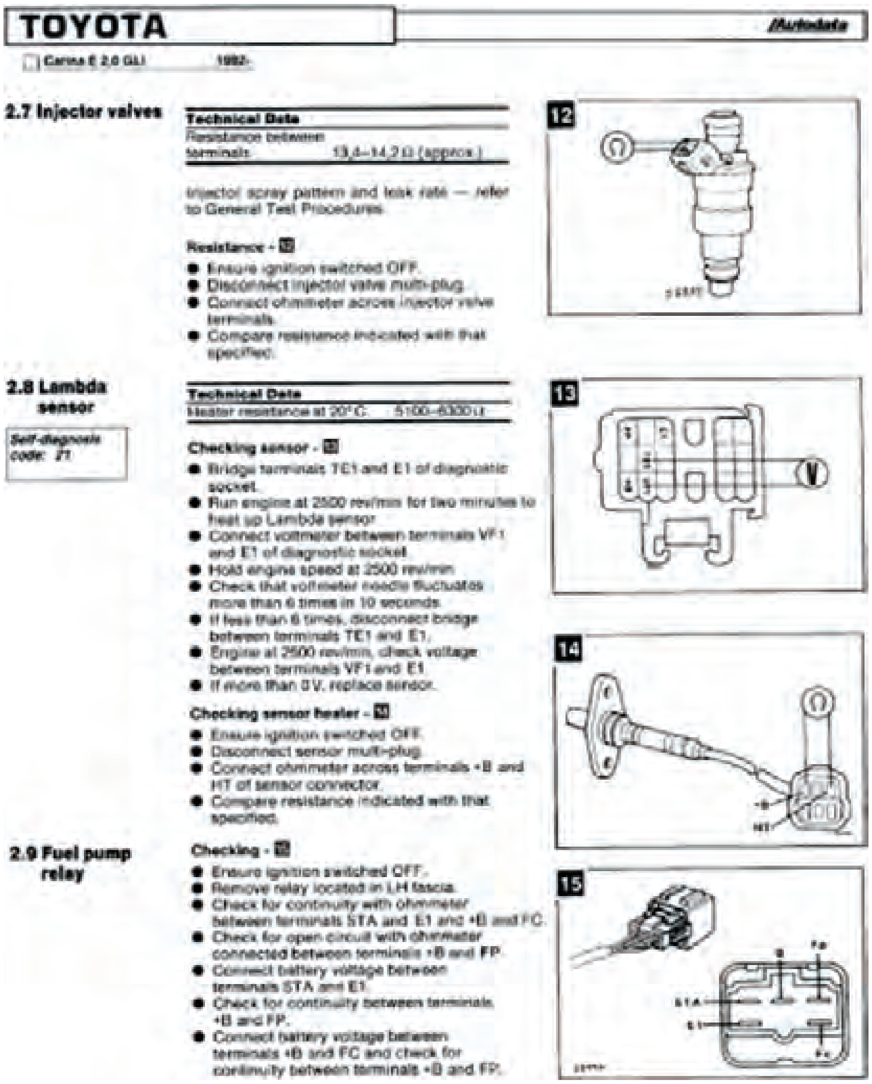
Figure 2.19 Example data sheet (Source: Autodata)

the newer ones (still 10s of millions) have engine management systems. These need quality test equipment to diagnose faults and system failures. Ineffective diagnostic work inevitably leads to vehicle problems, dissatisf ed customers and labour costs which far exceed a realistic invoice value for the workshop.

Good data will help reduce errors and increase satisfaction. The Bosch ESItronic system (Figure 2.21) runs from a DVD and as well as information about test procedures and test results, other details such as service data are included.

Key fact

There are already over 30 million registered cars in the United Kingdom and over 240 million in the United States.



TOYOTA

Autodata

Carina E 2.0 GLi 1992-

2.7 Injector valves

Technical Data	
Resistance between terminals	13,4–14,2 Ω (approx.)

Injector spray pattern and leak rate — refer to General Test Procedures.

Resistance - 12

- Ensure ignition switched OFF.
- Disconnect injector valve multi-plug.
- Connect ohmmeter across injector valve terminals.
- Compare resistance indicated with that specified.

2.8 Lambda sensor

Self-diagnosis code: 21

Technical Data	
Heater resistance at 20°C	5100–6300 Ω

Checking sensor - 13

- Bridge terminals TE1 and E1 of diagnostic socket.
- Run engine at 2500 rev/min for two minutes to heat up Lambda sensor.
- Connect voltmeter between terminals VF1 and E1 of diagnostic socket.
- Hold engine speed at 2500 rev/min.
- Check that voltmeter needle fluctuates more than 6 times in 10 seconds.
- If less than 6 times, disconnect bridge between terminals TE1 and E1.
- Engine at 2500 rev/min, check voltage between terminals VF1 and E1.
- If more than 0 V, replace sensor.

Checking sensor heater - 14

- Ensure ignition switched OFF.
- Disconnect sensor multi-plug.
- Connect ohmmeter across terminals +B and HT of sensor connector.
- Compare resistance indicated with that specified.

2.9 Fuel pump relay

Checking - 15

- Ensure ignition switched OFF.
- Remove relay located in LH fascia.
- Check for continuity with ohmmeter between terminals STA and E1 and +B and FC.
- Check for open circuit with ohmmeter connected between terminals +B and FP.
- Connect battery voltage between terminals STA and E1.
- Check for continuity between terminals +B and FP.
- Connect battery voltage between terminals +B and FC and check for continuity between terminals +B and FP.

Figure 2.20 Fuel injection testing example (Source: Autodata)

Figure 2.21 ESItronic data (Source: Bosch Media)

This data system can be used in conjunction with the Bosch diagnostic tool discussed in the next chapter.

2.9 Summary

Both of the previously mentioned companies as sources of data are excellent – and essential. It is possible to carry out diagnostic work without this, but much more diff cult and less reliable. The money for good data will be well spent.

CHAPTER

Tools and equipment

3.1 Basic equipment

3.1.1 Introduction

Diagnostic techniques are very much linked to the use of test equipment. In other words, you must be able to interpret the results of tests. In most cases this involves comparing the result of a test to the reading given in a data book or other source of information. By way of an introduction, Table 3.1 lists some of the basic words and descriptions relating to tools and equipment.

