moto zero
by Transitions Lab

03

MODULE 3

Fuel, ignition and electrical systems

How a motorcycle meters air and fuel, times its spark, generates and stores electrical energy, and how a technician measures each circuit from battery to sensor.



A technical course on how motorcycles work
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Contents

3.1 Air, fuel and mixture 3

3.2 Electronic fuel injection and engine management .....

3.3 Ignition systems .....

3.4 Battery, charging and starting 29

3.5 Lighting, signalling and wiring 35

3.6 Electrical diagnosis .....

Glossary 50

Further reading 51

THE SERIES

01 Foundations: the machine, its anatomy and the workshop

02 The engine: four-stroke and two-stroke

03 **Fuel, ignition and electrical systems**

04 Drivetrain and chassis

05 Electric motorcycles

Each chapter opens with learning objectives and closes with review questions and worked answers. Reference data comes from the K-Light 125 maintenance manual unless stated otherwise; always use the manual for the machine in front of you. Explorer exercises refer to the interactive anatomy explorer at transitionslab.org/motorcycle-anatomy.

CHAPTER 3.1

Air, fuel and mixture

LEARNING OBJECTIVES

- Calculate the stoichiometric air-fuel ratio of a hydrocarbon fuel and convert between AFR and lambda.
- Explain how rich and lean mixtures affect power, temperature, fuel consumption and exhaust emissions.
- Describe the intake path from air filter box to inlet valve and the effect of a restricted filter.
- Identify each carburettor circuit (float, pilot, slide cutaway, needle and needle jet, main jet, enricher) and the throttle range it governs.
- Diagnose mixture faults from symptoms, plug colour and carburettor settings, and synchronise multiple carburettors or throttle bodies.
- Explain the function of the fuel tap, tank vent and rollover valve, and the faults they cause.

Combustion chemistry

A spark-ignition engine releases chemical energy by oxidising a hydrocarbon fuel with the oxygen in air. Petrol is a blend of several hundred hydrocarbons in the C4 to C12 range, but its average composition is close to $CH_{1.87}$ by atom count, and iso-octane (C_8H_{18}) is a convenient model compound for calculation. Complete combustion turns all carbon into carbon dioxide and all hydrogen into water:

$$C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$$

$$m(\text{fuel}) = 8 \times 12 + 18 \times 1 = 114\ \text{g}$$

$$m(O_2) = 12.5 \times 32 = 400\ \text{g}$$

$$m(\text{air}) = 400 \div 0.232 \approx 1724\ \text{g}$$

$$\text{AFR(stoich)} = 1724 \div 114 \approx 15.1$$

where 0.232 is the mass fraction of oxygen in dry air. Real pump petrol contains aromatics and olefins with a lower hydrogen-to-carbon ratio than iso-octane, which lowers the oxygen demand per kilogram, so the accepted stoichiometric value for petrol is **14.7:1** by mass. Oxygenates lower it further, because the fuel carries some of its own oxygen: ethanol has a **stoichiometric AFR** of about 9.0:1, so E10 petrol is close to 14.1:1 and E20 close to 13.8:1. This is why a carburettor jetted for pure petrol runs measurably lean on E20, while a closed-loop injection system corrects the difference through its oxygen sensor.

Engineers express mixture strength as **lambda (λ)**, the ratio of actual AFR to stoichiometric AFR, because lambda is independent of fuel type:

$$\lambda = \text{AFR(actual)} \div \text{AFR(stoich)}$$

$$\lambda < 1 \text{ rich (excess fuel)}$$

$$\lambda > 1 \text{ lean (excess air)}$$

An engine running 13.2:1 on petrol is at $\lambda = 13.2 \div 14.7 \approx 0.90$. Older texts, including the MAVCC unit on carburetion, also quote AFR by weight in the form "12:1", meaning 12 kg of air for each kilogram of fuel.

Effects of mixture strength

Mixture strength is a compromise between power, efficiency, temperature and emissions, and each operating condition favours a different value:

Lambda	AFR (petrol)	Typical use	Consequence
0.80–0.88	11.8–12.9	Full load, cold start enrichment	Maximum power with charge cooling; high CO and HC; sooty plugs if sustained
0.88–0.95	12.9–14.0	Best-power region on most engines	Fastest flame speed, highest torque
1.00	14.7	Idle and cruise on catalyst engines	Only window where a three-way catalyst converts CO, HC and NOx together
1.05–1.15	15.4–16.9	Lean cruise on older open-loop engines	Best fuel economy, peak NOx, higher combustion temperature
above 1.3	above 19	Over-lean fault	Slow burn, misfire, surging, popping in the exhaust, hot exhaust valve and piston crown

A rich mixture burns cooler because the surplus fuel absorbs heat as it evaporates and because there is not enough oxygen to oxidise all of it; the penalty is high carbon monoxide, unburned hydrocarbons, carbon deposits and fouled plugs. A lean mixture burns more slowly, so combustion is still in progress when the exhaust valve opens; exhaust gas temperature rises, cylinder head temperature rises, and on an air-cooled single such as the K-Light 125 a **persistently lean mixture** leads to detonation, burned exhaust valves and piston seizure. The MAVCC text notes that a ratio near 12:1 delivers more power than 14.7:1, which is consistent with the best-power band in the table.

Air density changes the mass of oxygen entering the cylinder. At 2000 m altitude air is about 20 % less dense than at sea level, so a carburettor (which meters fuel in proportion to air velocity, not air mass) runs richer by roughly the same proportion, while an injection system with a manifold absolute pressure sensor and intake air temperature sensor recalculates the air mass and adjusts the pulse width.

Air intake and filter

Air enters through a snorkel or duct into the air filter box, which serves three functions: it holds the filter element, it provides a calm plenum so that each intake pulse draws from still air, and it acts as a **Helmholtz resonator** that both tunes the intake pressure wave and suppresses intake noise to meet the type-approval sound limit. From the box a rubber boot leads to the carburettor or throttle body, then to the inlet port.

Three element types are common. **Pleated paper** (cellulose or synthetic) is used on most road machines because it traps fine dust with high efficiency and needs no oiling; it is replaced, typically every 12 000–18 000 km on road bikes and far sooner on dusty roads. **Oiled polyurethane foam**, often in two densities, is standard on off-road machines and many small commuters: it is washed in solvent or detergent, dried, oiled with filter oil and squeezed out. The K-Light 125 specification table lists the filter as a sponge (foam) type. Oiled cotton gauze filters flow well but pass more fine dust.

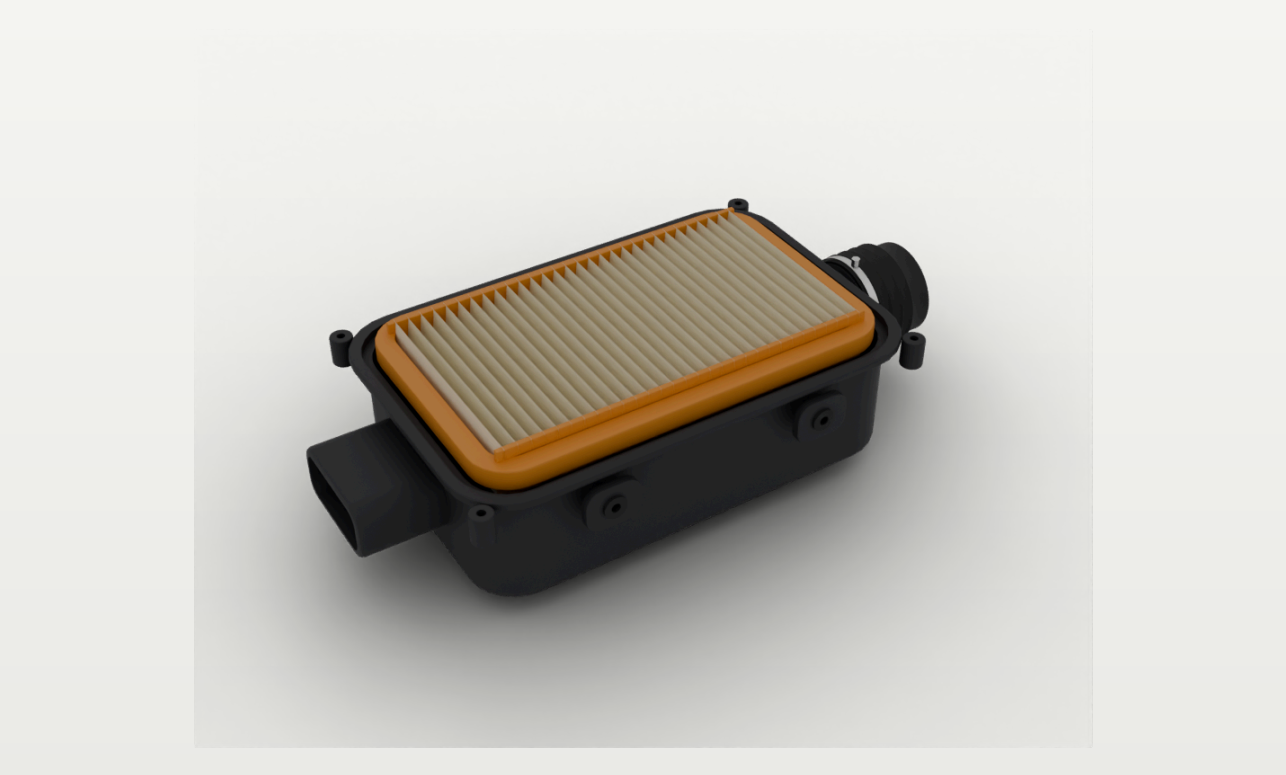


FIGURE 3.1 A pleated-paper panel filter seated in the lower half of an airbox.
Render: Transitions Lab, CC BY-SA 4.0

A blocked filter raises the depression downstream of the element. In a carburettor this depression acts on every fuel jet, so the mixture becomes richer at all openings (the K-Light fault-diagnosis tree lists a blocked air filter as the first check for an over-rich mixture). In a speed-density injection system the MAP sensor sees the lower manifold pressure and the ECU reduces fuel, so the main symptom becomes loss of power rather than black smoke. An **air leak** between the carburettor or throttle body and the engine (a split boot, a loose clamp, a cracked heat insulator) admits unmetered air and leans the mixture, mostly at idle where the metered flow is small.

> EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy **Intake volume and mixture**
>
> Open the explorer at transitionslab.org/motorcycle-anatomy, set bore 56.5 mm and stroke 49.5 mm (the K-Light 125), and run the cycle animation at 1500 and 9000 rpm. Note how the time available for the intake stroke falls from 20 ms to 3.3 ms, then select "Air filter box" and "Throttle body and injector" in the exploded diagram and trace the air path to the inlet valve.

How a carburettor meters fuel

A carburettor uses the pressure drop of air accelerating through a restriction. As the piston descends on the intake stroke, atmospheric pressure pushes air through the bore. At the venturi, or at the gap under the throttle slide, velocity rises and static pressure falls (**Bernoulli's principle**). A fuel nozzle opens into this low-pressure zone, while the float bowl above the fuel is vented to atmosphere, so atmospheric pressure pushes fuel up through calibrated jets into the airstream. The fuel emerges as droplets (**atomisation**) and evaporates on the way to and inside the cylinder (**vaporisation**). The carburettor therefore restricts and regulates air with the throttle, and regulates fuel with jets of different sizes.

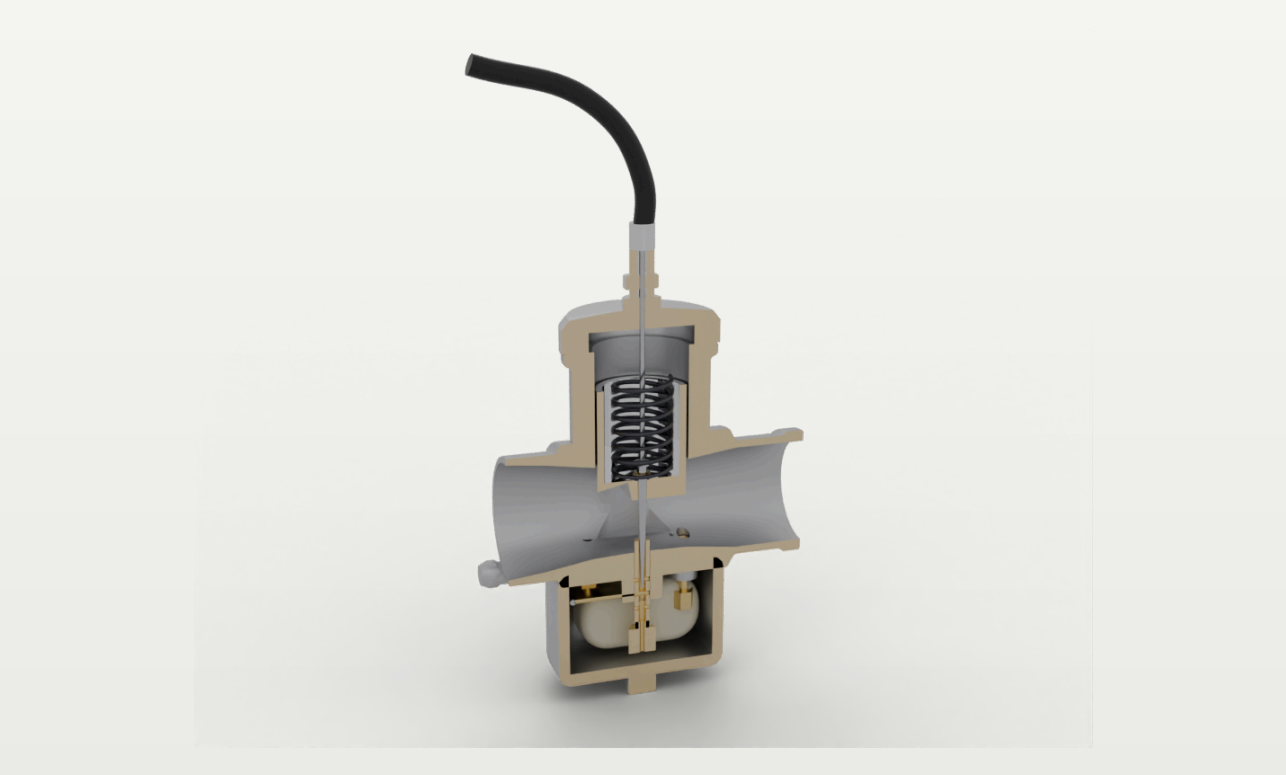


FIGURE 3.2 The same slide carburettor modelled in half section.
Render: Transitions Lab, CC BY-SA 4.0

The fundamental difficulty is that air and fuel do not respond to depression in the same way: air is compressible and its flow through the venturi follows a different curve from that of liquid fuel through a small orifice, so a single jet would give a mixture that richens as airflow rises. Carburettors therefore use several overlapping circuits, and air bleeds that emulsify fuel with air before it reaches the nozzle, to hold the mixture close to the target across the throttle range.

Slide and constant-velocity carburettors

In a **slide (piston-valve) carburettor** such as the Mikuni VM or Keihin PWK, the throttle cable lifts a cylindrical or flat slide directly. The rider controls the size of the venturi, which gives instant response, and two-stroke off-road machines such as the Yamaha YZ125 use this type. The disadvantage is that a large slide opened suddenly at low rpm causes the air velocity to collapse, fuel stops being drawn and the engine bogs.

In a **constant-velocity (CV) carburettor**, such as the Keihin CVK fitted to many four-stroke commuters including Honda CG125 variants, the cable turns a butterfly valve downstream of a piston. The piston is attached to a rubber diaphragm whose upper chamber is connected through a small hole to the venturi, while the lower chamber is vented to the air filter side. When the rider opens the butterfly, venturi depression rises, the diaphragm lifts the piston, and the venturi enlarges only as fast as the engine's airflow allows. Air velocity across the needle jet therefore stays roughly constant, hence the name. A torn diaphragm leaves the piston down, so the engine runs but will not rev beyond a moderate speed; the K-Light power-loss tree lists a cracked or damaged vacuum diaphragm of the plunger valve as a check.

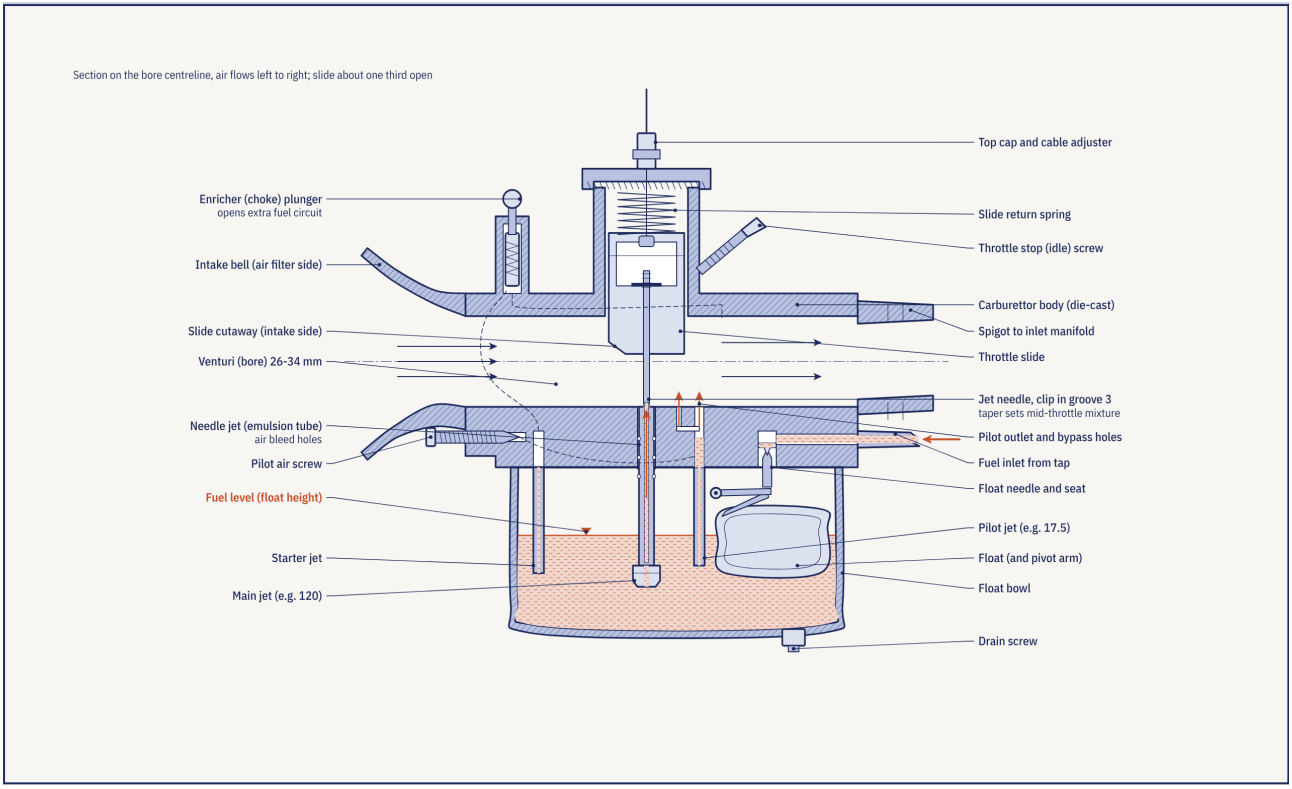


FIGURE 3.3 Slide carburettor in section: venturi, slide and needle, needle jet, main jet, pilot circuit, float bowl, float and float needle, with fuel shown tinted.

Circuits and throttle ranges

The circuits overlap, but each dominates a portion of throttle opening (not of rpm), a distinction that guides every jetting decision:

Throttle opening	Dominant circuit	Main tuning part	Effect of change
Closed to 1/8	Pilot (low-speed) circuit	Pilot jet, pilot (mixture) screw or air screw	Larger pilot jet or screw out on a fuel screw: richer idle and off-idle
1/8 to 1/4	Transition	Slide cutaway height, pilot by-pass holes	Higher cutaway: leaner
1/4 to 3/4	Mid-range	Jet needle taper and clip position, needle jet diameter	Clip lowered (needle raised): richer
3/4 to full	High-speed	Main jet	Larger number: richer
Cold start	Enricher (starter) or choke	Starter jet and plunger, or choke plate	Supplies λ around 0.5–0.7 for cranking

The **float circuit** sits beneath all of these. A float on a pivot closes a tapered needle against a seat when the fuel reaches a set height, so the head of fuel below the nozzles stays constant. A **float level set too high** reduces the lift required and enriches every circuit, and if the needle sticks open the bowl overflows through the overflow tube; a level set too low leans every circuit and causes high-speed surging. Float height is measured with the carburettor inverted, the float tang just resting on the needle, from the gasket face to the float bottom, against the manual figure.

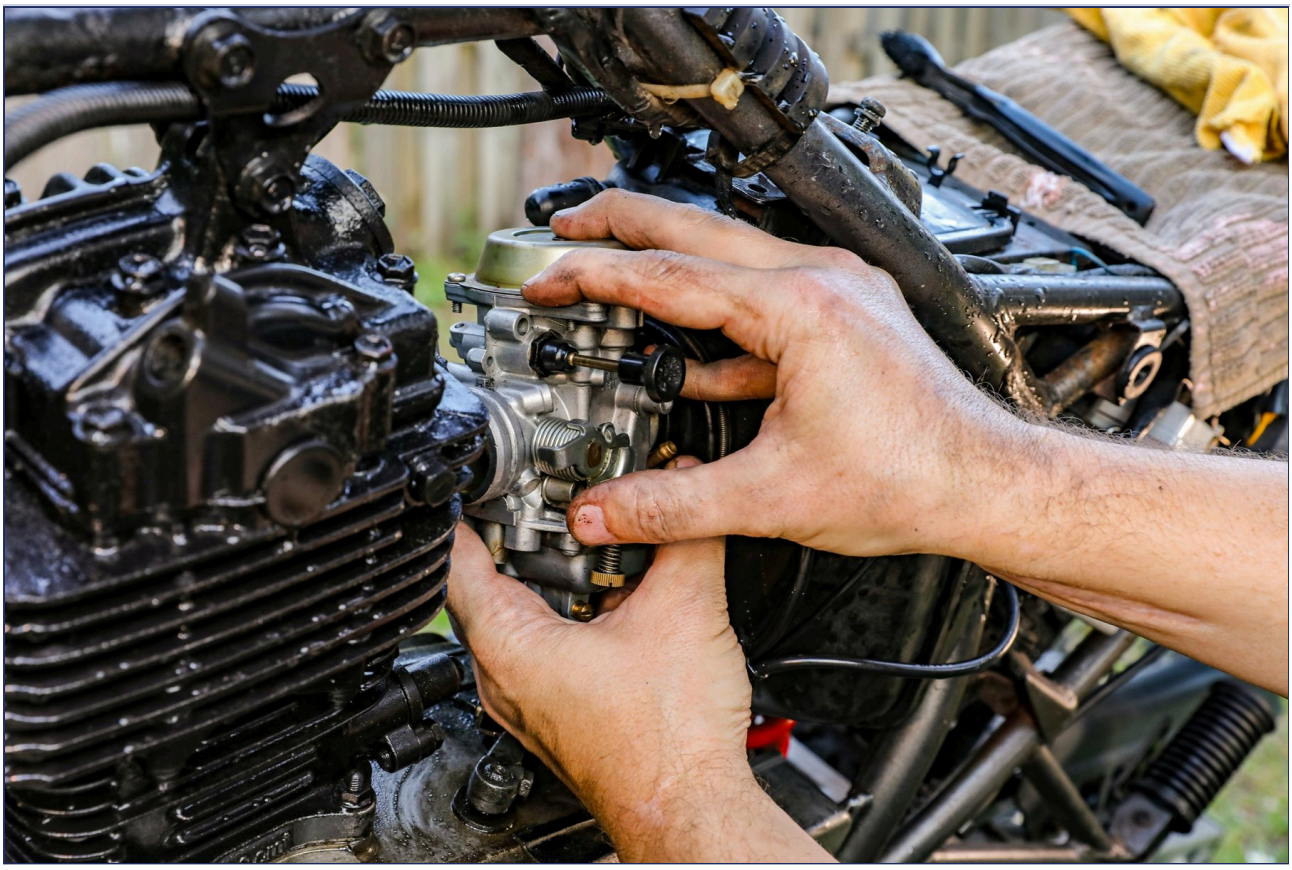


FIGURE 3.4 Refitting a constant-velocity carburettor between the intake rubber and the airbox on an air-cooled twin: the round diaphragm chamber sits on top, the pilot mixture screw and idle stop screw are on the side, and the float bowl is below.
Photograph: Transitions Lab collection

The **pilot circuit** draws fuel through a small pilot jet (typically numbered 15–42 on Keihin and Mikuni), mixes it with air from a pilot air jet or air passage, and delivers it through an outlet downstream of the throttle and through by-pass holes just upstream of the closed throttle edge. On a carburettor where the adjusting screw is on the engine side of the slide, it is a **fuel (mixture) screw** and turning it out richens; where the screw is on the intake side it is an **air screw** and turning it out leans. Many CV carburettors built since the 1980s have the fuel screw sealed with a plug for emissions reasons.

The **jet needle** hangs from the slide or piston into the needle jet. Fuel flow through the annulus between them depends on needle diameter at the height reached, so the taper profile controls mid-range mixture. Most needles carry five clip grooves; moving the clip down one groove raises the needle and richens the 1/4 to 3/4 range. The **main jet**, screwed into the base of the needle jet, is in series with all fuel reaching the needle jet; once the slide is high enough that the annulus area exceeds the main jet area (about 3/4 open), the main jet becomes the restriction. The jet number is proportional to flow on Mikuni hex mains and approximately to orifice diameter in hundredths of a millimetre on Keihin mains, so the same number does not mean the same size between brands.

The **enricher** on most modern carburettors is a separate plunger circuit: lifting the plunger opens a passage that draws fuel through a starter jet and discharges it downstream of the slide. Because it relies on the depression behind a closed throttle, it works best with the throttle shut, and opening the throttle during a cold start weakens it. A **choke plate** (butterfly upstream of the venturi) instead enriches by raising venturi depression. Some CV carburettors also carry an **accelerator pump**, a diaphragm pump linked to the throttle that squirts fuel into the bore when the throttle snaps open to cover the lean stumble caused by fuel lag.

Jetting method

Because circuits overlap, the correct order is **main jet first** (full-throttle runs, plug chop or wideband AFR), then needle, then cutaway, then pilot and fuel screw. A change of altitude, a free-flowing exhaust or a different filter alters airflow at all openings, so jetting is always confirmed by a road test across the range rather than at idle alone.

Synchronising carburettors and throttle bodies

A twin or four with one carburettor or throttle body per cylinder must open all throttles together, or one cylinder does more work than the others, causing vibration at low speed, rough idle and uneven plug colour. **Synchronisation (balancing)** uses a set of vacuum gauges, a mercury-free manometer or an electronic balancer connected to the vacuum port of each intake runner. With the engine at operating temperature and at the specified idle speed, the linkage screws between carburettors are adjusted until all intake depressions agree, usually within **10–20 mmHg (1.3–2.7 kPa)** of each other; then the idle speed is reset. On an injected engine the same procedure is done with the throttle-body balance screws or by-pass screws, and some systems require the ECU to be placed in a service mode so that the idle air control does not move during adjustment. A single-cylinder machine like the K-Light 125 needs no balancing.

Fuel tap, tank venting and fuel delivery

A gravity-fed carburettor engine draws from the tank through a **fuel tap** with a filter gauze on its standpipe. A manual tap has OFF, ON and RES (reserve) positions; the ON pick-up stands higher in the tank than the RES pick-up, so when fuel falls below the ON pipe the engine starves and the rider switches to reserve, typically leaving 1–3 litres. A **vacuum-operated tap** has a diaphragm connected to the intake manifold, so fuel flows only while the engine is turning; a PRI (prime) position bypasses the diaphragm to fill an empty bowl. A split vacuum diaphragm lets fuel flow continuously, and if the float needle also leaks the engine can fill the crankcase with petrol, diluting the oil.

The tank must breathe as fuel is drawn out, or a vacuum forms above the fuel and flow stops. Older caps carry a simple vent hole; modern tanks are sealed and vent through a one-way valve and a rollover valve into the evaporative emission canister (see Evaporative emission control in chapter 3.2). A **blocked vent** produces a characteristic fault: the engine runs normally for several kilometres, then loses power and stops, and restarts after the cap is opened with an audible hiss; the K-Light fault tree lists a blocked air hole of the fuel tank among the first checks for a no-start. On an injected bike the in-tank pump can collapse a plastic tank slightly if the vent fails.

> SAFETY **Fuel handling**
>
> Petrol vapour is heavier than air and ignites from a spark or a hot exhaust. Drain carburettor bowls into a container, never onto a running or hot engine, work in a ventilated area away from pilot lights and grinders, and disconnect the battery negative before opening a fuel line on an injected machine, whose line holds about 300 kPa.

REVIEW QUESTIONS

1. Using the iso-octane equation, show why one kilogram of fuel needs about 15 kg of air for complete combustion, and explain why the accepted figure for petrol is 14.7:1.
2. A wideband sensor reads AFR 12.5 on petrol at full throttle. Calculate lambda and state whether the mixture is rich or lean.
3. E10 has a stoichiometric AFR of 14.1:1. If a carburettor delivers 14.1:1 on pure petrol, what is lambda on pure petrol, and what happens to lambda on E10?

4. Explain why a blocked air filter makes a carburetted engine run rich but a speed-density injected engine lose power instead.
5. A slide carburettor runs well at full throttle but surges and runs hot at half throttle. Which component would you adjust, in which direction, and why?
6. State the throttle range governed by each of: pilot jet, slide cutaway, jet needle, main jet.
7. A CV-carburetted commuter idles well but will not exceed about 5000 rpm under load, with no misfire. Name the most likely fault and how to confirm it.
8. A bike stops after 15 km, restarts after the filler cap is opened. What is the fault and why does opening the cap cure it?
9. A twin's left cylinder header stays visibly cooler than the right at idle and the engine vibrates. Describe the adjustment required, including instrument and tolerance.
0. Air density at 2000 m is 20 % below sea level. If a carburettor gives λ = 0.95 at sea level, estimate lambda at 2000 m, assuming fuel flow unchanged and air mass flow reduced in proportion.

ANSWERS

1. 12.5 mol O_2 (400 g) burns 1 mol iso-octane (114 g); air is 23.2 % oxygen by mass, so 400 ÷ 0.232 = 1724 g air, and 1724 ÷ 114 ≈ 15.1. Petrol contains aromatics and olefins with less hydrogen per carbon than iso-octane, so its oxygen demand per kilogram is lower, giving 14.7:1.
2. λ = 12.5 ÷ 14.7 ≈ 0.85; rich, in the full-load enrichment range.
3. On pure petrol λ = 14.1 ÷ 14.7 ≈ 0.96. On E10, metering the same volume ratio gives λ ≈ 14.1 ÷ 14.1 = 1.0, so the engine is about 4 % leaner than on petrol, and a carburettor jetted lean already would move further lean.
4. In a carburettor the extra depression downstream of the filter acts on all jets, pulling more fuel for the same air mass. In a speed-density system the MAP sensor reads the lower manifold pressure, the ECU calculates less air and injects less fuel, so mixture stays near target but the engine is short of air, hence of power.
5. The jet needle, which governs 1/4 to 3/4 throttle. The symptoms indicate a lean mid-range, so lower the clip one groove to raise the needle (richer), or fit a needle with a thinner straight diameter.
6. Pilot jet: closed to 1/8. Slide cutaway: 1/8 to 1/4. Jet needle: 1/4 to 3/4. Main jet: 3/4 to full.
7. A torn or perished CV diaphragm, or a blocked piston vent hole, preventing the piston from rising. Remove the top cover, lift the piston by hand and check it falls smoothly; hold the diaphragm to a light to look for pinholes.
8. The tank vent (cap vent or one-way valve) is blocked. Fuel drawn from a sealed tank creates a vacuum that eventually equals the head of fuel and stops flow; opening the cap admits air.
9. Synchronise the carburettors: fit vacuum gauges or an electronic balancer to both intake vacuum ports, warm the engine, set idle to specification, turn the synchronising screw until both depressions agree within about 10–20 mmHg, then reset idle.
10. Air mass falls to 0.8 of the sea-level value with the same fuel, so AFR falls by the same factor: λ ≈ 0.95 × 0.8 = 0.76, which is very rich, and the bike would need smaller jets.

CHAPTER 3.2

Electronic fuel injection and engine management

LEARNING OBJECTIVES

- Describe the fuel delivery circuit of a motorcycle EFI system and the pressure it must hold.
- Explain how the ECU calculates injector pulse width from sensor inputs under speed-density and alpha-N strategies.
- State the function, signal type and typical values of the TPS, MAP, IAT, engine temperature, crankshaft position and oxygen sensors, using K-Light 125 data.
- Distinguish open-loop and closed-loop operation and describe cold start, idle control and fuel cut-off.
- Explain how CO, HC and NOx form and how the three-way catalyst, secondary air injection and EVAP canister reduce them.
- Summarise Euro 5, Euro 5+ and Bharat Stage VI requirements, including on-board diagnostics, and read and interpret P-codes.

Why injection replaced the carburettor

A carburettor cannot hold a mixture within the narrow lambda window a three-way catalyst needs, cannot compensate accurately for air density, temperature or fuel ethanol content, and cannot report its own faults. **Electronic fuel injection (EFI)** meters fuel by holding an electrically opened valve open for a calculated time, under constant fuel pressure, and corrects that time continuously from an oxygen sensor in the exhaust. Once Euro 3 and then Euro 4 limits made catalyst-equipped closed-loop control the practical route to type approval, injection spread from large machines to 125 cc commuters; in India the same shift came with Bharat Stage VI in April 2020, when even entry commuters moved to closed-loop injection (or, on some Bajaj models, a closed-loop electronically trimmed carburettor).

The K-Light 125 uses a small-engine system from Shanghai YESON Electric: a single port injector, a throttle body with throttle position sensor, combined intake pressure and temperature sensor and stepper-motor idle control, a cylinder-head temperature sensor, a crankshaft trigger on the flywheel, a heated oxygen sensor, an in-tank pump, a three-way catalyst and an OBD system with a malfunction indicator lamp (MIL) marked FI on the instrument panel. The ECU also controls ignition.

Fuel delivery: pump, regulator and filter

The **fuel pump assembly** sits in the bottom of the tank, submerged so that fuel cools the motor and suppresses vapour lock. It is a small permanent-magnet DC motor driving a turbine (regenerative) impeller, drawing through a strainer sock. Pressure is held by a **regulator**: on returnless systems such as the K-Light the regulator is built into the pump module and spills excess fuel straight back into the tank, so only one line runs to the injector. The K-Light manual specifies **300 kPa** at the injector rail at idle, with a fault threshold of **270 kPa**, below which the technician checks for leaks, a pump running in reverse (the manual notes a reversed connector can cause this) or a blocked filter. Older and larger systems put the regulator on the fuel rail and reference it to manifold pressure, holding a constant pressure difference across the injector; on a returnless single the ECU compensates for the changing difference in software.

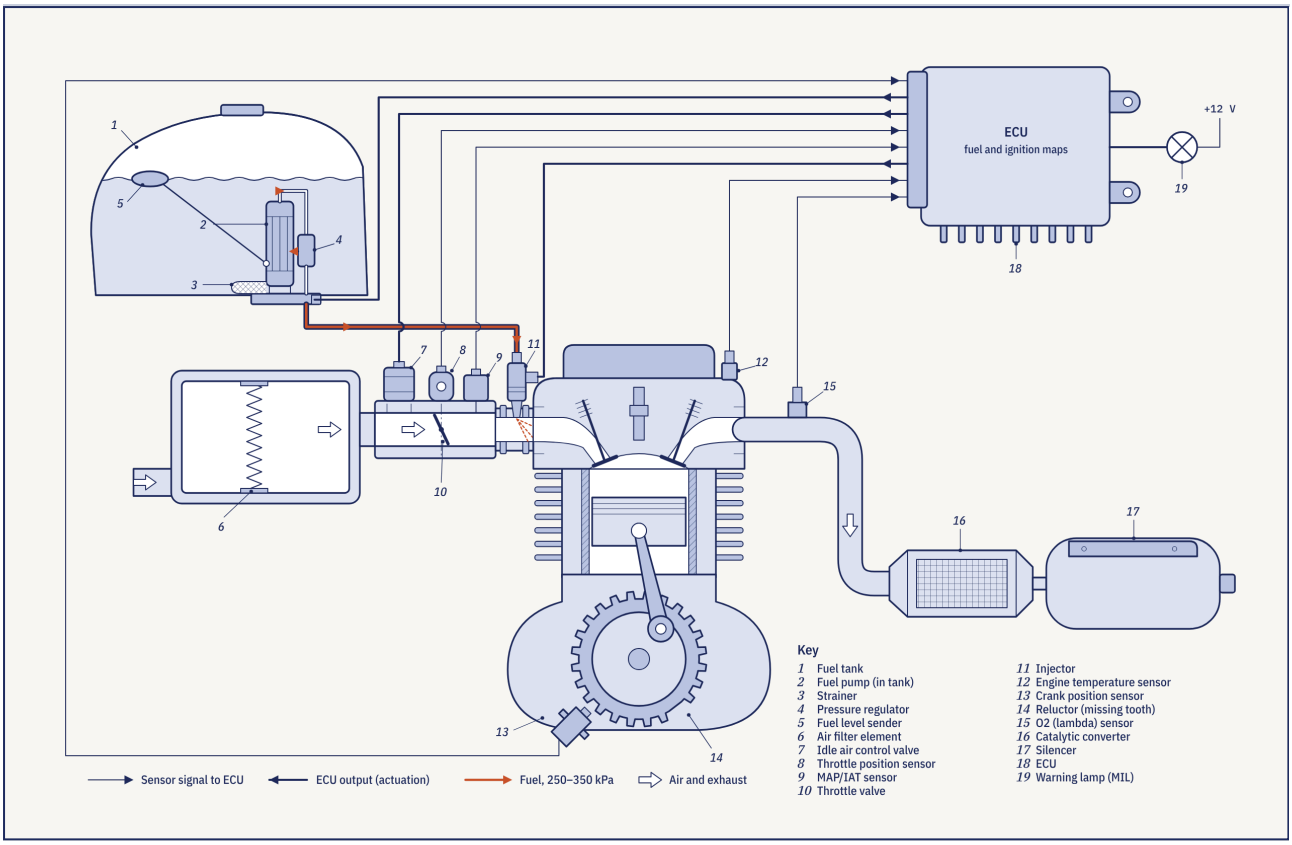


FIGURE 3.5 Electronic fuel injection system of a single-cylinder motorcycle, showing fuel delivery, sensors, ECU, actuators and catalyst, with sensor signal lines distinguished from actuation lines.