3.1.2 Basic hand tools

You will not learn how to use tools by reading a book; it is clearly a very practical skill. However, you can follow the recommendations made here and by the manufacturers. Even the range of basic hand tools is now quite daunting and very expensive. It is worth repeating the general advice given by Snap-on for the use of hand tools:

- Only use a tool for its intended purpose.
- Always use the correct size tool for the job you are doing.
- Pull a wrench rather than pushing whenever possible.
- Do not use a f le or similar, without a handle.
- Keep all tools clean and replace them in a suitable box or cabinet.
- Do not use a screwdriver as a pry bar.
- Always follow manufacturer's recommendations (you cannot remember everything).
- Look after your tools and they will look after you!

3.1.3 Accuracy of test equipment

Accuracy can be described in a number of slightly different ways:

- careful and exact;
- free from mistakes or errors;
- precise;
- adhering closely to a standard.

Consider measuring a length of wire with a steel rule. How accurately could you measure it? To the nearest 0.5 mm? This raises a number of issues. First, you could make an error reading the ruler. Second, why do we need to know

Advanced Automotive Fault Diagnosis.

Table 3.1 Tools and equipment

Hand tools	Spanners, hammers, screwdrivers and all the other basic bits
Special tools	A collective term for items not held as part of a normal tool kit etc. Or required for just one specific job
Test equipment	In general, this means measuring equipment. Most tests involve measuring something and comparing the result of that measurement to data. The devices can range from a simple ruler to an engine analyser
Dedicated test equipment	Some equipment will only test one specific type of system. The large manufacturers supply equipment dedicated to their vehicles. For example, a diagnostic device which plugs in to a certain type of fuel injection electronic control unit (ECU)
Accuracy	Careful and exact, free from mistakes or errors and adhering closely to a standard
Calibration	Checking the accuracy of a measuring instrument
Serial port	A connection to an ECU, a diagnostic tester or computer, for example. Serial means the information is passed in a 'digital' string, like pushing black and white balls through a pipe in a certain order
Code reader or scanner	This device reads the 'black and white balls' mentioned above or the on–off electrical signals, and converts them in to language we can understand
Combined diagnostic and information system	Now usually PC based, these systems can be used to carry out tests on vehicle systems, and they also contain an electronic workshop manual. Test sequences guided by the computer can also be carried out
Oscilloscope	The main part of 'scope' is the display, which is like a TV or computer screen. A scope is a voltmeter, but instead of readings in numbers it shows the voltage levels by a trace or mark on the screen. The marks on the screen can move and change faster allowing us to see the way voltages change

Def nition

Accuracy: How close the measured value of something is to the actual value.

Def nition

Resolution: The 'fineness' with which a measurement can be made.

the length of a bit of wire to the nearest 0.5 mm? Third, the ruler may stretch and not give the correct reading!

The f rst and second issues can be dispensed with by knowing how to read the test equipment correctly and also knowing the appropriate level of accuracy required. A micrometer for a plug gap? A ruler for valve clearances? I think you get the idea. The accuracy of the equipment itself is another issue.

Accuracy is a term meaning how close the measured value of something is to its actual value. For example, if a length of approximately 30 cm is measured with an ordinary wooden ruler, then the error may be up to 1 mm too high or too low. This is quoted as an accuracy of $\pm$1 mm. This may also be given as a percentage, which in this case would be 0.33%.

Resolution or, in other words, the 'f neness', with which a measurement can be made, is related to accuracy. If a steel ruler was made to a very high standard but only had markings of 1/cm, it would have a very low resolution even though the graduations were very accurate. In other words, the equipment is accurate but your reading will not be!

To ensure instruments are, and remain accurate, there are just two simple guidelines:

1 Look after the equipment, a micrometer thrown on the f oor will not be accurate.
2 Ensure instruments are calibrated regularly – this means being checked against known good equipment.

Table 3.2 Accurate measurement process

Step	Example
Decide on the level of accuracy required	Do we need to know that the battery voltage is 12.6V or 12.635V
Choose the correct instrument for the job	A micrometer to measure the thickness of a shim
Ensure the instrument has been looked after and calibrated when necessary	Most instruments will go out of adjustment after a time. You should arrange for adjustment at regular intervals. Most tool suppliers will offer the service or in some cases you can compare older equipment to new stock
Study the instructions for the instrument in use and take the reading with care. Ask yourself if the reading is about what you expected	Is the piston diameter 70.75 or 170.75mm
Make a note if you are taking several readings	Don't take a chance, write it down

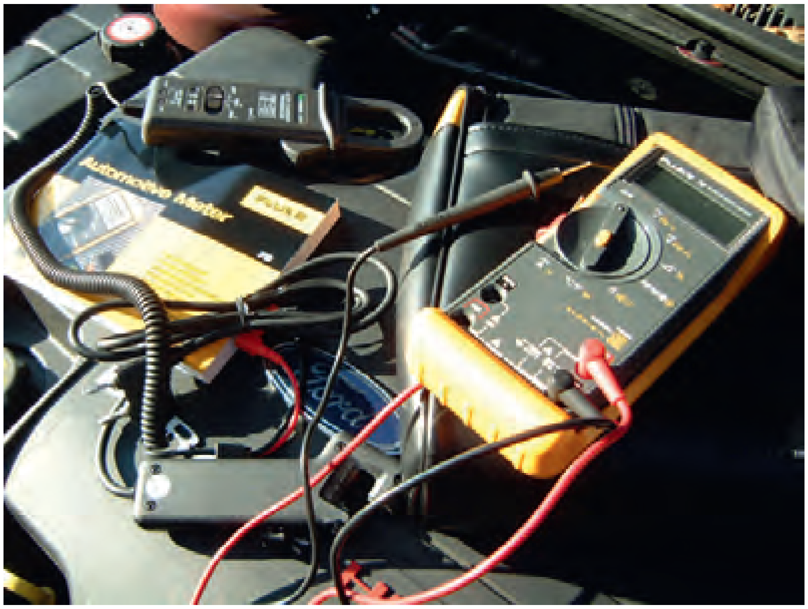


Figure 3.1 Multimeter and accessories

Table 3.2 provides a summary of the steps to ensure a measurement is accurate.

3.1.4 Multimeters

An essential tool for working on vehicle electrical and electronic systems is a good digital multimeter (often referred to as a DMM) (Figure 3.1). Digital meters are most suitable for accuracy of reading as well as available facilities they provide.

The list of functions presented in Table 3.3, broadly in order starting from essential to desirable, should be considered.

A way of determining the quality of a digital multimeter as well as the facilities they provide is to consider the following:

- accuracy;
- loading effect of the meter;
- protection circuits.