At key-on the ECU energises the pump relay for **about 3 seconds** to prime the line, then stops it unless it sees crankshaft pulses; this prevents the pump from emptying the tank through a broken line after a crash. On the K-Light the pump supply measured at its connector should be **12 ± 2 V** within those 3 seconds and during cranking. A filter (in the pump module or in line) is replaced at intervals; the K-Light manual gives 7000–10 000 km for the fuel filter and every 10 000 km or one year for throttle-body cleaning.

> **SAFETY** **Residual pressure**
>
> An EFI line remains pressurised after the engine stops. Relieve pressure (pump fuse removed, engine run until it stalls, or the quick connector wrapped in a rag) before disconnecting, and replace the injector O-rings and the pump flange gasket whenever they are disturbed; the K-Light manual treats both as single-use.

The injector and pulse width

The injector is a solenoid valve. Energising its coil lifts a ball or pintle off its seat against a return spring and the fuel pressure, and fuel sprays through a multi-hole director plate as a cone aimed at the back of the inlet valve. The K-Light injector coil measures **about 10 Ω** (high-impedance type, driven directly by a transistor in the ECU without a current-limiting resistor); an infinite reading means an open coil. The ECU controls fuel by **pulse width**, the time in milliseconds for which the injector is held open, because flow rate at fixed pressure is constant.

Pulse width is the sum of the time needed to deliver the calculated fuel mass and a battery-voltage-dependent **dead time** (the delay before the valve opens fully, typically 0.6–1.2 ms, longer at low voltage). A worked example for a 124 cm³ single:

$$m(air) = V(d) \times \rho(air) \times \eta(v) = 124 \times 10^{-6}\ m^3 \times 1.18\ kg/m^3 \times 0.85 \approx 0.124\ g$$

$$m(fuel) = m(air) \div AFR = 0.124\ g \div 14.7 \approx 8.5\ mg$$

$$t(open) = m(fuel) \div q = 8.5\ mg \div 1.67\ mg/ms \approx 5.1\ ms$$

$$PW = t(open) + t(dead) \approx 5.1 + 0.8 = 5.9\ ms$$

where V(d) is displacement, ρ is air density, η(v) is volumetric efficiency and q is injector static flow (here 100 g/min). One injection occurs per four-stroke cycle, that is every two revolutions, so at 9000 rpm the cycle lasts 2 × 60 ÷ 9000 = 13.3 ms and the injector duty cycle is 5.9 ÷ 13.3 ≈ 44 %. Injectors are sized so that duty cycle stays below about **80–85 %** at peak power; above that the valve no longer closes cleanly between pulses.

Common injector faults are clogging by varnish (lean running, hesitation), leakage (rich running, hard hot starting, high fuel consumption; the K-Light manual suggests suspecting a leaking injector if the oxygen sensor stays above 500 mV at normal temperature), and a disturbed spray angle if the injector body is rotated while the connector is fitted. Ultrasonic cleaning on a flow bench restores clogged injectors.

Throttle body

The throttle body carries the butterfly valve, return spring and cable pulley, the throttle position sensor on the spindle, a by-pass air passage controlled by the idle air control actuator, and on the K-Light the combined manifold pressure and intake temperature sensor. The idle stop screw is set at the factory to a minimum airflow and should not be adjusted; idle speed is controlled electronically (1500 ± 100 rpm on the K-Light). Carbon around the butterfly edge is part of the calibrated idle airflow, so cleaning uses carburettor cleaner sprayed into the bore with the butterfly opened by the cable (never by forcing a tool into the bore) and must not reach the TPS. After cleaning, many ECUs need an idle relearn.

Sensors

Most engine sensors are fed from a **regulated 5 V reference** by the ECU and share a sensor ground, so a short in one sensor can pull down the reference and set codes for several sensors at once. Temperature sensors are **negative temperature coefficient (NTC)** thermistors in a voltage divider with a pull-up resistor inside the ECU, so the signal voltage falls as temperature rises.

Sensor	Principle	Signal	K-Light 125 manual value
Throttle position (TPS)	Potentiometer on throttle spindle	0.5–0.9 V closed, 3.5–4.0 V fully open, from 5 ± 0.1 V reference	Closed output 14 % ± 5 % of reference
Manifold absolute pressure (MAP)	Piezoresistive silicon diaphragm	Analogue voltage rising with absolute pressure	4.25–4.75 V at 100 kPa, engine stopped
Intake air temperature (IAT)	NTC thermistor (in MAP housing)	Resistance and divider voltage	5.595 kΩ at 0 °C, 2.000 kΩ at 25 °C; supply 4.75–5.25 V
Engine (cylinder-head) temperature	NTC thermistor in head	Resistance and divider voltage	1.9–2.1 kΩ at 25 °C, 0.179–0.187 kΩ at 100 °C
Crankshaft position (CKP), trigger	Variable reluctance pick-up facing flywheel reluctor	AC pulse, amplitude rising with speed	150 ± 10 Ω; peak above 1.7 V when cranking
Oxygen (lambda)	Heated zirconia cell	0.1–0.9 V switching about 0.45 V	Rich above 750 mV, lean below 120 mV; heater 9.6 ± 1.5 Ω at 21 °C



FIGURE 3.6 An EFI throttle body with butterfly valve, injector and throttle position sensor.
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Throttle position sensor

A TPS is a three-wire **potentiometer**: 5 V reference, ground and a wiper output. The ECU uses it to identify idle (closed throttle), to calculate load on alpha-N systems, and to detect the rate of opening for acceleration enrichment. A worn track produces dropouts that cause stumbles at a particular opening; these show as a jagged trace when the throttle is swept slowly with a multimeter in bar-graph mode or an oscilloscope. The K-Light manual quotes a measurement range from 7 % to 93 % of travel.

MAP and IAT

The MAP sensor reads **absolute pressure** in the inlet tract behind the throttle. On a single cylinder engine manifold pressure pulsates violently with each intake stroke, so the ECU samples it at a fixed crank angle during the intake stroke rather than averaging. With the engine stopped the sensor reads atmospheric pressure, and many ECUs use that reading at key-on as a barometric correction. A persistently high idle MAP value indicates an intake leak, a too-small valve clearance holding the valve open, or a blocked exhaust, all of which the K-Light manual lists under data-stream analysis. The IAT sensor corrects air density for temperature: air at 40 °C is about 6 % less dense than at 20 °C.

Engine temperature

Air-cooled engines measure cylinder-head temperature, liquid-cooled engines measure coolant temperature (ECT). The value sets cold-start enrichment, warm-up idle speed and ignition advance. An open sensor circuit reads as extreme cold, so the ECU over-fuels and the engine floods when warm; a shorted circuit reads as extreme heat and gives a lean, hard cold start, consistent with the K-Light manual's warning that this sensor has a large effect on starting.

Crankshaft position sensor

The CKP is a **variable reluctance** coil wound on a magnet, facing raised reluctor tabs on the flywheel rim (on the K-Light it is integrated with the alternator stator, wires blue/white and green/white). As each tab passes, the changing magnetic flux induces an AC voltage pulse. A missing tooth or a single long tab marks a reference position near top dead centre. The ECU measures the interval between pulses to calculate rpm and crank angle and schedules both injection and spark from it, so without a CKP signal the engine neither sparks nor injects; on a four-stroke single the ECU often cannot tell compression TDC from overlap TDC and fires a wasted spark every revolution, or uses the MAP pulse shape to identify the phase. A gap that is too large (the K-Light no-start tree asks the technician to check it) gives too small a signal at cranking speed.

Oxygen sensor

The **narrowband zirconia sensor** is a ceramic thimble coated with porous platinum electrodes inside and out, with exhaust gas outside and reference air inside. At its working temperature (above roughly 300 °C, with the K-Light specifying 260–850 °C), zirconia conducts oxygen ions and the cell generates a voltage depending on the oxygen partial pressure difference. The output switches abruptly at λ = 1: about 0.8–0.9 V when rich and 0.1–0.2 V when lean. A narrowband sensor therefore tells the ECU only rich or lean, not how rich, which is sufficient for closed-loop control around stoichiometric. An electric heater (9.6 ± 1.5 Ω on the K-Light) brings it to temperature within seconds of starting. A healthy sensor at normal temperature and steady engine speed cycles between roughly 0.1 and 0.9 V several times per second; the K-Light test calls for continuous variation between 0 and 1 V after more than 2 minutes at 3000–5000 rpm with the engine at 80 °C. Lead, silicone sealant vapour and burning engine oil poison the electrodes and slow the response.

Large machines increasingly use **wideband** (planar, five-wire) sensors, which pump oxygen ions to hold a measuring cell at λ = 1 and report the pump current, giving a proportional lambda reading from about 0.7 to lean infinity. Euro 5+ catalyst monitoring adds a second, downstream sensor (see Emission standards and on-board diagnostics, below).

ECU strategy

Load measurement: speed-density and alpha-N

The ECU must know the air mass entering the cylinder on each cycle. Motorcycles rarely use a mass airflow meter, because the pulsating flow of one or two cylinders makes it inaccurate, so two indirect strategies dominate:

- **Speed-density**: air mass is calculated from manifold absolute pressure, rpm, intake air temperature and a stored volumetric-efficiency table. This responds automatically to altitude, filter restriction and wear, and is the main strategy on the K-Light.
- **Alpha-N**: air mass is read from a table indexed by throttle angle (alpha) and rpm (N), with barometric and temperature corrections. It is stable at large throttle openings where manifold pressure is close to atmospheric and changes little, so racing machines and engines with very aggressive cams (and therefore an erratic MAP signal) use it. It cannot detect intake leaks or a changed exhaust.

Many modern ECUs blend both, using MAP at small openings and TPS at large openings, and add the TPS rate of change for acceleration enrichment because manifold pressure lags a sudden throttle opening.

Base map and corrections

From the load estimate and rpm the ECU reads a base fuel quantity and a base ignition advance from three-dimensional tables, then applies corrections: engine temperature (cold enrichment and warm-up enrichment), air temperature, battery voltage (injector dead time), acceleration and deceleration, and the closed-loop trim. The same load and rpm axes index the ignition map described in chapter 3.3.

Open loop and closed loop

In **closed loop** the ECU nudges pulse width in small steps against the oxygen sensor: when the sensor reads rich it lean-shifts until the sensor reads lean, then reverses, so the mixture oscillates around λ = 1 a few times per second. This oscillation is useful to the catalyst, whose oxygen storage material alternately stores and releases oxygen. Long-term adaptive values (**self-learning**, which the K-Light manual describes as removing manufacturing differences and wear effects) are stored for each load region so that the short-term correction stays near zero.

The ECU drops to **open loop**, running from the map without oxygen feedback, when the sensor is cold, during cranking and warm-up, at full load (where it enriches to λ 0.85–0.92 to protect the valves and catalyst and to make power), during transients and during fuel cut-off. A disconnected or failed oxygen sensor forces permanent open loop and sets a fault code.

Cold start, idle air control and cut-off

At cranking the ECU injects a quantity from a temperature-based table, often with an extra prime pulse, and raises idle speed while the engine is cold: the K-Light raises idle when engine temperature is below 68 °C. Idle speed is held by the **idle air control (IAC)** actuator, which on the K-Light is a bipolar stepper motor whose two coils measure 50 Ω ± 10 % each, moving a pintle in the by-pass passage. The ECU counts steps from a known reference position, so if the stepper loses its reference (after a battery disconnection on some systems) idle may be erratic until it relearns. Large machines often use ride-by-wire throttles, in which the ECU positions the main butterfly and no separate IAC is needed.

When the throttle is closed above a threshold rpm (typically 1800–2500 rpm warm), the ECU stops injecting entirely (**deceleration fuel cut-off**) and resumes as rpm approaches idle; this saves fuel and stops HC emissions on overrun but contributes to snatchy throttle response at small openings. The **rev limiter** cuts fuel, spark or both at maximum rpm; a gentle soft limiter retards ignition first.

> NOTE **Do not open the throttle when starting an injected engine**
>
> The K-Light manual instructs riders not to touch the throttle while starting, because the ECU calculates cranking fuel and idle air itself. The exception is a flooded engine: holding the throttle fully open while cranking triggers a clear-flood mode on most ECUs, cutting injection while the cylinder dries.

Fault codes, the MIL and diagnostic tools

The ECU continuously checks each sensor signal against plausible limits (range checks), checks each output driver for short circuits and open circuits, and on OBD II systems checks emission-relevant functions such as closed-loop behaviour. A failed check stores a **diagnostic trouble code (DTC)** and, when the check is emission-relevant or the fault is confirmed, lights the MIL. Faults are classed as steady-state (present every time) or intermittent (often a connector or harness chafe), and most systems store a **freeze frame** of rpm, temperature and load at the moment the fault occurred.

At key-on the K-Light FI lamp lights as a bulb check, confirming the ECU is powered; if it stays dark, the fuse, earth and ECU connector are checked first. After starting it should go out. Selected K-Light codes, which follow the standard SAE J2012 / ISO 15031-6 P-code structure:

Code	Component	Detection criterion	Meaning
P0122 / P0123	TPS	Signal below 0.1 V / above 4.9 V	Short to ground / short to supply or open ground
P0107 / P0108	MAP	Signal below 0.1 V / above 4.9 V	Short to ground / short to supply

Code	Component	Detection criterion	Meaning
P0112 / P0113	Intake temperature	Below 0.1 V / above 4.9 V	Short to ground / open circuit or short to supply
P0117 / P0118	Engine temperature	Below 0.1 V / above 4.9 V	Short to ground / open circuit or short to supply
P0131 / P0132	Oxygen sensor	Below 0.3 V / above 0.7 V for more than 15 s	Stuck lean / stuck rich
P0134	Oxygen sensor	Held between 0.35 and 0.55 V	No activity (cold, poisoned or open)
P0335	Crankshaft position	Signal high with engine stopped	Circuit fault
P0201 / P0261 / P0262	Injector	Open circuit / short to ground / over 5 A	Driver or harness fault
P0505 / P0508 / P0509	Idle stepper	Open load below 100 mA / short over 2 A	Driver or harness fault
P0030 / P0031 / P0032	O2 sensor heater	Open / short to ground / over 5 A	Heater circuit fault
P2300 / P2301	Ignition coil primary	No clamp voltage / over 8.6 A	Short to ground / short to supply
P0627 / P0629	Fuel pump	Below 0.4 A / over 8.4 A	Open / short to supply
P0444 / P0458 / P0459	Canister purge valve	Open / short to ground / over 2 A	Driver or harness fault
P0601	ECU	Flash checksum mismatch	Internal memory fault

A range code points to a circuit, not necessarily a sensor: P0118 (engine temperature voltage high) is caused just as often by a backed-out connector pin as by the thermistor. The K-Light manual also warns that an unstable system earth can produce codes that do not match the actual fault; the remedy it gives is to remake the earth connection, disconnect the battery for 3 minutes and restart.

Diagnostic tools fall into three levels. **Blink codes** need no tool: on many Japanese machines, shorting a service-check connector (or, on Honda PGM-FI, a jumper across the data link connector) makes the MIL flash the stored code as long and short pulses, for example one long and two short for code 12. **Generic scan tools** read standard P-codes and live data through the 16-pin OBD connector (ISO 15031-3 shape) using the K-line (ISO 14230) or CAN (ISO 15765) protocol; the K-Light has a 16-port diagnostic interface and a K-line pin on its ECU. **Manufacturer tools** add actuator tests (pump, injector, stepper, MIL), idle and TPS relearns, and ECU reflashing. Some brands use their own connectors (four- or six-pin) requiring an adapter. The K-Light manual requires battery voltage above **8.5 V** while a diagnostic tool is connected and lists a digital multimeter with buzzer and a 0–600 kPa fuel pressure gauge as the essential hand instruments.

▤ REFERENCE DATA **K-Light 125 ECU supply and environment**

- Normal working supply: 9–16 V DC; survives 26 V for one minute and reverse polarity up to 13 V for under one minute.
- Working temperature −30 to 70 °C (80 °C maximum); storage −40 to 85 °C.
- The ECU is not serviceable: faults are resolved by reflashing the calibration or replacing the unit under warranty.
- Do not disconnect the battery or any connector with the ignition on, and never reverse battery polarity.

Exhaust emissions and how they form

Three regulated gaseous pollutants come from a petrol engine, and each forms by a different mechanism:

- **Carbon monoxide (CO)** results from incomplete oxidation of carbon when there is not enough oxygen, so it rises steeply as the mixture goes rich of λ = 1 and is almost absent lean.
- **Hydrocarbons (HC)** are unburned or partly burned fuel. Sources include fuel trapped in crevices (above the top ring, around the plug thread) where the flame is quenched, the quench layer on cold walls, oil films that absorb and release fuel, misfire and, on a two-stroke, fresh charge short-circuiting straight through the exhaust port during scavenging. HC rises with rich mixtures and again with very lean mixtures that misfire.
- **Oxides of nitrogen (NOx)** form when nitrogen and oxygen from the air combine at flame temperatures above about 1800 °C (the thermal or Zeldovich mechanism). NOx peaks slightly lean of stoichiometric, around λ 1.05–1.1, where both temperature and free oxygen are high, and rises with ignition advance and compression ratio.

Particulate matter is regulated only for direct-injection petrol engines at Euro 5. Carbon dioxide is not a pollutant in this sense but is measured to give the type-approval fuel consumption.

Emission control hardware

Three-way catalyst

A **three-way catalyst** consists of a honeycomb substrate (on motorcycles usually wound metal foil, which tolerates vibration and heats quickly, rather than the ceramic used on cars), a washcoat of alumina and ceria that multiplies the surface area and stores oxygen, and a thin layer of platinum, palladium and rhodium. Platinum and palladium promote oxidation of CO to CO_2 and HC to CO_2 and H_2O; rhodium promotes reduction of NOx to N_2 using CO and hydrogen as reductants. Both reactions can only proceed together in a narrow band around λ = 1 (within roughly ±0.5 % of AFR), which is why closed-loop control is a precondition. The catalyst does little below its **light-off temperature** (around 250–300 °C), so it is mounted close to the exhaust port, often in the header (part 16 of the exploded diagram: Exhaust header and catalytic converter), to light off quickly after a cold start.

Catalysts are damaged by leaded fuel and oil additives (poisoning), by misfire (unburned mixture burning in the catalyst can melt the substrate) and by an exhaust valve that does not seal; the K-Light manual warns that a too-small exhaust valve clearance raises exhaust temperature and shortens catalyst and oxygen-sensor life. A partially melted catalyst raises back pressure, giving a high MAP reading at idle and loss of top speed.

Secondary air injection

Secondary air injection admits fresh air into the exhaust port just behind the exhaust valve, where hot exhaust gas burns the remaining CO and HC. Most motorcycle systems are pulse-type (Honda and Suzuki call theirs PAIR): exhaust pressure pulses close a reed valve and the negative pulses draw air through it from the air filter box, with a vacuum- or solenoid-operated cut valve that closes on deceleration to stop exhaust popping. Because the extra oxygen passes the upstream oxygen sensor, the ECU must ignore or compensate for it, and many closed-loop designs dispense with secondary air entirely. A leaking reed or a cracked hose causes loud popping on the overrun.

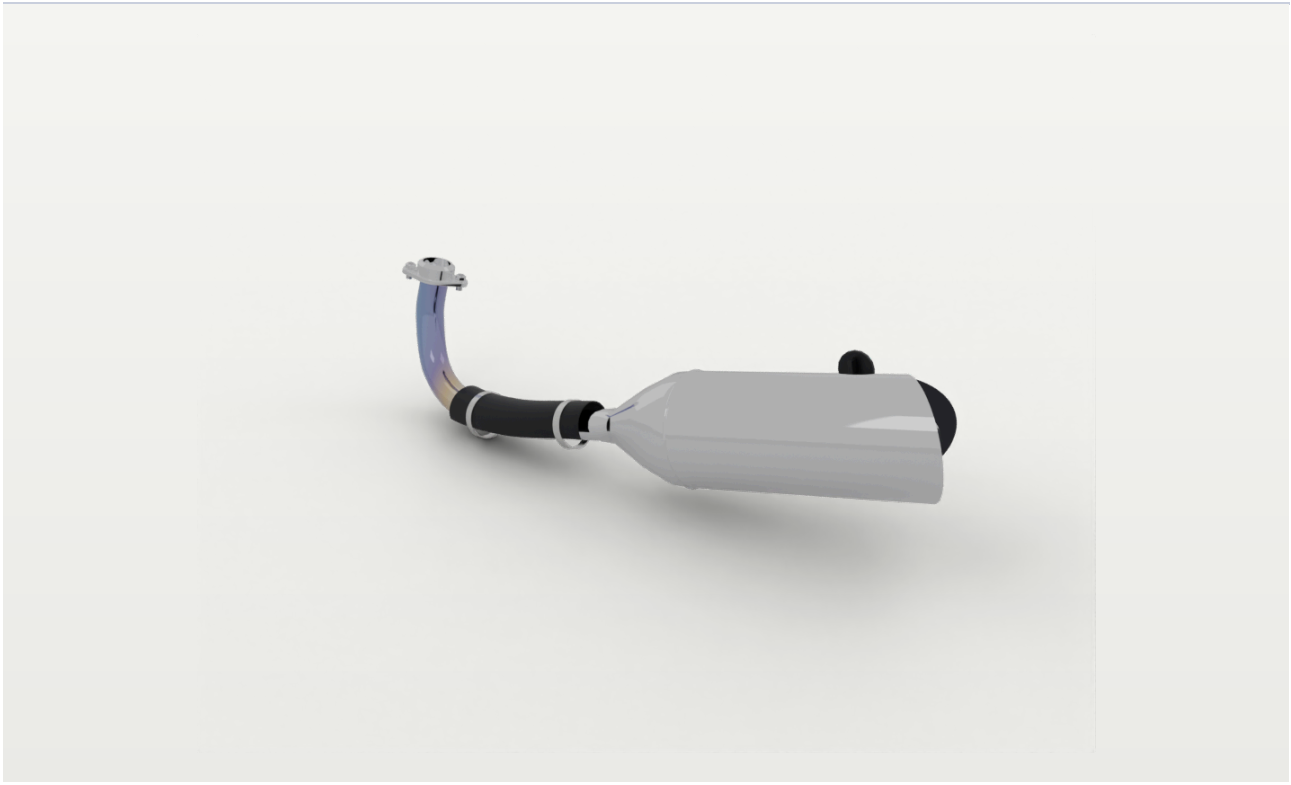


FIGURE 3.7 A four-stroke exhaust: header pipe with heat shield and a slash-cut silencer.
Render: Transitions Lab, CC BY-SA 4.0

Evaporative emission control (EVAP)

Fuel vapour from the tank is a source of HC even when the bike is parked. Euro 5 limits evaporative emission from L3e motorcycles to 1.5 g per test (the SHED test), and most current machines meet it with a sealed tank venting through a rollover valve into an **activated-charcoal canister**. The charcoal adsorbs vapour while the engine is stopped; when the engine runs, a purge line from the canister to the throttle body draws air back through the charcoal and the vapour is burned. On simple systems the purge is controlled by manifold vacuum; on the K-Light (where it is optional) a solenoid purge valve is driven by the ECU, which accounts for the extra fuel in its closed-loop trim. A blocked canister vent or a stuck-closed purge valve produces the same symptoms as a blocked tank vent, and a stuck-open purge valve gives a rich idle after refuelling.

Emission standards and on-board diagnostics

Euro 5 and Euro 5+

In the European Union, motorcycles (category L3e) and other L-category vehicles are type-approved under Regulation (EU) No 168/2013 and its delegated acts. Euro 5 applied to new types from **1 January 2020** and to all new vehicles from **1 January 2021**. The test uses the World Motorcycle Test Cycle (WMTC), and the limits for a positive-ignition L3e motorcycle are:

Pollutant	Euro 5 limit (mg/km)	Note
CO	1000	
THC	100	Total hydrocarbons
NMHC	68	Non-methane hydrocarbons
NOx	60	

Pollutant	Euro 5 limit (mg/km)	Note
PM	4.5	Direct-injection engines only

Euro 5 also requires durability: the emission limits must be met over a lifetime mileage of **20 000 km** for an L3e motorcycle with a maximum speed below 130 km/h and **35 000 km** above 130 km/h. Under Euro 5 manufacturers could demonstrate this by testing after a partial mileage and applying a deterioration factor (a common route was 3500 km of accumulation with emissions at least 30 % below the limits).

Euro 5 introduced on-board diagnostics stage II. **OBD stage I** (from Euro 4) detects electrical circuit faults: open, short and out-of-range signals of the kind in the K-Light code table. **OBD stage II** adds monitoring of emission-control degradation against emission threshold limits, for example a slow or inactive oxygen sensor or misfire that raises emissions, and lights the MIL when the threshold would be exceeded. Catalyst monitoring was deliberately excluded from the first stage II requirement.

The step commonly called **Euro 5+** (introduced by amendments including Regulation (EU) 2019/129) applies to new types from **1 January 2024** and to all new registrations from **1 January 2025**. The tailpipe limits and the WMTC cycle are unchanged, but:

- OBD stage II must now monitor **catalyst efficiency**. The usual method compares an oxygen sensor upstream of the catalyst with a second one downstream: a healthy catalyst stores oxygen, so the downstream signal stays steady while the upstream signal switches; as the catalyst ages, its oxygen storage falls and the downstream signal begins to mirror the upstream one.
- OBD threshold limits are tightened (from the Annex VI B1 to the stricter B2 values), and minimum **in-use performance ratios (IUPR)** require that each monitor actually runs often enough in normal riding.
- Durability can no longer be shown by the deterioration-factor shortcut alone: the vehicle or its emission-relevant parts must undergo full or partial mileage accumulation (or bench ageing of the catalyst) to show end-of-life emissions.
- The MIL or a warning must indicate when an operating mode that significantly reduces torque (limp-home) is active.

The cost of a second oxygen sensor, the calibration of catalyst monitors on small engines and the larger catalysts needed to pass full-life durability are the main reasons some low-volume models were withdrawn from the EU market at the end of 2024.

Bharat Stage VI

India moved directly from BS IV to BS VI on **1 April 2020**, adopting two-wheeler limits aligned with Euro 5 (CO 1.0 g/km, THC 0.1 g/km, NMHC 0.068 g/km and NOx 0.06 g/km for petrol motorcycles) and mandatory OBD. BS VI phase 2 from **1 April 2023** introduced OBD II for two-wheelers, including misfire detection from the crankshaft signal and oxygen-sensor monitoring, with a standard 16-pin connector. The catalyst-monitoring element was deferred to **1 April 2025**, after trials produced false MIL warnings, an issue the European industry had faced as well. BS VI vehicles are also designed for E20 petrol, which closed-loop systems handle through their fuel trims.

EFI fault diagnosis

Symptom	Likely cause	Check	Remedy
FI lamp does not light at key-on, engine will not start	Blown fuse, poor ECU earth, ECU connector loose	Fuse continuity; voltage at ECU supply pin; earth voltage drop	Replace fuse, clean earth, reseat connector

Symptom	Likely cause	Check	Remedy
No pump sound at key-on	Pump relay, pump, harness, no CKP signal during cranking	12 ± 2 V at pump connector in first 3 s; pump on direct 12 V	Replace relay or pump; repair harness
Pump runs, no start, plug dry	Low fuel pressure, blocked filter, injector not opening	Pressure at rail (300 kPa, minimum 270 kPa); injector 10 Ω; noid light on injector connector	Replace filter or pump; clean or replace injector
No start, plug wet	Flooding, leaking injector, engine temperature sensor open	Clear-flood crank at full throttle; injector leak-down; ECT resistance	Dry plug; replace injector or sensor
Idle too high when warm	Air leak at throttle body joint, stepper fault, idle by-pass leak, excess exhaust valve clearance	Spray test at joints; stepper resistance 50 Ω; MAP at idle	Replace boot or O-ring; replace stepper; adjust valves
Idle too low or unstable, stalls on deceleration	Dirty throttle body or by-pass, low fuel pressure, tight valve clearance	Inspect bore and by-pass; pressure test; valve clearance	Clean and relearn idle; repair fuel supply; adjust valves
High fuel consumption, black exhaust	Loose or failed O2 sensor, leaking injector	O2 reading always above 500 mV warm; sensor torque and seal	Refit or replace sensor; replace injector
Loss of power at high speed	Blocked catalyst, low fuel pressure, restricted filter	Back pressure or high idle MAP; pressure under load	Replace catalyst or filter
Backfire when starting	Loose ignition coil, loose trigger reluctor	Coil mounting and earth; flywheel and trigger security	Tighten or replace

REVIEW QUESTIONS

1. Calculate the fuel mass per cycle for a 250 cm³ single at volumetric efficiency 0.90, air density 1.18 kg/m³ and λ = 1, and the open time for an injector flowing 150 g/min.
2. For the K-Light 125 example in the text (pulse width 5.9 ms), calculate injector duty cycle at 6000 rpm.
3. A TPS reads 0.70 V at closed throttle with a 5.00 V reference. Express this as a percentage and state whether it is within the K-Light specification.
4. A K-Light engine temperature sensor measures 2.0 kΩ with the engine cold in a workshop at 25 °C and 2.0 kΩ after a 20-minute ride. What does this indicate and what driveability fault would you expect?
5. Explain why a narrowband oxygen sensor cannot be used to tune full-throttle mixture.
6. Distinguish speed-density and alpha-N load calculation, and give one advantage of each.
7. Why does a three-way catalyst require λ = 1, and why is closed-loop control a precondition?
8. List three conditions in which the ECU operates in open loop.
9. An oxygen sensor reads steadily 0.45 V at 4000 rpm on a warm engine. Which code would the K-Light set, and what are the possible causes?
0. What did Euro 5+ add to Euro 5 for motorcycle OBD, and how is catalyst efficiency normally monitored?
1. Fuel pressure on the K-Light reads 240 kPa at idle. Name three possible causes from the manual and the order in which you would check them.
2. Why might a code P0118 be caused by something other than a faulty sensor?

ANSWERS

1. m(air) = 250 × 10^{-6} × 1.18 × 0.90 = 0.2655 g; m(fuel) = 0.2655 ÷ 14.7 = 18.1 mg. Flow 150 g/min = 2.5 mg/ms, so open time = 18.1 ÷ 2.5 ≈ 7.2 ms (plus dead time).
2. Cycle time = 2 × 60 ÷ 6000 = 20 ms; duty cycle = 5.9 ÷ 20 ≈ 30 % (in practice the pulse width at 6000 rpm and part load would differ from the full-load value).
3. 0.70 ÷ 5.00 = 14 %, exactly the nominal value of 14 % ± 5 %, and within the 0.5–0.9 V closed-throttle range.
4. The resistance should have fallen towards 0.18 kΩ at 100 °C; no change means the ECU is reading 25 °C permanently (or the sensor is not in thermal contact). The ECU continues cold enrichment and raised idle when hot, giving rich running, high idle and high consumption.
5. Its output switches between about 0.1 and 0.9 V over a very small range around λ = 1, so it reports only rich or lean; at λ 0.85–0.90 it simply reads rich (around 0.85 V) and gives no measure of how rich. A wideband sensor is required.
6. **Speed-density** uses MAP, rpm and IAT: it compensates automatically for altitude, filter restriction and wear. Alpha-N uses throttle angle and rpm: it is stable at wide throttle and with cams that give an erratic MAP signal.
7. Oxidation of CO and HC needs oxygen, while reduction of NOx needs an absence of free oxygen and the presence of CO and H_2; both are only possible together in a narrow band around stoichiometric. Only closed-loop feedback can hold the mixture in that band in the face of wear, fuel variation and temperature.
8. Any three of: cold sensor during warm-up; cranking; full load enrichment; rapid transients; deceleration fuel cut-off; failed oxygen sensor.
9. P0134 (no activity, between 0.35 and 0.55 V). Causes: heater circuit open (check 9.6 Ω), sensor poisoned or aged, signal wire open, sensor loose allowing air in, or exhaust leak ahead of the sensor.
10. Catalyst monitoring within OBD stage II, tighter OBD thresholds, IUPR requirements and mileage-based durability. Efficiency is monitored by comparing the switching activity of an upstream and a downstream oxygen sensor: a healthy catalyst's oxygen storage damps the downstream signal.
11. A leak in the fuel line, a fuel pump running in reverse (connector reversed), or a blocked filter. Check visually for leaks first, then confirm the pump direction and connector, then replace the filter and retest; if still low, replace the pump module (which includes the regulator).
12. P0118 is a circuit range check (signal above 4.9 V), which an open circuit anywhere between the 5 V pull-up and ground produces: a backed-out terminal, a broken wire, a corroded connector or an open sensor ground all give the same voltage as an open thermistor.

CHAPTER 3.3

Ignition systems

LEARNING OBJECTIVES

- State the voltage and energy a spark plug needs and the factors that raise the requirement.
- Explain how an ignition coil multiplies voltage through its turns ratio and the collapse of its magnetic field.
- Compare contact-breaker, AC-CDI, DC-CDI, transistorised (TCI) and ECU-mapped digital ignition.
- Explain ignition advance and how the pulser or crankshaft position sensor times the spark.
- Select, read and gap a spark plug, decode a plug designation such as D7RTC, and explain resistor plugs and caps.

What the spark has to do

The spark must ionise the gas between the plug electrodes and deliver enough energy to start a self-sustaining flame kernel. The **breakdown voltage** needed rises with electrode gap, with gas density at the moment of firing (so with compression ratio and load), with rounded worn electrodes and with lean mixtures, and falls with temperature. Typical requirements are 5–10 kV at idle on a new plug and 15–25 kV at full load on a worn plug. A stoichiometric mixture can be ignited by less than 1 mJ in the laboratory, but practical systems deliver 20–80 mJ so that lean, turbulent or fouled conditions still ignite. The difference between the voltage the coil can deliver and the voltage the plug needs is the **ignition reserve**; the K-Light coil produces **25–35 kV** from a 9–14 V supply, comfortably above the requirement of a 0.7 mm gap.

The ignition coil

An ignition coil is a step-up transformer. A **primary winding** of a few hundred turns of thick wire and a **secondary winding** of 15 000–25 000 turns of fine wire share a laminated iron core. When current flows in the primary, it stores energy in the magnetic field:

$$E = \tfrac{1}{2} \times L \times I^2$$

$$V_{(secondary)} \approx V_{(primary)} \times N_{(secondary)} \div N_{(primary)}$$

where L is primary inductance and I the primary current at the moment of interruption. A coil with L = 4 mH switched off at 3 A stores ½ × 0.004 × 3² = 18 mJ. When the primary current is interrupted, the collapsing field induces a self-induced voltage (the **inductive kick**) of 200–400 V in the primary, and the secondary, with a **turns ratio** near 100:1, multiplies it to 20–40 kV. The voltage rises only until the plug gap breaks down, then falls to a burn voltage of about 1–2 kV while the remaining energy discharges across the arc for 1–2 ms.

The K-Light 125 manual gives the coil values used in Job sheet 3.6.3: primary **4 Ω ± 10–15 %**, secondary **18.6 kΩ ± 15 %** measured through the plug cap and **13.6 kΩ ± 15 %** without it, which shows that the suppressor cap contributes about 5 kΩ. With 12 V across a 4 Ω primary, steady current is I = V ÷ R = 3 A.

Contact-breaker ignition

Until the late 1970s most motorcycles switched the coil primary with a **contact breaker** (points) opened by a cam on the crankshaft or camshaft. A **condenser** (capacitor of about 0.2–0.3 µF) across the points absorbs the inductive kick long enough for the contacts to separate without arcing, which would erode them and waste energy. The spark occurs at the instant the points open, not when they close; the **point gap** (typically 0.3–0.4 mm) sets the **dwell**, the crank angle for which the points are closed and the field builds. Because dwell and timing are linked, a change in gap changes timing, so points are always gapped first and timed second, statically with a test lamp or buzzer at the F mark and dynamically with a timing light, as in the MAVCC basic ignition tune-up unit. Points need service every few thousand kilometres, the rubbing block wears, and at high rpm the dwell becomes too short for the coil to saturate, all reasons for their replacement by electronic systems. The MAVCC text also describes **energy-transfer** (ET) magneto systems on off-road machines, in which a flywheel generator coil feeds the ignition coil directly without a battery.