Definition

DMM: Digital multimeter

Table 3.3 Multimeter functions

Function	Range	Accuracy
DC voltage	500 V	0.3%
DC current	10 A	1.0%
Resistance	0–10 MΩ	0.5%
AC voltage	500 V	2.5%
AC current	10 A	2.5%
Dwell	3, 4, 5, 6, 8 cylinders	2.0%
RPM	10 000 rpm	0.2%
Duty cycle	% On/off	0.2%/kHz
Frequency	Over 100 kHz	0.01%
Temperature	>9000 °C	0.3% + 30 °C
High current clamp	1000 A (DC)	Depends on conditions
Pressure	3 bar	10.0% of standard scale

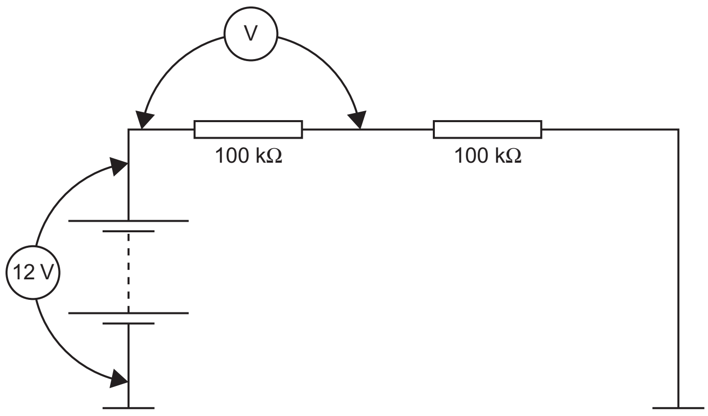


Figure 3.2 Loading effect of a meter

The loading effect is a consideration for any form of measurement. With a multimeter, this relates to the internal resistance of the meter. It is recommended that the internal resistance of a meter should be a minimum of 10 MΩ. This not only ensures greater accuracy but also prevents the meter from damaging sensitive circuits.

Figure 3.2 shows two equal resistors connected in series across a 12 V supply. The voltage across each resistor should be 6 V. However, the internal resistance of the meter will affect the circuit conditions and change the voltage reading. If the resistor values were 100 kΩ, the effect of meter internal resistance would be as follows:

Meter resistance 1 MΩ

The parallel combined value of 1 MΩ and 100 kΩ is 91 kΩ. The voltage drop in the circuit across this would be

$$\frac{91}{(100+91)} \times 12 = 5.71\text{V}$$

This is an error of approximately 5%.

Figure 3.3 Logic probe(Source: Maplin)

Meter resistance 10 MΩ

The parallel combined value of 10 MΩ and 100 kΩ is 99 kΩ. The voltage drop in the circuit across this would be

$$\frac{99}{(100 + 99)} \times 12 = 5.97\,\text{V}$$

This is an error of approximately 0.5%.

Of course, understanding accuracy is important, but there are two further skills that are important when using a multimeter: where to put the probes and what the reading you get actually means!

Key fact

An 'invasive measurement' error is in addition to the basic accuracy of the meter.

3.1.5 Logic probe

This device is a useful way of testing logic circuits, but it is also useful for testing some types of sensor. Figure 3.3 shows a typical logic probe. Most types consist of two power supply wires and a metal 'probe'. The display consists of three LEDs labelled 'high', 'low' and 'pulse'. These LEDs light up together with an audible signal in some cases, when the probe touches either a high, low or pulsing voltage. Above or below 2.5 V is often used to determine high or low on a 5 V circuit.

Key fact

A voltmeter connects in parallel across a circuit

An ammeter connects in series

An ohmmeter connects across a component – but the circuit must be isolated.

3.2 Oscilloscopes

3.2.1 Introduction

There were traditionally two types of oscilloscope; analogue or digital. However, the digital scope is now universal. An oscilloscope draws a graph of voltage (the vertical scale or Y axis) against time (the horizontal scale or X axis).

The trace is made to move across the screen from left to right and then to 'f y back' and start again. The frequency at which the trace moves across the screen is known as the time base, which can be adjusted either automatically or manually.

Key fact

An oscilloscope draws a graph of voltage against time.

The signal from the item under test can either be amplif ed or attenuated (reduced), much like changing the scale on a voltmeter.

The trigger, which starts the trace moving across the screen, can be caused internally or externally. When looking at signals such as ignition voltages, triggering is often external; for example, each time an individual spark f res or each time number one spark plug f res.

The voltage signal under test is A/D converted and the time base is a simple timer or counter circuit. Because the signal is plotted digitally on a screen from data in memory, the picture can be saved, frozen or printed. The speed of data conversion and the sampling rate as well as the resolution of the screen are very important to ensure accurate results.

Def nition

USB: Universal serial bus.

The highly recommended Pico Automotive Diagnostics kit (Figure 3.4) turns a laptop or desktop PC into a powerful automotive diagnostic tool for faultf nding sensors, actuators and electronic circuits.

The high-resolution PC oscilloscope connects to a USB port on a PC and can take up to 32 million samples per trace, making it possible to capture complex automotive waveforms – including CAN bus and FlexRay signals (more on this later) – and then zoom in on areas of interest. Being PC based, these waveforms can then be saved for future reference, printed or emailed.

The scope can be used to measure and test virtually all of the electrical and electronic components and circuits in any modern vehicle, including

- ignition (primary and secondary);
- injectors and fuel pumps;
- starter and charging circuits;
- batteries, alternators and starter motors;
- lambda, airf ow, knock and MAP sensors;

Figure 3.4 Automotive oscilloscope kit (Source: Pico Tech)

- glow plugs/timer relays;
- CAN bus, LIN bus and FlexRay.

This powerful and f exible automotive diagnostic tool has been designed for ease of use, so is equally suitable for both novice and expert users. It is powered directly from the USB port, eliminating the need for power leads or battery packs and making it suitable for use in the workshop or on the road.

Excellent software is included, which means that the user can simply select the sensor or circuit to be tested and the software will automatically load the required settings. It will also give full details of how to connect the scope, along with advice on what the waveform should look like and general technical information on the component being tested.

All the waveforms shown in this book were captured using this piece of equipment. Visit http://www.picoauto.com for more information.

3.2.2 Waveforms

You will f nd the words ‘waveform’, ‘pattern’ and ‘trace’ are used in books and workshop manuals but they mean the same thing. I will try to stick to waveform.

When you look at a waveform on a screen, it is important to remember that the height of the scale represents voltage and the width represents time. Both of these axes can have their scales changed. They are called axes because the ‘scope’ draws a graph of the voltage at the test points over a period of time. The time scale can vary from a few microseconds to several seconds. The voltage scale can vary from a few millivolts to several kilovolts. For most test measurements only two connections are needed just like a voltmeter. The time scale will operate at intervals preset by the user. It is also possible to connect a ‘trigger’ wire so that the time scale starts moving across the screen each time the ignition coil f res, for example. This keeps the display in time with the speed of the engine. Figure 3.5 shows an example waveform.

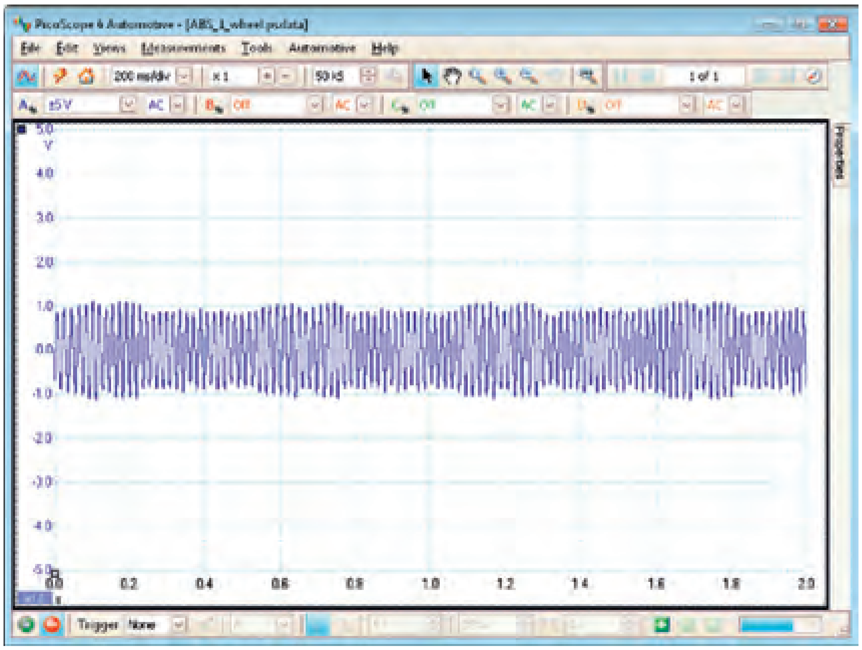


Figure 3.5 ABS waveform captured on a PicoScope®

Most of the waveforms shown in various parts of this book are from a correctly operating vehicle but some incorrect ones are also presented for comparison. The skill you will learn by practice is to note when your own measurements vary from the ideal – and how to interpret them.

Def nition

OBD: On-board diagnostics.

3.3 Scanners/Fault code readers and analysers

Note: Please refer to Chapter 5 for full details about on-board diagnostics (OBD) systems.

3.3.1 On-board diagnostics introduction

OBD is a generic term referring to a vehicle's self-diagnostic and reporting system. OBD systems give the vehicle owner or a technician access to information for various vehicle systems.

The amount of diagnostic information available via OBD has varied considerably since its introduction in the early 1980s. Early versions of OBD would simply illuminate a malfunction indicator light (MIL) if a problem was detected, but did not provide any information about the problem. Modern OBD systems use a standardised digital communications port to provide real-time data in addition to a standardised series of diagnostic trouble codes (DTCs), which allow a technician to identify and remedy faults on the vehicle. The current versions are OBD2 and European OBD2 (EOBD2). The standard OBD2 and EOBD2 are quite similar.

3.3.2 Serial port communications

Most modern vehicle systems now have ECUs that contain self-diagnosis circuits. The information produced is read via a serial link using a scanner.

A special interface, stipulated by one of a number of standards (see section 3.3.3), is required to read the data. The standards are designed to work with a single- or two-wire port allowing many vehicle electronic systems to be connected to a central diagnostic plug. The sequence of events to extract DTCs from the ECU is as follows:

1 Test unit transmits a code word.
2 ECU responds by transmitting a baud rate recognition word.
3 Test unit adopts the appropriate setting.
4 ECU transmits fault codes.

The test unit converts the DTCs to suitable output text. Further functions are possible, which may include the following:

- Identif cation of ECU and system to ensure the test data is appropriate to the system currently under investigation.
- Read out of current live values from sensors. Spurious f gures can be easily recognised. Information such as engine speed, temperature, airf ow and so on can be displayed and checked against the test data.
- System function stimulation to allow actuators to be tested by moving them and watching for suitable response.
- Programming of system changes such as basic idle CO or changes in basic timing can be programmed into the system.

Figure 3.6 Diagnostic data link connector (DLC)

3.3.3 OBD2 signal protocols

Five different signalling protocols are permitted with the OBD2 interface. Most vehicles implement only one of them. It is often possible to deduce the protocol used based on which pins are present on the J1962 connector (Figure 3.6).

Some details of the different protocols are presented here for interest. No need to memorise the details!

SAE J1850 PWM (pulse-width modulation): A standard of Ford Motor Company

- Pin 2: Bus+.
- Pin 10: Bus−.
- High voltage is +5 V.
- Message length is restricted to 12 bytes, including cyclic redundancy check (CRC).
- Employs a multi-master arbitration scheme called 'Carrier Sense Multiple Access with Non-Destructive Arbitration' (CSMA/NDA).

SAE J1850 VPW (variable pulse width): A standard of General Motors

- Pin 2: Bus+.
- Bus idles low.
- High voltage is +7 V.
- Decision point is +3.5 V.
- Message length is restricted to 12 bytes, including CRC.
- Employs CSMA/NDA.

ISO 9141-2: Primarily used by Chrysler, European, and Asian vehicles

- Pin 7: K-line.
- Pin 15: L-line (optional).
- UART signalling.
- K-line idles high, with a 510 Ω resistor to Vbatt.
- The active/dominant state is driven low with an open-collector driver.
- Message length is restricted to 12 bytes, including CRC.

Def nition

Protocol: A set of rules which is used to allow computers to communicate with each other

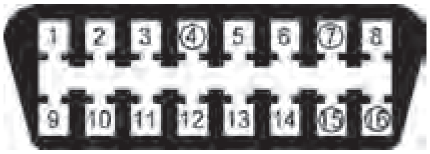


Figure 3.7 Connector pin-out: 4 – battery ground/earth, 7 – K-line, 15 – L-line, 16 – battery positive

Figure 3.8 AutoTap scanner and extension cable

Def nition

ISO: International Standards Organisation.

Def nition

CAN: Controller area network.

ISO 14230 KWP2000 (Keyword Protocol 2000)

- Pin 7: K-line.
- Pin 15: L-line (optional).
- Physical layer identical to ISO 9141-2.
- Message may contain up to 255 bytes in the data f eld.

ISO 15765 CAN: The CAN protocol was developed by Bosch for automotive and industrial control. Since 2008, all vehicles sold in the United States (and most others) are required to implement CAN as one of their signalling protocols.