Capacitor discharge ignition

A **capacitor discharge ignition** (CDI) stores energy in a capacitor (typically 0.5–2 µF) charged to 200–400 V and dumps it into the coil primary through a thyristor (SCR) when a trigger pulse arrives. The coil is then acting as a pulse transformer rather than an energy store, which is why CDI coils have very low primary resistance (0.1–1 Ω). The secondary voltage rises in a few microseconds, ten times faster than an inductive system, so the spark fires before charge can leak away across a fouled insulator; this is why CDI suits two-strokes, whose plugs foul with oil. The penalty is a short spark duration of about 0.1–0.3 ms.

- **AC-CDI** charges the capacitor from an **exciter (charge) coil** on the alternator stator, producing 100–400 V AC, rectified by a diode. No battery is needed, which suits off-road machines such as the Yamaha YZ125 and many small commuters, but spark energy is low at kickstart cranking speeds.
- **DC-CDI** charges the capacitor from the battery through an inverter (oscillator and step-up transformer) inside the CDI unit. Spark energy is then independent of cranking speed, but the engine will not run with a flat battery.

Timing is taken from a **pulser coil** (pick-up) facing a raised tab on the flywheel. Early CDI units used analogue advance from the pulser waveform; later digital CDI units contain a microcontroller with a stored advance curve.

Transistorised and ECU-controlled ignition

A **transistor-controlled ignition** (TCI) keeps the inductive coil but replaces the points with a power transistor (now usually an IGBT) switched by the pulser signal. The control unit calculates dwell so that the coil reaches its target current just before the firing point, and limits primary current to protect the coil. Inductive systems give a longer spark duration (1–2 ms) than CDI, which helps the lean or slow-burning mixtures of four-stroke engines at part load.

On an injected engine the ECU itself drives the coil, as on the K-Light 125 whose manual describes the ignition as electronic automatic advance "solidified" in the ECU, needing no adjustment. The ECU reads crank position from the CKP sensor, load from MAP and TPS, and temperature, and looks up advance from a three-dimensional **ignition map**. It retards timing for cold starts, for idle stability (fast advance changes hold idle speed), for knock protection on engines with a knock sensor, during gear changes for quickshifters, and as a traction-control intervention. The coil primary driver is monitored (codes P2300 and P2301 on the K-Light).

Multi-cylinder engines use one coil per pair of cylinders firing together on a **wasted-spark** system (one cylinder on compression, its partner on exhaust) or one **stick coil** (plug-top coil) per cylinder, which removes HT leads altogether.

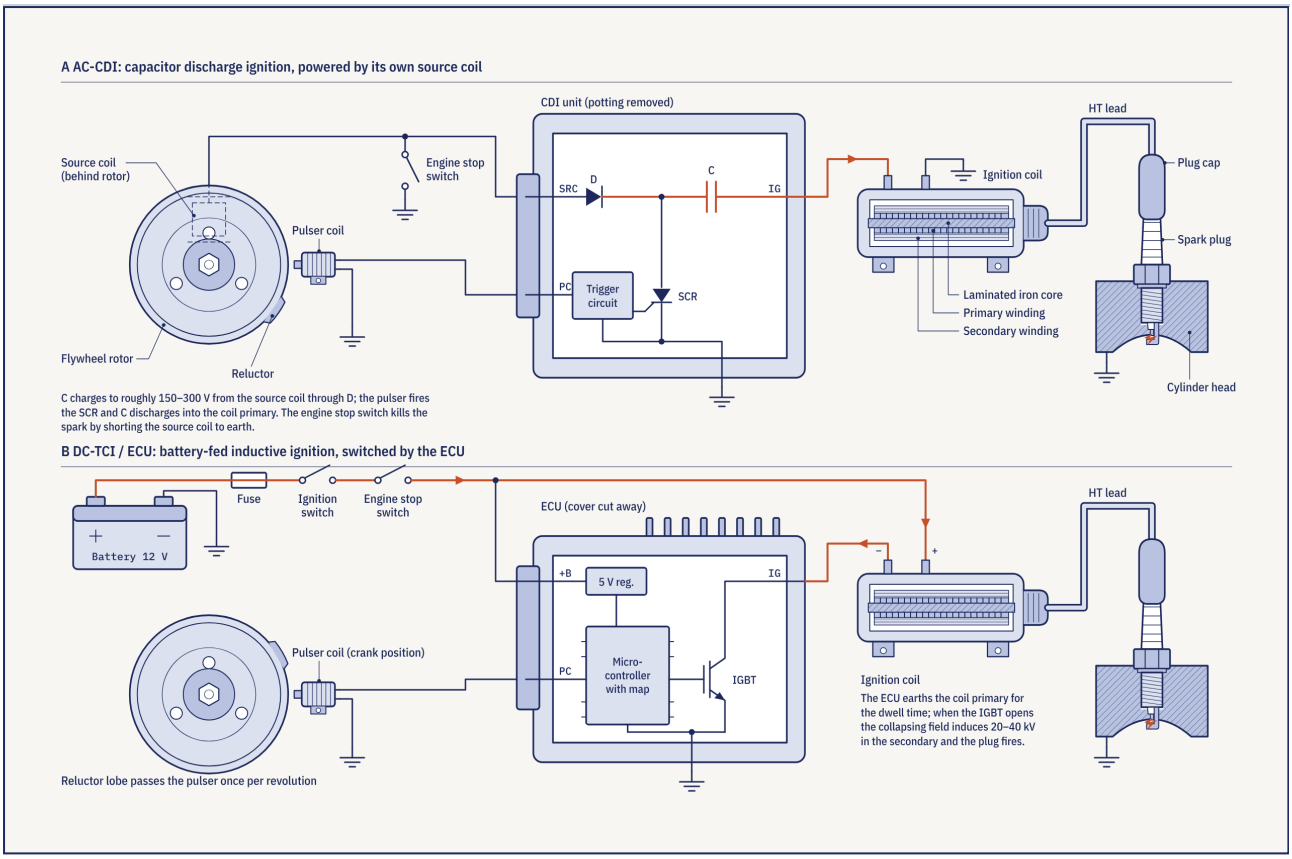


FIGURE 3.8 Ignition circuit variants: AC-CDI with exciter and pulser coils, and DC-TCI or ECU-controlled ignition, with ignition coil, spark plug and engine stop switch.

Ignition timing and advance

The spark must occur before top dead centre because the flame takes a roughly constant time (about 1–3 ms, depending on mixture and turbulence) to burn the charge, and peak cylinder pressure should arrive at about 10–15° after TDC for maximum work. As rpm rises, the same burn time covers more crank angle, so the spark must advance:

$$t = \theta \div (6 \times n)$$

where t is time in seconds, θ is crank angle in degrees and n is speed in rpm (one revolution per minute is 6° per second). At 9000 rpm, 30° before TDC corresponds to 30 ÷ (6 × 9000) = 0.56 ms. Typical advance runs from 5–15° BTDC at idle to 30–40° BTDC at mid and high rpm at part load, with less advance at full load because the denser charge burns faster and is closer to detonation. **Too much advance** causes detonation (pinking), high cylinder head temperature and, in extreme cases, holed pistons; **too little advance** wastes energy into the exhaust, overheats the exhaust valve and header and costs power. The K-Light fault trees direct the technician to check timing with a timing light when the engine overheats or lacks power; on an ECU system an incorrect reading points to a loose flywheel, a sheared key or a loose trigger rather than an adjustment.

> EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy **Crank angle and time**
>
> On the explorer at transitionslab.org/motorcycle-anatomy, run the four-stroke cycle animation and move the RPM slider from 1500 to 9000. Watch how much shorter the power stroke becomes in milliseconds while staying 180° of crank angle, which is why the spark must advance with speed.

Spark plugs

A spark plug consists of a steel **shell** with thread and sealing seat, an aluminium-oxide ceramic **insulator**, a **centre electrode** (nickel alloy, often with a copper core, or fine-wire platinum or iridium), a **ground (side) electrode** welded to the shell, and on resistor plugs an internal resistor of about 5 kΩ.

The **heat range** describes how fast the insulator nose transfers heat to the shell and cylinder head. The insulator tip must run between about **450 °C**, below which carbon and oil deposits accumulate and the plug fouls, and about **850 °C**, above which the tip glows and causes pre-ignition. A **hot plug** has a long insulator nose and runs hotter, suiting low-load commuting; a **cold plug** has a short nose and suits sustained high load. In the NGK system (and in brands that follow it), a higher number means a colder plug. **Reach** is the thread length (a plug with too long a reach can strike the piston or valves; too short leaves carbon in the exposed head threads), and the **gap** is set with a wire gauge, never a flat feeler on a worn electrode.

▤ REFERENCE DATA **K-Light 125 spark plug**

- Plug: **D7RTC** or equivalent; gap **0.7 ± 0.1 mm**.
- Replace if electrodes are eroded or corroded, the insulator is cracked, or the plug is carbon-fouled.
- Coil-to-ECU circuit checks: coil terminal 1 to ECU pin 1 and coil terminal 2 to ECU pin 13 must show continuity.

Plug designations encode thread, heat range and construction. In the D7RTC code used on the K-Light (a Torch designation that follows NGK's scheme), D denotes the M12 × 1.25 thread family, 7 the heat rating, R a built-in resistor and C a copper-cored centre electrode, while the remaining letter is a construction or reach code defined in the maker's chart; it is generally cross-referenced to the NGK DR7EA. Always confirm equivalents from a published cross-reference rather than by matching digits, because Bosch and Champion number heat ranges in the opposite direction.

Reading plugs

Appearance	Interpretation	Action
Light tan to grey-brown insulator, little deposit	Correct mixture and heat range (the K-Light tree describes this as brown)	None
Black dry soot	Rich mixture, blocked air filter, enricher stuck on, too cold a plug, weak spark	Check filter, enricher, mixture and ignition
Black wet oily deposit	Oil entry past rings or valve guides; on a two-stroke, excess premix or flooding	Compression and leak-down test
White, blistered insulator, eroded electrodes	Lean mixture, over-advance, too hot a plug, air leak	Check mixture, timing and plug grade
Wet with fuel after cranking	Flooding or no spark	Spark test, check for leaking injector or high float



FIGURE 3.9 A 14 mm resistor spark plug of the D7RTC class: threaded shell with sealing gasket, 16 mm hex, ribbed alumina insulator to stop flashover, terminal nut, and the centre and ground electrodes that form the 0.6–0.8 mm gap.

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Resistor plugs and caps

The spark is a fast current pulse that radiates broadband radio interference and can corrupt ECU and instrument signals. A **resistor plug**, a **suppressor cap** (typically 5 kΩ) or resistive HT lead limits the peak current and damps the oscillation. Fitting a non-resistor plug and non-resistor cap to an ECU-controlled engine can cause erratic running or ECU resets, while fitting a resistor plug and a resistor cap where the designer intended only one adds resistance and weakens the spark slightly. A cap that has cracked or absorbed water tracks the spark to earth, giving a misfire in wet weather.

> SAFETY **High voltage**
>
> Ignition systems produce up to **35 kV**. **Never** hold a plug lead or plug during a spark test with bare hands, and use an insulated spark tester rather than holding a plug against the cylinder head. Do not crank a CDI or ECU-controlled engine with the HT lead disconnected and unearthed: the unrestrained secondary voltage can break down the coil insulation or damage the ECU.

Ignition fault diagnosis

Symptom	Likely cause	Check	Remedy
No spark at plug	Flat battery, poor connector, engine stop switch, side-stand or neutral logic, coil, pulser or ECU	Battery voltage; connectors; switch continuity; coil and pulser resistance; peak voltages	Repair circuit; replace failed part

Symptom	Likely cause	Check	Remedy
Weak spark, good at HT lead	Fouled plug or failed cap	Spark test at lead end with cap removed; cap resistance	Replace plug or cap
Misfire under load only	Worn plug, tracked cap or coil, gap too large	Plug gap; coil insulation inspection in darkness	Replace plug, cap or coil
Misfire in wet weather	Cracked cap, moisture in coil connector	Spray mist test with engine running	Replace cap, seal connector
Backfire when starting	Loose ignition coil earth, loose trigger or flywheel	Coil mounting, flywheel nut torque (50–60 N·m on K-Light)	Tighten; replace key if sheared
Overheating, detonation	Over-advanced timing, wrong plug grade	Timing light; plug designation	Correct cause; fit specified plug

REVIEW QUESTIONS

1. A coil primary measures 4 Ω. Calculate steady primary current at 12.0 V and 14.0 V, and the stored energy at 12.0 V if primary inductance is 4 mH.
2. A coil has 200 primary turns and 20 000 secondary turns. What secondary voltage is available from a 300 V primary kick, ignoring losses?
3. The K-Light secondary measures 13.6 kΩ without the cap and 18.6 kΩ with it. What is the resistance of the cap, and what would a reading of 40 kΩ through the cap indicate?
4. Why do two-stroke engines favour CDI, and what is CDI's disadvantage?
5. Distinguish AC-CDI and DC-CDI and state which engine still sparks with a dead battery.
6. Calculate the time between a spark at 32° BTDC and TDC at 8000 rpm.
7. Why must advance increase with rpm but often decrease at full load?
8. What does the 7 in D7RTC indicate, and would an 8 suit a bike that fouls plugs in city riding?
9. A plug comes out with a white blistered insulator. Give three possible causes.
0. On a points system, explain why changing the point gap also changes ignition timing.

ANSWERS

1. I = 12.0 ÷ 4 = 3.0 A; I = 14.0 ÷ 4 = 3.5 A. E = ½ × 0.004 × 3.0^2 = 18 mJ.
2. Ratio 20 000 ÷ 200 = 100, so 300 V × 100 = 30 kV.
3. 18.6 − 13.6 = 5.0 kΩ. A total of 40 kΩ means the cap is about 26 kΩ (or the secondary has partly opened); a cap resistance far above specification weakens the spark, so measure the cap alone and replace it.
4. CDI's rise time is a few microseconds, so the spark fires before energy leaks through oil deposits on the insulator. Its spark duration is short (about 0.1–0.3 ms), which can be marginal with lean or slow-burning mixtures.
5. AC-CDI charges its capacitor from an exciter coil on the stator; DC-CDI uses the battery through an inverter. AC-CDI sparks without a battery.
6. t = 32 ÷ (6 × 8000) = 0.67 ms.
7. Burn time is roughly constant, so at higher rpm the spark must start earlier in crank angle. At full load the denser charge burns faster and is closer to detonation, so less advance gives peak pressure at the right point without knock.

8. 7 is the heat rating; in this scheme a higher number is colder, so an 8 would run colder and foul even more readily. A city bike that fouls needs a hotter plug (6), after checking for over-rich mixture.
9. Lean mixture (air leak or blocked jet or injector), over-advanced ignition, too hot a plug, engine overheating from insufficient cooling or oil.
10. The cam opens the points at a fixed cam position; a wider gap means the rubbing block is contacted earlier on the cam ramp, so the points open earlier (more advance) and close later (less dwell).

CHAPTER 3.4

Battery, charging and starting

LEARNING OBJECTIVES

- → Compare flooded lead-acid, AGM (VRLA) and lithium iron phosphate 12 V batteries and interpret Ah and CCA ratings.
- → Estimate state of charge from rested open-circuit voltage and choose a safe charging method.
- → Explain single-phase and three-phase permanent-magnet alternators, field-coil alternators, and shunt versus series (MOSFET) regulation.
- → State the regulated charging voltage window and the K-Light 125 charging specifications.
- → Trace the electric starting circuit through relay and interlocks to the starter motor and starter clutch, and describe the kickstarter.

Lead-acid batteries

A lead-acid cell has a lead dioxide positive plate, a sponge lead negative plate and dilute sulphuric acid electrolyte. On discharge both plates convert to lead sulphate and the acid weakens; charging reverses the reaction. Each cell gives a nominal **2.1 V**, so a 12 V battery has six cells in series. The MAVCC battery unit records the classic hydrometer check: specific gravity of **1.265 or above** indicates full charge and **below 1.200** requires charging, read at least 30 minutes after topping up with distilled water.

- **Flooded (conventional)** batteries such as the 12N12A-4A-1 have removable cell caps and a vent tube; electrolyte is topped up with distilled water only. The JIS-style code gives voltage (12), N for Japanese standard and capacity (12 Ah).
- **AGM** (absorbent glass mat) batteries, also called **VRLA** (valve-regulated lead-acid) or "maintenance-free", hold the electrolyte in glass-fibre separators and recombine gas internally, venting only through a pressure valve. They tolerate vibration and any mounting angle. The K-Light 125 uses a **12 V 6 Ah YTX7A-BS** AGM battery, and its manual warns against substituting a liquid-filled type.

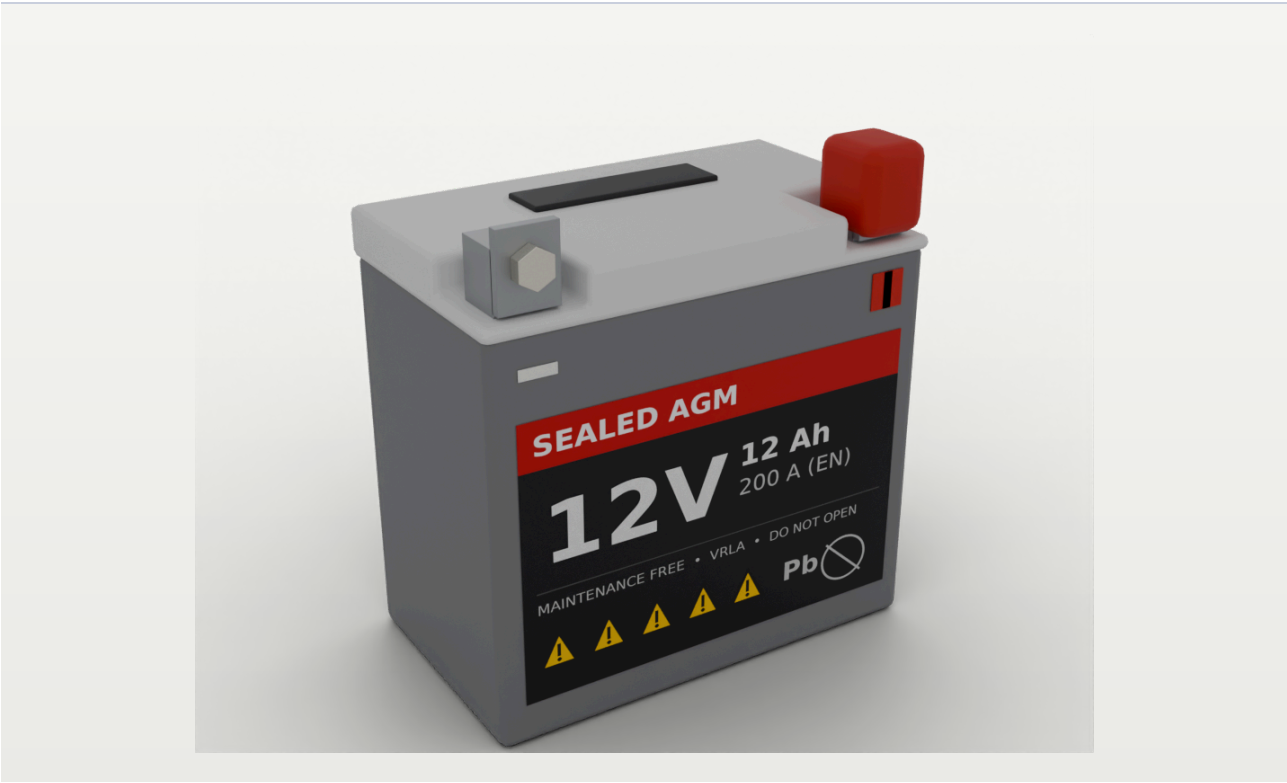


FIGURE 3.10 A 12 V sealed AGM service battery with its terminals.
Render: Transitions Lab, CC BY-SA 4.0

Ampere-hour (Ah) capacity is normally stated at the 10-hour rate for motorcycle batteries: a 6 Ah battery delivers 0.6 A for 10 hours to 10.5 V. **Cold cranking amps (CCA)** is the current the battery can deliver at −18 °C for 30 seconds while staying above 7.2 V; a 6 Ah AGM battery is typically rated around 100 A. Ah governs how long the battery runs the lights and ECU without charge; CCA governs whether it turns the engine on a cold morning. **Sulphation**, the growth of hard lead sulphate crystals in a battery left partly discharged, permanently reduces both; the K-Light manual notes that a battery left discharged loses life quickly, that self-discharge requires charging about every **3 months** in storage, and that capacity typically declines after 2–3 years.