- Pin 6: CAN high
- Pin 14: CAN low

All OBD2 pin-outs use the same connector but different pins, with the exception of pin 4 (battery ground) and pin 16 (battery positive) (Figure 3.7).

3.3.4 AutoTap OBD scanner

Author's Note: This section outlines the use and features of the AutoTap scanner. I have chosen this particular tool as a case study because it provides some very advanced features at a very competitive price. The scanner is designed specif cally to work with OBD2 systems. However, it worked f ne on all the petrol engined EOBD systems I have used so far. For more information, visit http://www.autotap.com.

Like any professional scanner or code reader, the AutoTap scan tool connects the special OBD2 DLC, which is always accessible from the driver's seat (often on or under the dash) (Figure 3.8). A USB cable makes the scanner connection to a computer. The scanner translates the signals from the vehicle's computer controlled sensors to easy-to-read visual displays. It also reads out any diagnostic trouble codes.

The software also allows the technician (or hobbyist) to choose which parameters or signals they want to see, and whether they are to be viewed as tables, graphs, meters or gauges (Figure 3.9).

It is possible to set the ranges and alarms and pick display colours. Once a screen conf guration is created, it can be saved for future use. Different

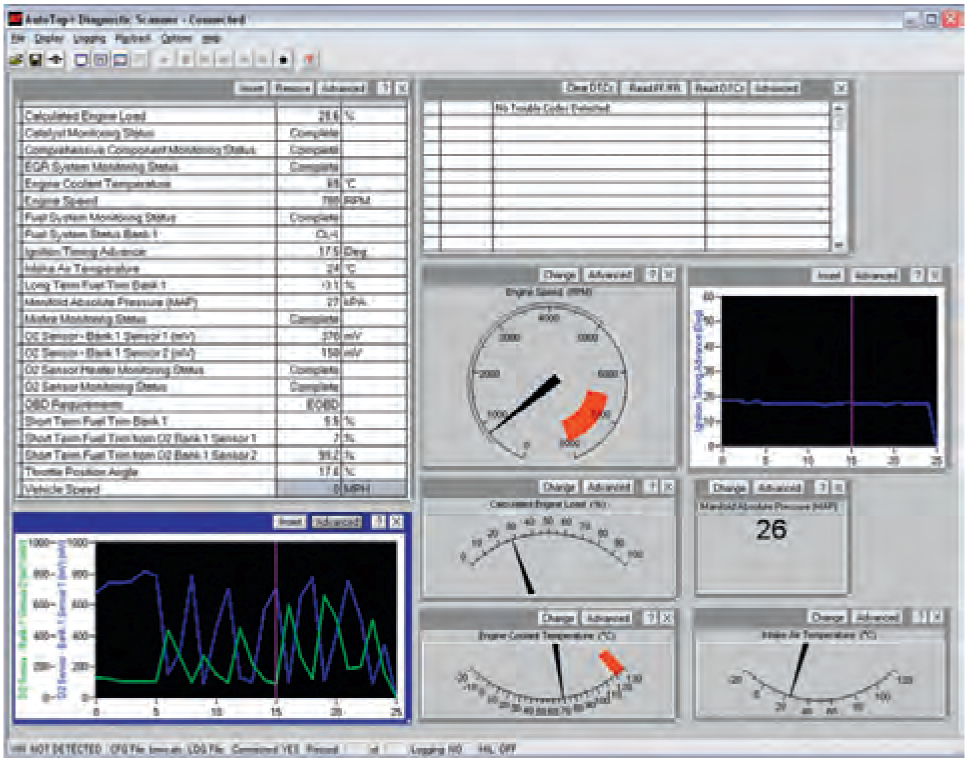


Figure 3.9 Screen grab from the AutoTap software showing tables, gauges and graphs

screen conf gurations are useful for different vehicles, or perhaps one for major maintenance, one for tuning, one for quick checks at a race track.

Lots of data are provided in easy-to-read views with multiple parameters. Graphs can be used to show short-term logs and gauges for instant readings.

DTCs can be checked immediately on connecting the scanner and starting up the software. This gives the critical info needed in the shortest time possible. When repairs are completed, the tool can be used to turn off the MIL. This light is also described as the check engine light.

The software will also log data, for example, during a road test. This is particularly useful for diagnosing intermittent faults. The data can be played back after a road or dynamometer test. It can also be exported to a spreadsheet f le for later analysis.

Overall, to read live data and get access to powertrain (engine-related) system DTCs, this is an excellent piece of equipment.

Def nition

MIL: Malfunction indicator light.

3.3.5 Bosch KTS diagnostic equipment

Author's Note: This section will outline the use and features of the Bosch KTS 650 diagnostic system. I have chosen this particular tool as a case study because it provides everything that a technician needs to diagnose faults, but at a professional price. The system is a combination of a scanner, multimeter, oscilloscope and information system (when used with Esitronic). For more information, visit http://www.bosch.com.

Modern vehicles are being f tted with more and more electronics. This complicates diagnosis and repair, especially as the individual systems are often interlinked. The work of service and repair workshops is being fundamentally

Figure 3.10 Diagnostic system in use (Source: Bosch Media)

Figure 3.11 Adapter and cable kit (Source: Bosch Media)

changed. Automotive engineers have to continually update their knowledge of vehicle electronics. But this is no longer suff cient on its own. The ever-growing number of electrical and electronic vehicle components is no longer manageable without modern diagnostic technology – such as the latest range of KTS control unit diagnostic testers from Bosch. In addition, more and more of the previously purely mechanical interventions on vehicles now require the use of ECUs – such as the oil change (Figure 3.10).

Vehicle workshops operate in a very competitive environment and have to be able to carry out demanding repair work eff ciently, to a high standard and at a competitive price on a wide range of vehicle makes and models. The Bosch KTS control-unit diagnostic testers, used in conjunction with the comprehensive Esitronic workshop software, offer the best possible basis for eff cient diagnosis and repair of electrical and electronic components (Figure 3.11). The testers are available in different versions, suited to the individual requirements of the particular workshop.

The portable KTS 650 with built-in computer and touch-screen can be used anywhere. It has a 20 GB hard drive, a touch-screen and a DVD drive. When being used away from the workshop, the power supply of the KTS 650 comes from the vehicle battery or from rechargeable batteries with one to two hours' service life. For use in the workshop, there is a tough wheeled trolley with a built-in charger unit. In addition to having all the necessary adapter cables, the trolley can also carry an inkjet printer and an external keyboard, which can be connected to the KTS 650 via the usual PC interfaces.