State of charge

Open-circuit voltage indicates state of charge only after the battery has rested for at least 1 hour (the K-Light manual uses this condition) or after a light load has removed the surface charge left by charging:

State of charge	Flooded lead-acid (V)	AGM (V)	LiFePO4 (V)
100 %	12.65–12.7	12.8–13.1	13.3–13.4
75 %	12.4	12.6	13.2
50 %	12.2	12.3	13.1
25 %	12.0	12.0	13.0
0 %	11.8 or less	11.8 or less	12.0 or less

The K-Light figures are **13.1 V** fully charged and **12.3 V** needing charge (after 1 hour without running). The flat LiFePO4 curve shows why voltage is a poor state-of-charge gauge for lithium; its BMS or a dedicated tester is more informative.

Charging lead-acid batteries

The MAVCC rule that charging current should not exceed **10 % of the Ah rating** remains the safe workshop practice: the K-Light 6 Ah battery is charged at a standard **0.6 A for 10–15 hours**, with a quick charge of 6 A for 30 minutes permitted only in an emergency and with the battery removed from the vehicle. Charging is complete when open-circuit voltage 30 minutes after charging is **12.8 V or more**. Modern smart chargers apply constant current, then constant voltage at about 14.4–14.7 V (absorption), then a float at 13.5–13.8 V, and some offer a desulphation pulse mode. Car chargers without a low-current setting overcharge small batteries, and jump-starting from a running car exposes the motorcycle's electronics to voltage transients.

> SAFETY **Battery safety**
>
> Charging releases hydrogen, which is explosive. Charge in a ventilated area, switch the charger off before connecting or disconnecting the clips, and wear eye protection; flush acid from skin with water and neutralise spills with baking soda. When removing a battery disconnect the **negative first**, and when fitting it connect the **positive first and negative last**, so that a spanner touching the frame cannot short the live terminal.

Lithium iron phosphate batteries

LiFePO4 starter batteries use four cells of nominal 3.2 V in series (12.8 V) and weigh roughly a third as much as an equivalent AGM battery, with very low self-discharge and high cranking current for their size. They need a built-in **battery management system** (BMS) for cell balancing and protection against over-discharge, overcharge and overcurrent. They must **never** be charged with a desulphation or pulse mode, must not be held above about **14.6 V**, and must not be charged below about 0 °C, because lithium plating damages the cells; many BMS units block charging in the cold. Their high internal acceptance makes them harder on a marginal regulator, and a battery whose BMS has disconnected after deep discharge can read near 0 V until reactivated. Fitting one is acceptable only when the charging system regulates within the battery maker's window.

Alternators

Almost all small motorcycles use a **permanent-magnet alternator** (often called a magneto or flywheel generator): a steel rotor carrying magnets, bolted to the crankshaft taper, rotates around a stator of laminated poles wound with copper coils. Output frequency and voltage are proportional to rpm, and open-circuit AC voltage from a typical three-phase stator rises to 50–80 V AC at 5000 rpm, so regulation is essential.

- **Single-phase** alternators, often half-wave rectified, are found on mopeds and older commuters; on some, a separate lighting coil feeds the headlight directly with AC, so lamp brightness varies with rpm.
- **Three-phase** alternators have three windings at 120° spacing (three wires of the same colour, white on the K-Light, yellow on many Japanese bikes), give smoother output and higher efficiency, and are rectified full-wave by six diodes.
- **Field-coil** (electromagnet rotor) alternators, as used on many large touring machines and on car-derived designs, energise the rotor through slip rings. The regulator varies field current, so the alternator produces only the power demanded and runs cooler.

Alternator output at a given rpm is limited by the stator design, and on a small single it is only just larger than the load with lights on, which explains why prolonged idling with the headlight on can drain the battery.

▤ REFERENCE DATA **K-Light 125 charging system**

- Alternator: three-phase, stated as **160 W at 5000 rpm** in the charging chapter (the specification table gives 100 W at 5000 rpm; confirm against the parts catalogue for the build).
- Stator coil resistance: **0.8 ± 0.3 Ω** between each pair of white wires at 20 °C.
- Regulator/rectifier: three-phase full-wave; battery charging voltage **14.5 ± 0.5 V at 5000 rpm**.
- Flywheel nut torque **50–60 N·m**; stator and cover bolts 10–12 N·m; trigger 6–9 N·m; rectifier bolt 5.0 N·m.

Regulator/rectifier

The **regulator/rectifier** (part 29 in the exploded diagram) converts stator AC to DC through a diode bridge and holds battery voltage within the specified window, generally **13.5–15.0 V** at 5000 rpm on lead-acid systems. Too low a voltage leaves the battery undercharged; too high a voltage boils electrolyte, dries AGM separators and blows bulbs, a pattern the K-Light fault trees use to separate regulator faults from battery faults.

- **Shunt regulators** are the traditional type. When battery voltage reaches the set point, thyristors (SCRs) short the stator phases to earth for part of each cycle. The stator therefore always produces full current, whether the bike needs it or not, and the excess is dissipated as heat in the stator and regulator. This is why shunt regulators carry large cooling fins, why stators on small bikes fail from overheating, and why a regulator with corroded connectors overheats its plug.
- **Series regulators** (now usually MOSFET-switched) open the circuit between stator and battery instead of shorting it, so the stator runs at low current when demand is low. They run much cooler and are a common upgrade for bikes with chronic stator or regulator failures, provided the connector and fuse are rated for the current.

Electric starting

The electric starter is a DC motor (permanent-magnet field on small machines) that turns the crankshaft through a reduction gear train and a one-way clutch. Because it draws tens to over a hundred amps, its supply cannot pass through handlebar switches; a **starter relay** (solenoid) switches the heavy battery-to-motor cable, while the start button only carries the relay coil current of a few hundred milliamps. The main fuse (often mounted on the relay) protects the rest of the system; the K-Light circuit diagram shows a 20 A main fuse and two 10 A circuit fuses.

The relay coil circuit runs through a chain of **interlocks** so that the engine cannot be started in a dangerous condition:

- the **neutral switch** permits starting with the gearbox in neutral;
- the **clutch switch** permits starting in gear with the clutch lever pulled, isolated from the neutral path by a diode so that the neutral lamp does not light;
- the **side-stand switch** stops the engine (through the ECU or ignition unit) if a gear is selected with the stand down;
- on many scooters and on the K-Light 125, a **brake lever switch** must be closed; the K-Light test checks for battery voltage at the relay's green/yellow wire with the main switch on and the brake lever pulled, and for continuity from the relay's black wire to earth with the start button pressed;
- the **engine stop (kill) switch** usually also interrupts the relay supply.

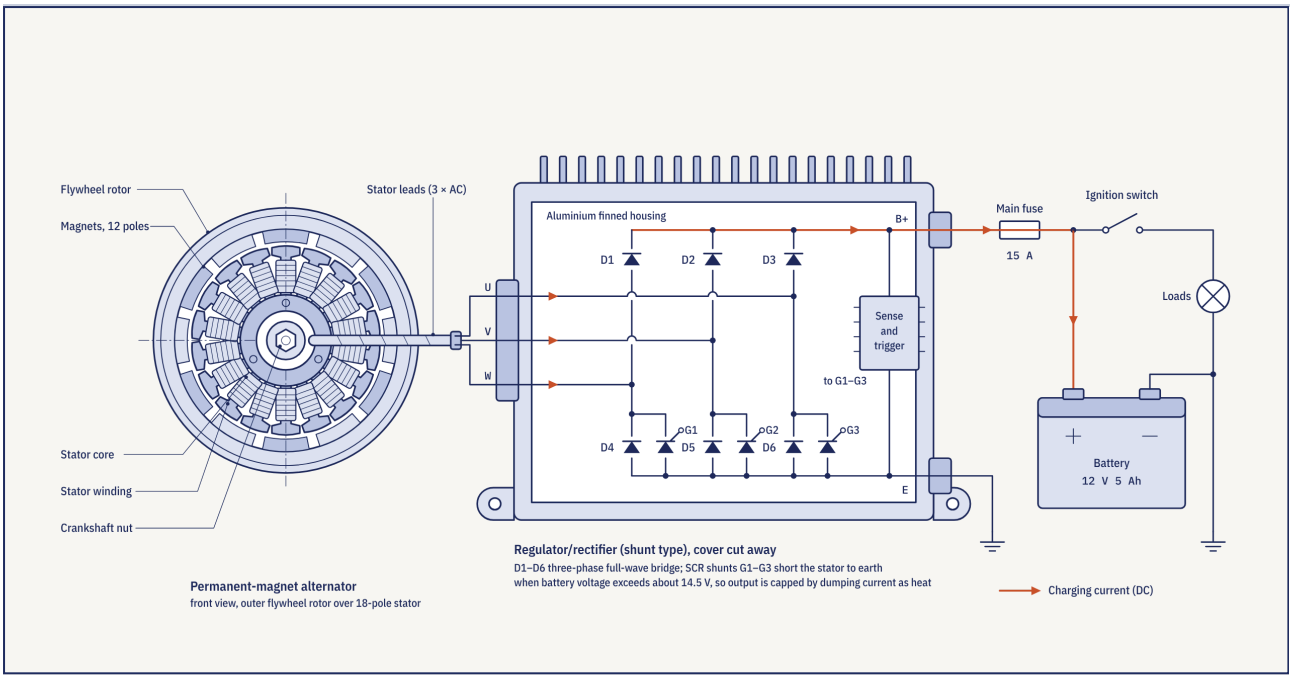


FIGURE 3.11 Charging circuit with a three-phase permanent-magnet alternator, shunt-type regulator/rectifier, main fuse, battery and load.

The **starter clutch** (sprag or roller one-way clutch) lets the starter drive the crankshaft and freewheels once the engine overruns it. A roller type has spring-loaded rollers wedging in tapered pockets; a sprag type has figure-of-eight sprags. A slipping clutch lets the starter spin noisily without turning the engine (the MAVCC starting-systems unit names it as the commonest starter fault); a seized clutch drives the starter at engine speed and destroys it. Starter motors wear their brushes: the K-Light brush length is 12.5 mm new with a service limit of **8.5 mm**.

The **kickstarter** survives on many small machines, including the K-Light 125, as a backup. A pedal on a splined shaft rotates a pinion through a ratchet that engages only on the downstroke; a return spring pulls the pedal back and a ramp disengages the ratchet so it does not grind against the gear when the engine runs. The MAVCC unit notes that most kickstart faults come from assembling the ratchet with its alignment mark out of register with the return spring hole; a worn ratchet or burred teeth make the lever slip under load.

REVIEW QUESTIONS

1. A 6 Ah battery is charged at the 10 % rule. What current is used, and how long will charging from 50 % take if charge efficiency is 80 %?
2. A rested AGM battery reads 12.3 V. Estimate its state of charge and state what the K-Light manual says to do.
3. Explain the difference between Ah and CCA and which one matters for starting on a cold morning.
4. Why must a LiFePO4 battery not be charged at 0 °C or with a desulphation mode?
5. A three-phase stator measures 0.8, 0.8 and 0.2 Ω between its three pairs of wires. Interpret the readings.
6. Compare shunt and series regulators in terms of stator heating.
7. The K-Light charging voltage reads 16.2 V at 5000 rpm. What fault is likely, and what damage follows if it is not corrected?
8. Why does the start button operate a relay instead of switching the starter current directly?
9. The starter spins freely and whines but the engine does not turn. Name the faulty part.

10. A rider can start in neutral but not in gear with the clutch pulled. Which components are suspect?

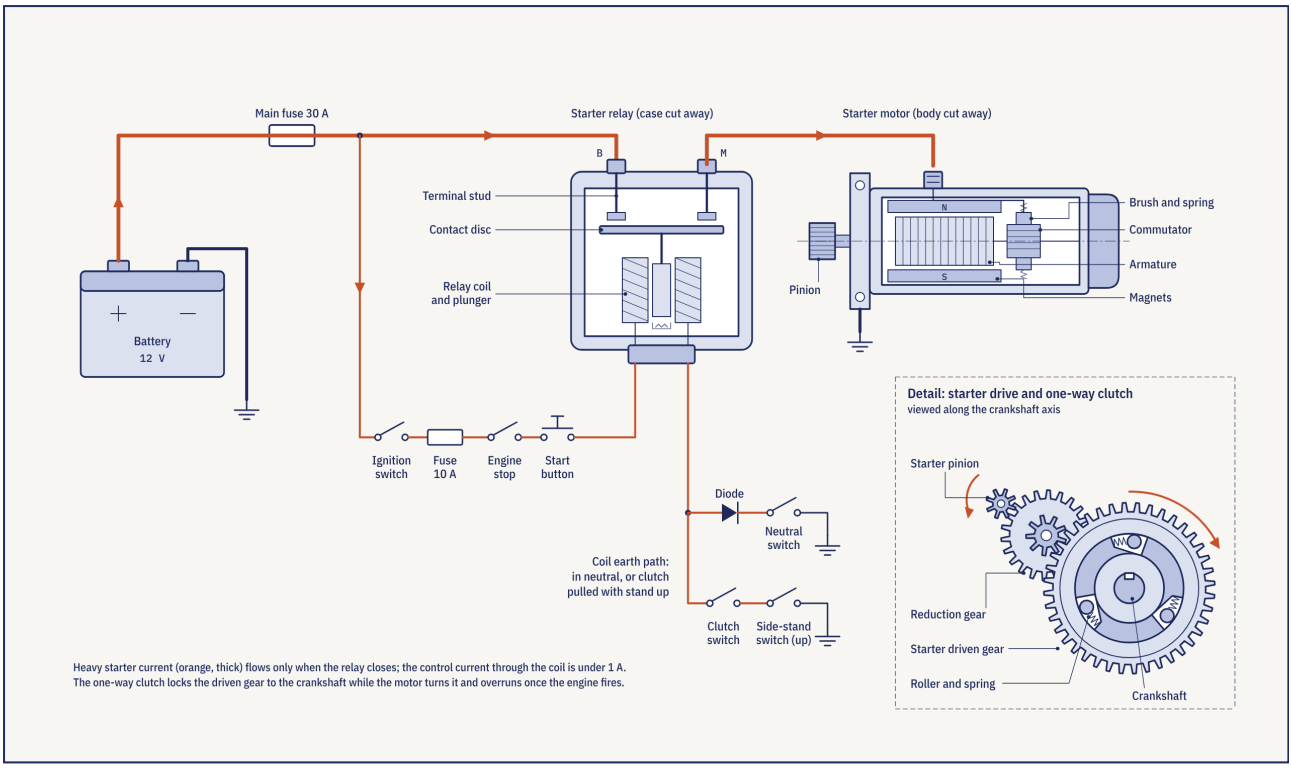


FIGURE 3.12 Electric starting circuit showing battery, main fuse, ignition switch, start button, clutch, neutral and side-stand interlocks, starter relay, starter motor and starter clutch.

ANSWERS

1. 0.6 A. Charge needed = 50 % of 6 Ah = 3 Ah; at 80 % efficiency input = 3 ÷ 0.8 = 3.75 Ah; time = 3.75 ÷ 0.6 ≈ 6.3 h.
2. About 50 %; the K-Light manual says a battery at 12.3 V after 1 hour without running must be charged.
3. Ah is energy capacity at a slow rate; CCA is the high current available at −18 °C while holding 7.2 V. CCA determines cold starting.
4. Charging below about 0 °C plates metallic lithium on the anode, permanently reducing capacity and risking internal short circuit; desulphation pulses apply voltages above the 14.6 V cell limit that a lead-acid battery tolerates but a lithium battery does not.
5. Two pairs at 0.8 Ω are within 0.8 ± 0.3 Ω; the low pair suggests shorted turns between those windings, so the stator will give low output. Confirm with AC output and short-to-earth tests (Job sheet 3.6.2).
6. A shunt regulator shorts the stator to earth when the battery is full, so stator current stays at maximum and the stator and regulator dissipate heat continuously. A series regulator opens the circuit, so stator current and heat fall when demand is low.
7. A failed regulator (open sense circuit or failed SCR control), or a poor regulator earth. Overcharging dries the battery, distorts plates and blows bulbs and can damage the ECU.
8. Starter current (tens to over a hundred amps) would burn out a handlebar switch and require heavy cable to the bars; the relay lets a small current through the interlocks control the heavy circuit near the battery.
9. The starter (one-way) clutch, which is slipping.
10. The clutch switch, its connector or wiring, or the diode that links the clutch switch into the relay circuit; the side-stand switch if the stand is down.

CHAPTER 3.5

Lighting, signalling and wiring

LEARNING OBJECTIVES

- Compare filament, halogen and LED lighting and describe headlight beam patterns.
- Explain thermal and electronic flasher relays and solve the LED hyper-flash problem.
- Describe switches, fuses, connectors, wire colour codes and earth paths.
- Read a motorcycle wiring diagram, using the K-Light 125 circuit diagram as the example.
- Explain CAN bus networking and how to add accessory power safely.

Lamps

A **filament bulb** heats a tungsten coil to around 2500–3000 K; only about 2–3 % of the input power appears as visible light. A **halogen** bulb (H4 on the K-Light headlight) fills the glass with a halogen gas that redeposits evaporated tungsten on the filament, allowing a hotter, whiter filament and longer life. The quartz envelope must not be touched, because skin oil creates hot spots; the K-Light manual advises wiping a contaminated bulb with alcohol. An H4 contains two filaments, typically 60 W main and 55 W dipped, with a shield under the dipped filament that cuts off the upper half of the beam.

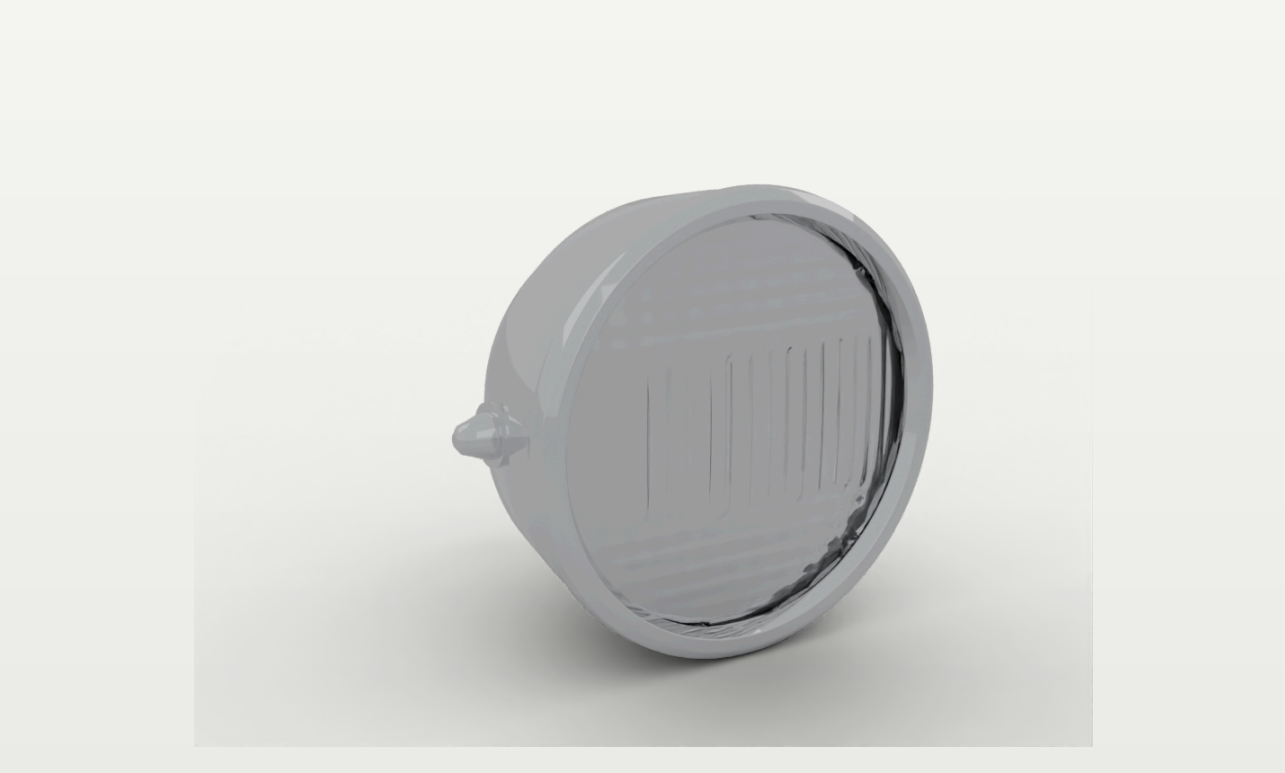


FIGURE 3.13 A seven-inch round chrome headlight with glass lens and reflector.
Render: Transitions Lab, CC BY-SA 4.0

An **LED** converts current to light at 80–150 lumens per watt and lasts tens of thousands of hours, but its output falls as junction temperature rises, so LED headlights carry heat sinks and a constant-current driver. LEDs are polarity-sensitive and draw far less current than the bulbs they replace, which affects flashers and bulb-failure warnings.

The **dipped beam** must have a sharp horizontal cut-off (with a step on the near side in UNECE patterns) to avoid dazzling oncoming traffic; the **main beam** is a concentrated hot spot along the road axis. Reflector and projector designs both shape the pattern; a halogen bulb fitted with an LED retrofit that does not place its emitters exactly where the filament was scatters light above the cut-off, which is why such retrofits are generally not type-approved for road use. Beam height is set against a wall chart at the manufacturer's distance with the rider seated.

> ▤ REFERENCE DATA **K-Light 125 lamps**
>
> - Headlight **H4**; front position lamp **W3W**.
> - Turn signals **R10W**; tail/brake light **P21/5W**; licence plate light **W5W**.
> - Flasher: variable-frequency type; horn mounting bolt 10–12 N·m.

Indicators, flasher relays and horn

UNECE rules require indicators to flash at 90 ± 30 flashes per minute. A **thermal flasher** uses a bimetal strip heated by the lamp current: it only reaches its switching temperature at the designed load, so when one bulb fails, current halves and the rate changes (slow or fast, depending on design), which serves as a failure warning. An **electronic flasher** uses a timer circuit and a relay or MOSFET; standard types also sense current and flash fast (hyper-flash) when the load falls. Replacing two 10 W bulbs with LEDs drawing about 1.5 W each reduces load current far below the design value:

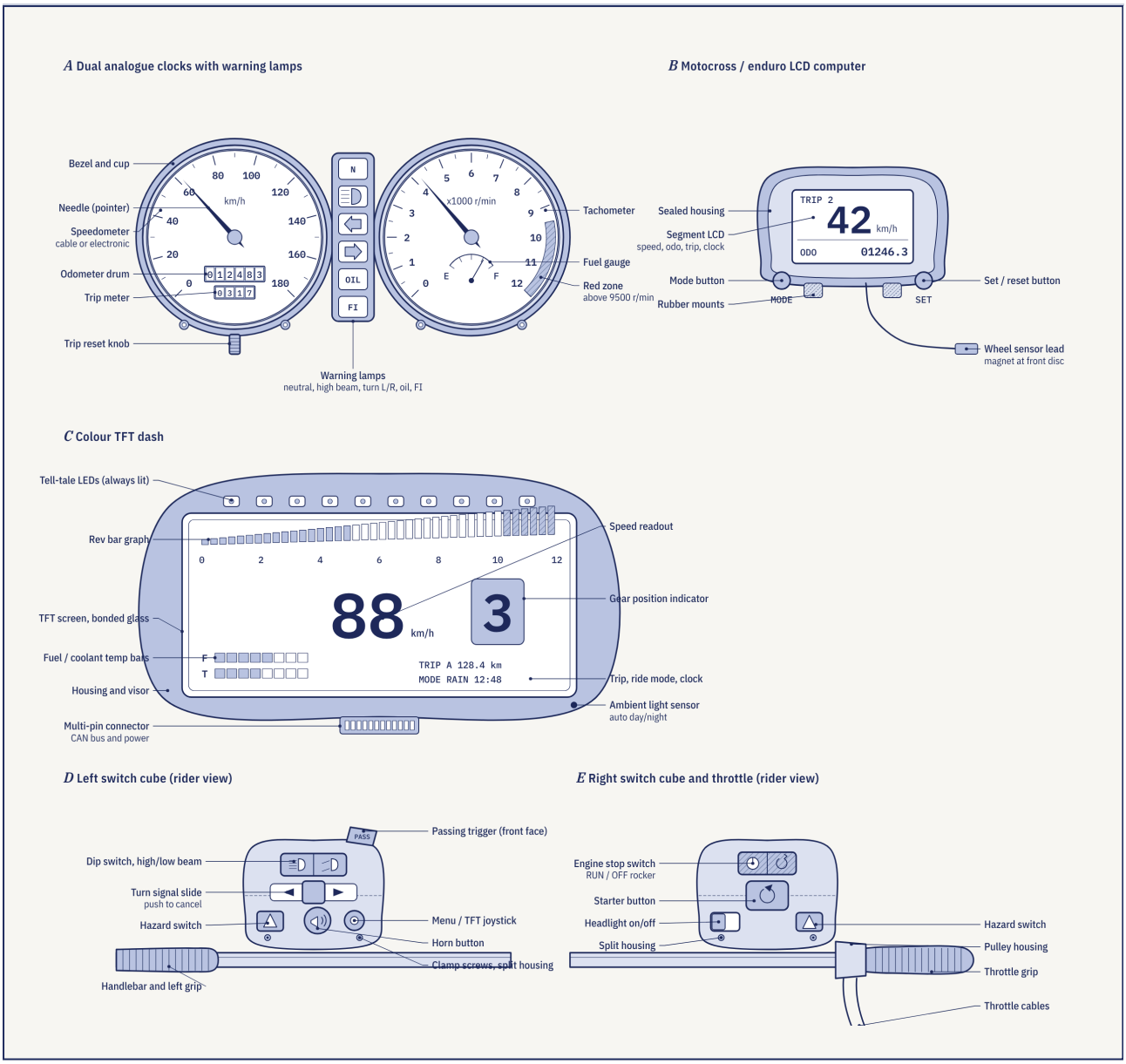


FIGURE 3.14 Instruments and switchgear: twin analogue clocks with warning lamps, a motocross LCD, a TFT dash, and the left and right switch cubes with every switch named.

```
I(bulbs) = 2 × 10 W ÷ 12 V ≈ 1.67 A
I(LED) = 2 × 1.5 W ÷ 12 V = 0.25 A
R(load) = V² ÷ P = 12² ÷ 10 = 14.4 Ω (10 W dissipated, per side)
```

The two remedies are a **load-independent electronic flasher** designed for LEDs (preferred, because it wastes no power) or a **load resistor** in parallel with each LED indicator, which must be mounted on metal because it dissipates as much heat as the bulb it replaces.

The **horn** is usually an electromagnetic diaphragm type with self-interrupting contacts; the K-Light manual tests it by connecting it directly to the battery. On many bikes the horn button switches the horn's earth side, as the K-Light horn fault tree implies when it asks the technician to bridge the button terminal to earth.

Switches, fuses and connectors

Handlebar switch clusters contain sliding or rocker contacts that oxidise and wear, giving intermittent faults that a continuity test with the switch operated through each position will reveal. Manuals give a **continuity table** for each switch, showing which wire colours connect in each position; the K-Light ignition switch table, for example, connects red to red/white in the ON position.



FIGURE 3.15 A main wiring harness with its branches, multi-pin connectors, fuse box and relays.
Render: Transitions Lab, CC BY-SA 4.0

A **fuse** protects the wiring, not the load: it must be rated below the current-carrying capacity of the smallest wire it protects. Blade fuses (ATO or mini) in 10 A and 20 A ratings are typical; the K-Light diagram shows a **20 A main fuse** and two **10 A** branch fuses. A fuse that blows repeatedly indicates a short circuit downstream, never a reason to fit a larger fuse; a fuse that has merely corroded in its holder gives high resistance and heat.

Connectors on modern bikes are sealed multi-pin housings with locking tabs and individual wire seals; the K-Light manual warns that all its connectors have claws that must be released before separation. Water and vibration cause most faults: fretting corrosion on tinned terminals, backed-out pins after careless probing, and chafing where harnesses pass the steering head. **Dielectric grease** on seals, never as a substitute for clean contact, slows corrosion. Repairs should use crimped terminals of the correct type and, for splices, a soldered and heat-shrunk joint as in the MAVCC splicing job sheet, with the splice staggered from its neighbours.

Wire colours and earth paths

Most motorcycles use a **single-wire earth-return** system: battery negative connects to the frame and engine, and each load returns current through the metal structure or through a dedicated black earth wire to a common earth point. Modern bikes run dedicated earth wires to electronic components because painted, plastic or rubber-mounted parts do not provide a reliable frame return, and because a few tenths of a volt of earth offset corrupts sensor signals.

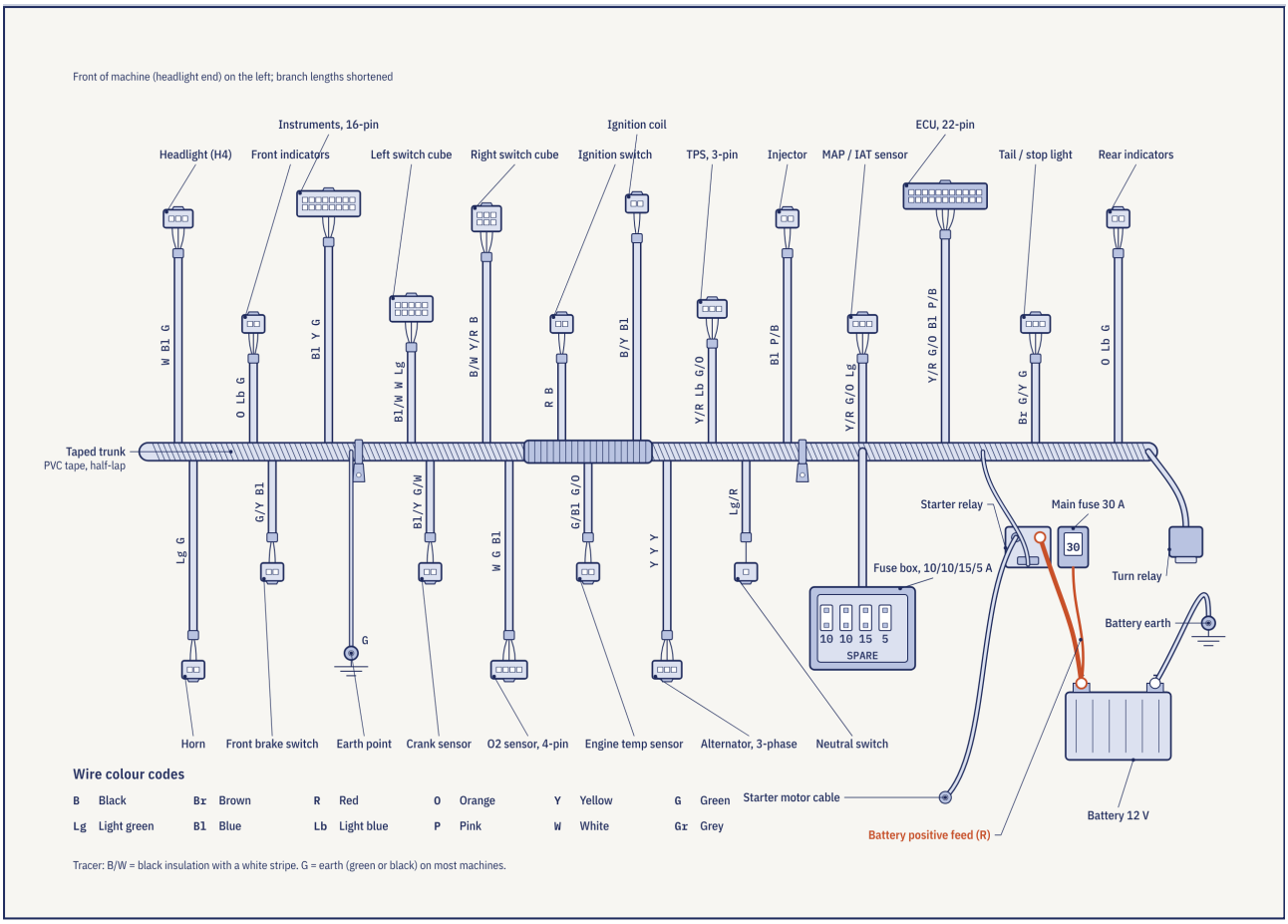


FIGURE 3.16 The main harness laid flat: trunk, branches to each component, connectors, fuse box, relays, earth points and wire colour codes.

Wire colours follow the manufacturer's code, with a stripe colour after a slash. The K-Light 125 circuit diagram uses B black, BL blue, LBL light blue, N brown, G green, O orange, Y yellow, R red, LR pink, W white, P purple, Gr grey and DG dark green; for example R is battery positive, R/W is switched supply after the main switch, B is earth, G/Y and O/R appear in the starter relay circuit, and the three white wires are the alternator phases. Japanese makers commonly use similar abbreviations but not identical meanings, so the code printed on the diagram for the specific model is the only authority.

Reading a wiring diagram

A wiring diagram shows components by symbol or outline and wires by colour code, with connectors drawn as boxes and their pin numbers. The systematic method, taught in the MAVCC brake-light tracing exercise and applicable to the K-Light diagram, is:

1. Find the load (for example the tail/brake light) and identify which of its wires is supply and which is earth.
2. Trace the supply back through each switch (brake switches front and rear), connector and fuse to the main switch and battery, writing down each colour change.
3. Identify every other circuit sharing that fuse, because a blown fuse disables them all: if the horn and the brake light both fail together, the shared fuse is the first suspect.
4. Trace the earth path back to the battery negative or its earth point.
5. Mark test points at roughly the middle of the circuit so that a single voltage measurement splits the circuit in half.

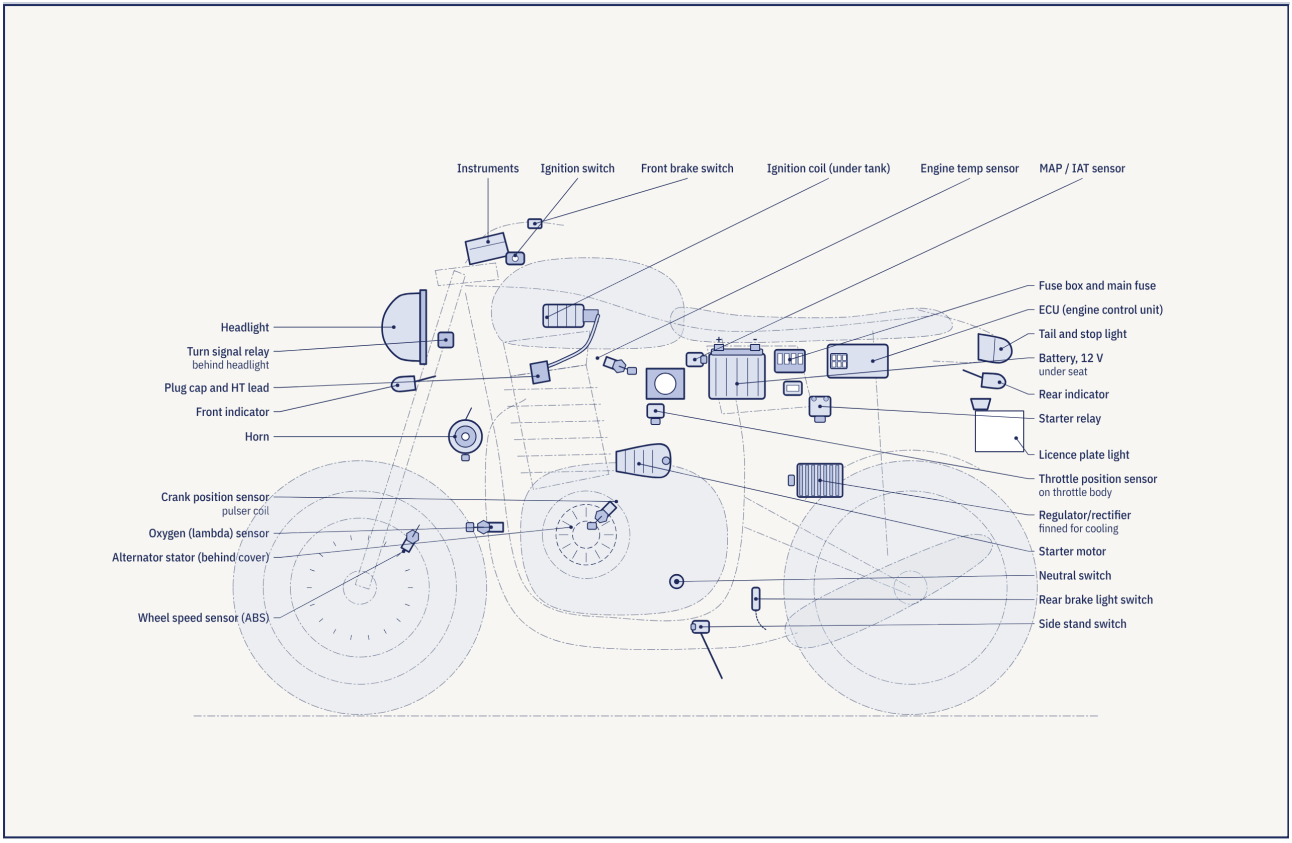


FIGURE 3.17 Where the electrical components sit on a road motorcycle: battery, fuses, regulator/rectifier, ECU, ignition coil, relays, sensors, lights and horn.