The Esitronic software package accounts for the in-depth diagnostic capacity of the KTS diagnostic testers. For example, with the new common rail diesel systems, even special functions such as quantitative comparison and compression testing can be carried out. This allows for reliable diagnosis of the faulty part and avoids unnecessary dismantling and re-assembly or the removal and replacement of non-faulty parts.

Modern diagnostic equipment is also indispensable when workshops have to deal with braking systems having electronic control systems such as ABS, ASR and ESP. Nowadays, the diagnostic tester may even be needed for bleeding a brake system.

In addition, KTS and Esitronic allow independent workshops to reset the service interval warning, for example, after an oil change or a routine service, or perhaps f nd the correct default position for the headlamps after one or both have been replaced.

Besides the ISO norms for European vehicles and SAE norms for American and Japanese vehicles, the KTS testers can also deal with CAN norms for checking modern CAN bus systems, which are coming into use more and more frequently in new vehicles. The testers are connected directly to the diagnostics socket via a serial diagnostics interface by means of an adapter cable.

The system automatically detects the control unit and reads out the actual values, the error memory and other controller-specif c data. Thanks to a built-in multiplexer, it is even easier for the user to diagnose the various systems in the vehicle. The multiplexer determines the connection in the diagnostics socket so that communication is established correctly with the selected control unit.

The sequence of images in Table 3.4 shows a number of steps taken to diagnose a fault, using the KTS, on a vehicle that had poor running symptoms and in which the MIL was illuminated.

3.3.6 Engine analysers

Some form of engine analyser has become an almost essential tool for fault f nding modern vehicle engine systems. The latest machines are now generally based around a personal computer. This allows more facilities that can be added to by simply changing the software. However, the latest more portable systems such as the Pico Automotive kit will now do as many tests as the engine analyser, currently with the exception of exhaust emissions.

Although engine analysers are designed to work specif cally with the motor vehicle, it is worth remembering that the machine consists basically of three parts (Figure 3.19):

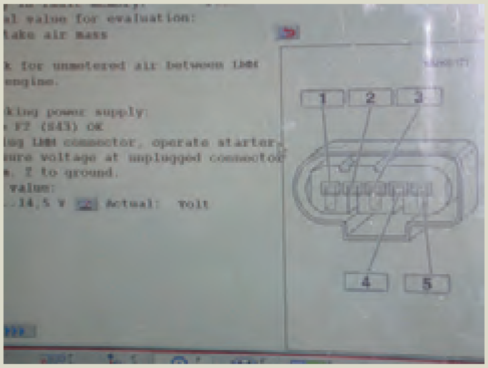
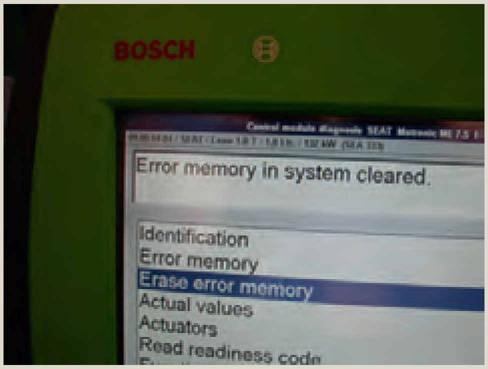
- multimeter;
- gas analyser;
- oscilloscope.

Table 3.4 Fault diagnosis with the KTS

The first step in this procedure was to connect the equipment to the car's diagnostic socket. The ignition should be off when the connection is made and then switched on	 **Figure 3.12** Connect the serial lead to the diagnostic socket
On this system the data for a wide range of vehicles is included on the system. The particular make and engine etc. can be selected from the menu system	 **Figure 3.13** Choose the vehicle type
The standard test for stored DTCs was run and the result suggested that there was a fault with the airflow sensor. The specific fault was that the signal value was too low. No real surprise as we had disconnected the sensor to simulate a fault	 **Figure 3.14** Take a readout from the control unit memory (DTC display)
This is the connection that was causing the problems. Further information about its pin configuration can be looked up in the Esitronic database	 **Figure 3.15** Airflow sensor connection

(Continued)

Table 3.4 (Continued)

The system also provides typical readings that should be obtained on different pins; for example, the supply and earth as well as the signal outputs Additional tests can be carried out to determine the fault	 **Figure 3.16** Esitronic information for the airflow sensor
The faulty connection was repaired and general checks carried out to ensure no other components had been disturbed during the testing and repair process	 **Figure 3.17** Make repairs
The final task is to clear the fault code memory and turn off the MIL Road tests showed that the fault had been rectified	 **Figure 3.18** Erase the fault from the memory

This is not intended to imply that other tests available such as cylinder balance are less valid, but to show that the analyser is not magic, it is just able to present results of electrical tests in a convenient way so as to allow diagnosis of faults. The key component of any engine analyser is the oscilloscope facility, which allows the user to 'see' the signal under test.

The trend with engine analysers seems to be to allow both guided test procedures with pass/fail recommendations for the less skilled technician and freedom to test any electrical device using the facilities available in any reasonable way. This is more appropriate for the highly skilled technician. Some of the routines available on modern engine analysers are listed below:

Tune-up: A full prompted sequence that assesses each component in turn with results and diagnosis displayed at the end of each component test. Stored data

Figure 3.19 Engine analysers

allows pass/fail diagnosis by automatically comparing results of tests with data on the disk. Printouts can be taken to show work completed.

Symptom analysis: This allows direct access to specif c tests relating to reported driveability problems.

Waveforms: A comprehensive range of digitised waveforms can be displayed with colour highlights (Table 3.5). The display can be frozen or recalled to look for intermittent faults. A standard lab scope mode is available to allow examination of electronic fuel injection (EFI) or ABS traces for example. Printouts can be made from any display. An interesting feature on some systems is 'transient capture', which ensures even the fastest spikes and intermittent signals are captured and displayed for detailed examination.

Adjustments: Selecting specif c components from a menu can make simple quick adjustments. Live readings are displayed appropriate to the selection.

UK MOT emissions test: Full MOT procedure tests are integrated and displayed on the screen with pass/fail diagnosis to the department of transport specif cations, for both gas analysis and diesel smoke, if appropriate options are f tted. The test results include engine rpm and oil temperature as well as the gas readings. All these can be printed for garage or customer use.

Engine analyser connections to the vehicle are similar for most equipment manufacturers (Table 3.6).

Table 3.5 Typical waveforms that can be displayed on most analysers and automotive oscilloscopes

Primary	Secondary	Diagnostic	Cylinder test
Primary waveform	Secondary waveform	Voltage waveform	Vacuum waveform
Primary parade waveform	Secondary parade waveform	Lab scope waveform	Power balance waveform
Dwell bar graph	kV histogram	Fuel injector waveform	Cylinder time balance bar graph
Duty cycle/Dwell bar graph	kV bar graph	Alternator waveform	Cylinder shorting even/odd bar graph
Duty cycle/Voltage bar graph	Burn time bar graph		Cranking amps bar graph

Table 3.6 Analyser connections

Connection	Purpose or one example of use
Battery positive	Battery and charging voltages
Battery negative	A common earth connection
Coil positive	To check supply voltage to coil
Coil negative (adapters are available for DIS)	To look at dwell, rpm and primary waveforms
Coil high-tension lead clamp (adapters are available for DIS)	Secondary waveforms
Number one cylinder plug lead clamp	Timing light and sequence of waveforms
Battery cable amp clamp	Charging and starting current
Oil temperature probe (dip stick hole)	Oil temperature
Vacuum connection	Engine load
Exhaust pipe	Emissions testing

3.4 Emission testing

3.4.1 Introduction

Checking the exhaust emissions of a vehicle has three main purposes:

1. ensure optimum performance;
2. comply with regulations and limits;
3. provide diagnostic information.

There are many different exhaust testing systems available.

3.4.2 Exhaust gas measurement

It has now become standard to measure four of the main exhaust gases, namely

- carbon monoxide (CO);
- carbon dioxide (CO_2);
- hydrocarbons (HC);
- oxygen (O_2).

Table 3.7 Exhaust examples

Reading	CO%	HCppm	CO_2%	O_2%	Lambda (λ)	AFR
Before catalyst	0.6	120	14.7	0.7	1.0	14.7
After catalyst	0.2	12	15.3	0.1	1.0	14.7

Key fact

The Greek symbol lambda (λ) represents the ideal air/fuel ratio (AFR) of 14.7:1 by mass.

On many analysers, lambda value and the air/fuel ratio (AFR) are calculated and displayed in addition to the four gases. The Greek symbol lambda (λ) is used to represent the ideal AFR of 14.7:1 by mass; in other words, just the right amount of air to burn up all the fuel. Table 3.7 lists gas, lambda and AFR readings for a closed loop lambda control system, before (or without) and after the catalytic converter. These are applicable for a modern engine in excellent condition and are a guide only – always check current data for the vehicle you are working on.

The composition of exhaust gas is now a critical measurement, hence a certain degree of accuracy is required. To this end, the infrared measurement technique has become the most suitable for CO, CO_2 and HC. Each individual gas absorbs infrared radiation at a specific rate. Oxygen is measured by electro-chemical means in much the same way as the on-vehicle lambda sensor.

Accurate measurement of exhaust gas is not only required for annual tests but is essential to ensure an engine is correctly tuned. Table 3.7 lists typical values measured from a car exhaust. Note the toxic HC and CO emissions, although small, are nonetheless dangerous.

3.4.3 Exhaust analyser

The facilities of an exhaust analyser produced by Bosch are outlined here.

The measuring system shown in Figures 3.20 and 3.21 can be used for petrol/gasoline, diesel and natural gas vehicles (a statutory requirement in Germany). It is designed for quick and mobile use in workshops and is a robust design. It measures the usual four gases, weighs less than 15 kg and can be ready for operation in just a few minutes. The system is controlled by software, which takes users through the test sequence. The device can be serviced by users themselves every six months.

Definition

Bluetooth: A proprietary open wireless protocol for exchanging data over short distances from fixed and mobile devices, creating personal area networks (PANs).

The system measures the HC, CO, CO_2 and O_2 exhaust components for petrol/gasoline engines. It can also be expanded to measure nitrogen oxide (NO), if necessary. It records engine speed and temperature. Adding a smoke opacity measuring device means exhaust gas analyses can be carried out on diesel vehicles. Linking with the KTS (Section 3.3.5) allows important OBD engine and transmission control unit data as well as the gases to be read. The laptop and KTS can be connected via a cable or Bluetooth.

3.4.4 Emission limits

Limits and regulations relating to exhaust emissions vary in different countries and in different situations. For example, in the United Kingdom, certain limits have to be met during the annual test. The current test default limits (for vehicles since September 2002 fitted with a catalytic converter) are as follows:

- Minimum oil temperature (60 °C)
- Fast idle (2500–3000 rpm)
  - CO ≤0.2%

Figure 3.20 Exhaust gas measuring components (Source: Bosch Media)

Figure 3.21 Exhaust gas measuring system in use (Source: Bosch Media)

Table 3.8 European past and future emission limits

Emissions standard	Particulate matters (PM)/ (mg/km)		Oxides of nitrogen (NO_x) (mg/km)		Hydrocarbons (HC) (mg/km)	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
Euro 2 (1996)	80–100	–	–	–	–	–
Euro 3 (2000)	50	–	500	150	–	200
Euro 4 (2005)	25	–	250	80	–	100
Euro 5 (2009)	5	5	180	70	–	100
Euro 6 (2014)	5	5	80	70	–	100

 - HC ≤200 ppm
 - Lambda 0.97–1.03
- Idle (450–1500 rpm)
 - CO ≤0.3%

Manufacturers, however, have to meet stringent regulations when producing new vehicles. In Europe, the emission standards are def ned in a series of EU directives staging the progressive introduction of increasingly stringent standards (Table 3.8).

In the United States, Tier 2 standards are divided into several numbered ‘bins’ (Table 3.9). Eleven bins were initially def ned, with bin 1 being the cleanest (zero emission vehicle) and 11 the dirtiest. However, bins 9, 10 and 11 are temporary. Only the f rst 10 bins were used for light-duty vehicles below 8500 pounds gross vehicle weight rating (GVWR), but medium-duty passenger vehicles up to 10 000 pounds (4536 kg) GVWR used all 11 bins. Manufacturers can make vehicles which f t into any of the available bins, but still must meet average targets for their entire f eets.

The two least-restrictive bins, 9 and 10, for passenger cars phased out at the end of 2006. However, bins 9 and 10 were available for classifying a restricted number of light-duty trucks until the end of 2008, when they were removed along with bin 11 for medium-duty vehicles. As of 2009, light-duty trucks must meet the same emissions standards as passenger cars.

Phase 2 was from 2004 to 2009, and now even more stringent standards are coming into use. Also, the California Air Resources Board (CARB) may adopt and enforce its own emissions standards. However, regardless of whether a manufacturer receives CARB approval, all new motor vehicles and engines must still receive certif cation from the environmental protection agency (EPA) before a vehicle is introduced.

3.5 Pressure testing

3.5.1 Introduction

Measuring the fuel pressure on fuel injection engine is of great value when fault f nding. Many types of pressure testers are available and they often come as part of a kit consisting of various adapters and connections (Figure 3.22). The principle of mechanical gauges is that they contain a very small tube wound in

Table 3.9 Tier 2 exhaust emission standards (United States)

Standard		Emission limits at 50 000 miles					Emission limits at full useful life (120 000 miles)[a]				
		NO_x (g/mi)	NMOG (g/mi)	CO (g/mi)	PM (g/mi)	HCHO (g/mi)	NO_x (g/mi)	NMOG (g/mi)	CO (g/mi)	PM (g/mi)	HCHO (g/mi)
Federal	Bin 1	–	–	–	–	–	0	0	0	0	0
	Bin 2	–	–	–	–	–	0.02	0.01	2.1	0.01	0.004
	Bin 3	–	–	–	–	–	0.03	0.055	2.1	0.01	0.011
	Bin 4	–	–	–	–	–	0.04	0.07	2.1	0.01	0.011
	Bin 5	0.05	0.075	3.4	–	0.015	0.07	0.09	4.2	0.01	0.018
	Bin 6	0.08	0.075	3.4	–	0.015	0.1	0.09	4.2	0.01	0.018
	Bin 7	0.11	0.075	3.4	–	0.015	0.15	0.09	4.2	0.02	0.018
	Bin 8	0.14	0.100/0.125[c]	3.4	–	0.015	0.2	0.125/0.156	4.2	0.02	0.018
	Bin 9[b]	0.2	0.075/0.140	3.4	–	0.015	0.3	0.090/0.180	4.2	0.06	0.018
	Bin 10[b]	0.4	0.125/0.160	3.4/4.4	–	0.015/0.018	0.6	0.156/0.230[c]	4.2/6.4	0.08	0.018/0.027
	Bin 11[b]	0.6	0.195	5	–	0.022	0.9	0.28	7.3	0.12	0.032

[a]In lieu of intermediate useful life standards (50 000 miles) or to gain additional NO_x credit, manufacturers may optionally certify to the tier 2 exhaust emission standards with a useful life of 150 000 miles.
[b]Bins 9–11 expire in 2006 for light-duty vehicles and light light-duty trucks and in 2008 for heavy light-duty trucks and medium-duty passenger vehicles.
[c]Pollutants with two numbers have a separate certification standard (first number) and in-use standard (second number).
NMOG – non-methane organic gases.
HCHO – formaldehyde.

Figure 3.22 Fuel pressure gauge kit

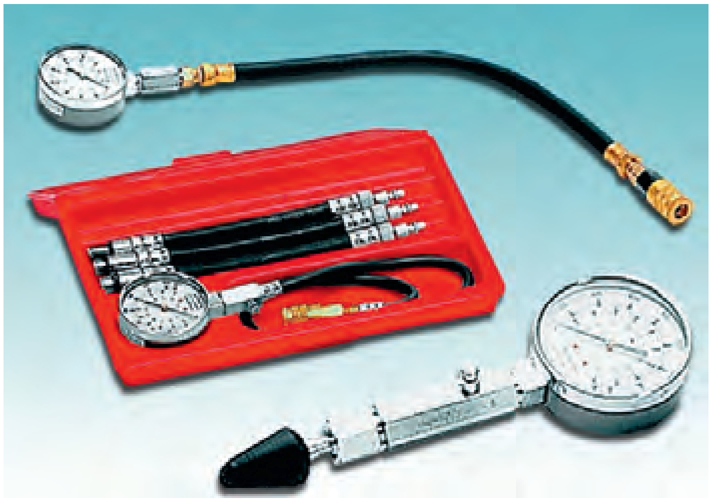


Figure 3.23 Compression tester

Figure 3.24 Automotive pressure transducer (Source: PicoTech)

Def nition

Transducer: A device that converts a physical quantity (e.g. force, torque, pressure, rotation) to an electrical signal.

a spiral. As f uid or gas under pressure is forced into the spiral tube, it unwinds causing a needle to move over a graduated scale.

Measuring engine cylinder compression or leakage is a useful test. Figure 3.23 shows an engine compression tester. This device is used to compare cylinder compressions as well as to measure actual values.

3.5.2 Automotive pressure oscilloscope transducer

PicoTech has developed an accurate pressure transducer (Figure 3.24) that can be used for pressure analysis of many automotive systems.

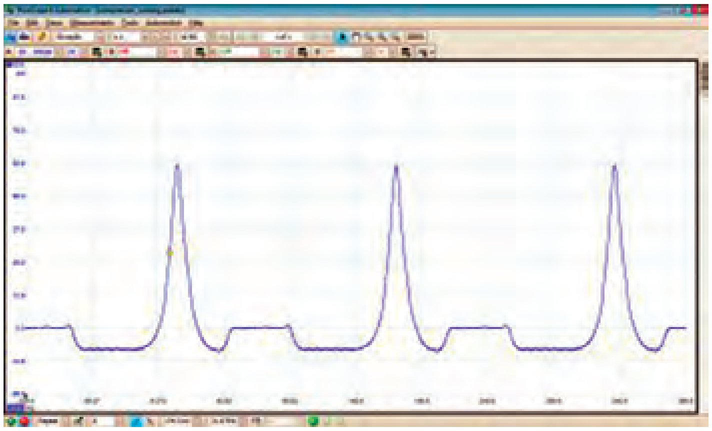


Figure 3.25 Running compression waveform

Some of the key features are as follows:

- range accurate from 0.07 psi (5 mbar) to 500 psi (34.5 bar);
- 100 μs response time;
- zoom function for enhanced analysis;
- temperature compensation.

These result in an accurate representation of rapidly changing signals that span across a broad pressure range.

The three pressure ranges of the device allow for accurate measurement and analysis of many automotive pressures, including

- cylinder compression;
- fuel pressure;
- intake manifold vacuum;
- pulses from the exhaust.

The f rst range gives high resolution and accuracy for high-pressure tests such as cranking and running cylinder compression or fuel pressure testing.

The second range measures from −15 to 50 psi (approximately −1 to 3.45 bar). This range is ideal for vacuum tests and fuel system tests. The zoom function is especially useful on these tests as it makes it easy to analyse the valves operating with the vacuum waveform, or the injectors through the fuel waveform (Figure 3.25).

With the third range you can measure −5 to 5 psi (approximately −0.34 to 0.34 bar). This setting is sensitive enough to allow analysis of small pressures or pulses such as from the exhaust. This is an excellent way of checking even for running cylinders.