On the K-Light diagram the ECU connector is drawn with its 34 pins numbered; pin 1 and pin 13 serve the ignition coil, pin 2 the fuel pump control, pin 29 the TPS signal, and pins 4, 10, 22 and 24 the stepper motor, matching the circuit checks in the EFI chapter of the manual.

CAN bus

Larger modern machines connect the ECU, instrument cluster, ABS modulator, body control module, keyless ignition and switch clusters over a **CAN bus** (Controller Area Network, ISO 11898), a two-wire twisted pair carrying messages typically at 500 kbit/s. In the recessive (idle) state both CAN-H and CAN-L sit at about 2.5 V; in the dominant state CAN-H rises to about 3.5 V and CAN-L falls to about 1.5 V, so receivers read the difference and reject common-mode noise. Each end of the bus is terminated by a 120 Ω resistor, so with the battery disconnected the resistance between CAN-H and CAN-L should be about **60 Ω**; 120 Ω means one terminator or one branch is open, and close to 0 Ω means the wires are shorted together. A single faulty module can hold the bus dominant and make every unit report communication faults, so modules are unplugged one at a time to isolate it. Electric motorcycles use CAN extensively between battery management system, motor controller and vehicle control unit (module 4 covers these).

Accessory power

Heated grips, navigation units, USB chargers and auxiliary lights add load to an alternator that may have only 50–100 W of surplus on a small machine. The rule set by the MAVCC tap-splice guidance, to check that the electrical system will support the added load first, applies with greater force today. Good practice is to take accessory power through a separate fuse and a relay switched by the ignition circuit (so it cannot drain the battery when parked), to avoid tapping into CAN wires or sensor circuits, and on CAN-bus machines to use the manufacturer's accessory connector where one exists, because some ECUs monitor circuit current and flag unexpected loads as faults.

REVIEW QUESTIONS

1. Calculate the current drawn by an H4 headlamp on main beam (60 W) at 13.5 V, and the power lost in a 0.15 Ω connector carrying that current.
2. Why does a thermal flasher change rate when one bulb fails?
3. Two R10W indicator bulbs on one side are replaced with 1.5 W LEDs. Calculate the resistance and power rating of a parallel load resistor that restores the original load at 12 V.
4. State the rule for choosing a fuse rating.
5. Both the horn and the brake light are dead, everything else works. Using the wiring-diagram method, what is the first check?
6. On the K-Light diagram, what do the colour codes R, R/W and B indicate?
7. You measure 120 Ω between CAN-H and CAN-L with the battery disconnected. What does this indicate?
8. Why do electronic components need dedicated earth wires rather than frame earth?
9. Why are LED retrofits for halogen headlight reflectors generally not road-legal?
0. An owner wants to add 2 × 35 W auxiliary lamps to a 125 cc commuter. What must you check, and how should they be wired?

ANSWERS

1. $I = 60 \div 13.5 \approx 4.4$ A; $P = I^2R = 4.4^2 \times 0.15 \approx 2.9$ W lost as heat in the connector, with a voltage drop of 0.67 V that dims the lamp noticeably.
2. The bimetal is heated by lamp current; with half the current it heats more slowly (or, in some designs, not enough to switch), so the flash rate changes.
3. Each 10 W bulb replaced needs $R = 12^2 \div 10 = 14.4$ Ω dissipating 10 W, so two such resistors (one per LED) or one 7.2 Ω, 20 W resistor per side; mount on metal for cooling.
4. Below the current capacity of the smallest wire protected, and above the normal maximum load current of the circuit.
5. Identify whether they share a fuse; if so, test that fuse first.
6. R is battery positive (unswitched), R/W is the switched supply from the main switch, B is earth.
7. One 120 Ω terminating resistor is missing or open, or the wiring to one end of the bus is broken.
8. Plastic, painted and rubber-mounted parts give unreliable frame contact, and any voltage drop in the earth path offsets sensor signals referenced to that earth.
9. The LED emitters cannot occupy the exact position and shape of the filament, so the reflector focuses light above the cut-off and dazzles; the combination is not type-approved.
10. Load is $70 \text{ W} \div 12 \text{ V} \approx 5.8$ A, likely more than the alternator surplus; measure charging voltage with all loads on at cruising rpm. If acceptable, wire through a fused relay switched by the ignition circuit, with heavy enough cable, and consider LED lamps of lower power.

CHAPTER 3.6

Electrical diagnosis

LEARNING OBJECTIVES

- Use a digital multimeter correctly for voltage, resistance, continuity and current measurements.
- Perform voltage-drop tests and interpret the results against limits.
- Measure parasitic battery drain and locate its source.
- Recognise open circuits, short circuits and high-resistance faults from their symptoms and readings.
- Carry out the battery, charging, ignition, starter and EFI job sheets using K-Light 125 reference values.
- Use troubleshooting tables derived from the K-Light fault-diagnosis trees.

The multimeter

A digital multimeter (DMM) with **10 MΩ** input impedance on its voltage ranges loads a circuit so lightly that it can be used on ECU sensor lines; an old analogue meter or a test lamp can draw enough current to disturb a 5 V reference. The MAVCC text remains correct that a **test lamp** is a quick way to confirm that voltage is present, but it cannot measure how much, and it should not be used on ECU circuits.

- **Voltage** is measured in parallel, with the circuit operating. DC volts is used for battery, charging and sensor tests; AC volts for stator output.
- **Resistance** is measured with the circuit unpowered and the component disconnected, otherwise parallel paths and circuit voltage falsify the reading. Probe resistance (typically 0.1–0.3 Ω) is subtracted when measuring low values such as a stator winding at 0.8 Ω, by shorting the probes first and using the relative (REL) function.
- **Continuity** is a low-resistance test with a buzzer; it shows a path exists but not that the path can carry current, because a single surviving strand of a broken wire reads continuous yet drops volts under load.
- **Current** is measured in series, on the 10 A range for anything above a few hundred milliamps, and never across a voltage source; connecting an ammeter across the battery blows the meter fuse at best. A clamp meter measures starter and charging current without breaking the circuit.
- **Diode test** applies a small current and displays the forward voltage (0.4–0.7 V for a silicon diode), which is used to check regulator/rectifier diodes, as in the K-Light procedure.
- **Peak voltage** of pulser, exciter and coil primary signals is read with a peak-voltage adapter, because these pulses last too short a time for a normal DMM to register.

Probes should be applied to the back of a connector beside the wire seal or through a purpose-made back-probe pin, never by piercing insulation, which admits water and starts corrosion inside the wire.

Fault types

Fault	Effect	Typical reading
Open circuit	No current, load dead	Full supply voltage across the break; infinite resistance
Short to earth	Excess current, fuse blows	Near 0 Ω from supply wire to earth with load disconnected
Short to supply (cross-short)	Load operates when it should not, or two circuits interact	Voltage present on a wire that should be dead

Fault	Effect	Typical reading
High resistance	Load weak or intermittent, connector hot	Voltage drop across a connection or wire under load

Voltage-drop testing

A **voltage-drop test** measures the voltage across one section of a circuit while full current flows, so it reveals high resistance that a resistance test misses. Ohm's law gives the drop:

```
V(drop) = I × R
```

At 100 A of starter current, a connection of only 0.002 Ω drops 0.2 V; at 3 A of coil current, 0.2 V would require 0.067 Ω. Typical limits are **0.2 V** per connection or switch, **0.5 V** for an entire positive or negative side of a starter circuit, and **0.1 V** for electronic earths. The meter's positive probe goes on the end nearer battery positive and the negative probe on the end nearer the load (or on the earth side, nearer the load and then battery negative), so that a reading of a few tenths of a volt directly shows the lost voltage.

Parasitic drain

With the ignition off, some loads draw current permanently: the ECU memory, the clock, an immobiliser or alarm. The K-Light fault tree for an undercharged battery specifies a leakage current of **not more than 1 mA**. The test is made by disconnecting battery negative and connecting an ammeter in series between the negative terminal and the negative lead, starting on the 10 A range (to survive any wake-up surge) and stepping down to the mA range once the reading settles; modern ECUs may take several minutes to go to sleep. If the drain is excessive, fuses are pulled one at a time until it drops, which identifies the circuit. A stuck brake-light switch, which the K-Light tree checks first, is a frequent cause.

```
t(flat) = C ÷ I
```

A 6 Ah battery with a 1 mA drain would discharge fully in 6 ÷ 0.001 = 6000 h (250 days), but it falls below 50 % after about four months, consistent with the manual's three-monthly charging advice; a 20 mA alarm would reach 50 % in 150 hours, about six days.

Job sheet 3.6.1: Battery test and charge

Tools and materials	Reference values
DMM, battery charger with 0.6 A setting, eye protection, terminal brush, petroleum jelly, hydrometer for flooded batteries	K-Light YTX7A-BS 12 V 6 Ah: full 13.1 V; charge required at 12.3 V; standard charge 0.6 A for 10–15 h; after charge at least 12.8 V

1. Switch the ignition off, remove the left side cover and disconnect the **negative** lead, then the positive lead. Remove the vent tube on flooded batteries.
2. Inspect the case for swelling, cracks or leaks; a swollen AGM battery has been overcharged and is replaced, and a flooded battery with whitish sulphate visible on its plates is replaced without charging.

3. Let the battery rest for at least 1 hour after riding or charging and measure open-circuit voltage. Below 12.3 V the battery requires charging; below about 11.8 V after a full charge attempt, a cell has failed.
4. On a flooded battery, check each cell with a hydrometer; readings should be 1.265 or above when charged and should not differ between cells by more than 0.050.
5. Charge at no more than 10 % of the Ah rating (0.6 A for the K-Light battery) for 10–15 hours in a ventilated area, switching the charger on only after the clips are connected. Stop if the case becomes hot to the touch (above about 45 °C).
6. Wait 30 minutes and measure voltage again: 12.8 V or more indicates a completed charge.
7. Load-test: with the battery fitted and the headlight on, voltage should stay above about **10.5 V**; during cranking it should not drop below about **9.6 V** for a healthy battery (the MAVCC unit gives 8.5 V as the absolute minimum).
8. Refit positive first, then negative, tighten the terminals and coat them lightly with petroleum jelly, keeping it off the case.

Pass criteria: open-circuit voltage at least 12.8 V 30 minutes after charging, no case damage, cranking voltage above 9.6 V and a battery that holds charge (less than about 0.1 V loss over 24 h rest).

Job sheet 3.6.2: Charging system output test

Tools and materials	Reference values
DMM (DC volts, AC volts, ohms, diode test), tachometer or diagnostic tool, fully charged battery	Charging voltage 14.5 ± 0.5 V at 5000 rpm; stator 0.8 ± 0.3 Ω between whites; no continuity stator to earth; regulator diodes conduct one way only

1. Confirm the battery is fully charged (Job sheet 3.6.1), because a flat battery pulls voltage down and hides a regulator fault.
2. Warm the engine. Connect the DMM on DC volts across the battery terminals and raise speed slowly to 5000 rpm. Voltage should rise from battery voltage to **14.0–15.0 V** and then stop rising. Repeat with headlight on main beam; voltage may fall slightly but should stay above 13.5 V.
3. Interpret: voltage that stays at battery voltage means no charge (stator, regulator or wiring); voltage above 15.0 V means the regulator is not limiting (regulator, or a poor regulator earth or sense wire).
4. Check the main wiring at the regulator connector with it unplugged: battery voltage between the red wire and earth, continuity between the black wire and earth.
5. Stop the engine, disconnect the stator connector and measure resistance between each pair of white wires: 0.8 ± 0.3 Ω for all three pairs. A pair reading low indicates shorted turns; an infinite reading means an open winding.
6. Measure from each white wire to engine earth on the highest resistance range: there must be **no continuity**. Any reading indicates a winding shorted to the stator core, often visible as darkened varnish.
7. Reconnect the battery, run the engine with the stator connector unplugged and measure AC volts between each pair of whites at a fixed rpm (typically 5000 rpm): the three readings should be equal within about 10 %, and in the 50–80 V AC range for a typical small three-phase stator. A low reading on one pair confirms a stator fault.

8. With the regulator unplugged, use diode test from the red terminal to each white terminal and from each white terminal to the black terminal, then reverse the probes: each diode should conduct in one direction (about 0.4–0.7 V) and block in the other. The K-Light manual warns that readings vary between meters, so compare all three phases rather than relying on absolute values.

Pass criteria: regulated voltage within 14.5 ± 0.5 V at 5000 rpm, stator windings 0.8 ± 0.3 Ω and isolated from earth, balanced AC output, all regulator diodes conducting in one direction only.

Job sheet 3.6.3: Ignition system test

Tools and materials	Reference values
Insulated spark tester, DMM, peak-voltage adapter, feeler wire gauge, new plug D7RTC	Plug gap 0.7 ± 0.1 mm; coil primary 4 Ω ± 10–15 %; secondary 18.6 kΩ with cap, 13.6 kΩ without; trigger 150 ± 10 Ω, peak above 1.7 V

1. Check battery voltage first (above 12.4 V); low voltage weakens an ECU-driven inductive spark. Inspect all ignition connectors, which the K-Light manual names as the commonest cause of ignition faults.
2. Remove the plug and inspect it (see Reading plugs in chapter 3.3). Fit the plug or a new one into an insulated spark tester set to about 6–8 mm, earth the tester and crank. A strong blue-violet spark is good; a weak orange spark or none leads to the next steps.
3. Repeat at the HT lead with the cap removed. A good spark at the lead but not through the cap condemns the cap.
4. Check that the engine stop switch, side-stand and neutral circuits allow ignition (correct position, continuity per the switch table).
5. With the ignition off and the coil disconnected, measure primary resistance between the primary terminals: 4 Ω ± 10–15 %; infinite means an open winding.
6. Measure secondary resistance from the HT lead (with cap) to a primary terminal or earth: 18.6 kΩ ± 15 %; without the cap 13.6 kΩ ± 15 %. Remember that a coil can pass resistance tests and still break down under voltage, so substitution with a known good coil is the final test.
7. Disconnect the trigger (crankshaft sensor) connector and measure between the blue/white and green/white wires: 150 ± 10 Ω. Higher means an open circuit; lower means shorted turns. Check also for no continuity to earth.
8. With a peak-voltage adapter connected to the trigger wires (connector reconnected or back-probed), crank the engine: the peak should exceed **1.7 V**. A low peak with correct resistance indicates an excessive air gap or a damaged reluctor.
9. Check coil circuits to the ECU: coil terminal 1 to ECU pin 1 and coil terminal 2 to ECU pin 13 must show continuity, and only one of them should carry 12 V to earth with the key on. If all components pass, suspect the ECU.

Pass criteria: strong spark across a 6 mm tester gap, coil, cap and trigger resistances within specification, trigger peak above 1.7 V when cranking, and coil circuit continuity to the ECU.

Job sheet 3.6.4: Starter circuit voltage-drop test

Tools and materials	Reference values
DMM on DC volts (2 V range), charged battery, clamp ammeter (optional), insulated jumper	Positive side drop ≤ 0.5 V; negative side ≤ 0.3 V; relay contacts ≤ 0.2 V; brush length ≥ 8.5 mm (new 12.5 mm)

1. Charge the battery (Job sheet 3.6.1). Disable the engine so it cranks without starting (engine stop switch off is not suitable if it also interrupts the relay; instead remove the fuel pump fuse or the plug cap earthed through a spark tester).
2. With the ignition on and the brake lever (or clutch and neutral interlocks) satisfied, press the start button and listen for the relay click. No click: measure relay coil supply at the green/yellow wire (battery voltage with brake lever pulled) and earth through the black wire with the button pressed, then bench-test the relay: 12 V across its coil should click and give 0 Ω across its contacts.
3. Measure battery voltage while cranking: above about 9.6 V. A lower voltage with a good battery points to a heavy mechanical drag or a shorted starter.
4. Positive side: one probe on the battery positive post (not the clamp), the other on the starter motor terminal, while cranking. Reading should be **0.5 V or less**; a higher reading is located by moving the probes across each section (cable, fuse, relay contacts, terminal) in turn.
5. Relay contacts: probes on the two heavy relay terminals while cranking, **0.2 V or less**; above this the contacts are burned.
6. Negative side: one probe on battery negative post, the other on the starter motor body, while cranking: **0.3 V or less**; above this clean the engine earth strap and battery negative terminal.
7. If all drops pass and the starter still turns slowly, remove the starter and measure brush length (limit 8.5 mm), inspect the commutator and brush springs. If the starter spins without turning the engine, inspect the starter clutch.

Pass criteria: relay clicks and its contacts drop no more than 0.2 V, positive and negative side drops within limits, cranking voltage above 9.6 V and brushes above the service limit.

Job sheet 3.6.5: Reading EFI fault codes and testing a TPS

Tools and materials	Reference values
Diagnostic tool with 16-pin adapter, DMM, back-probe pins, wiring diagram	Battery above 8.5 V during diagnosis; TPS reference 5 ± 0.1 V; TPS signal 0.5–0.9 V closed, about 3.5–4.0 V fully open; P0122 below 0.1 V, P0123 above 4.9 V

1. Turn the key on and confirm that the FI lamp lights as a bulb check. If not, check the fuse, earth and ECU connector before going further.
2. Connect the diagnostic tool to the 16-pin interface with the ignition off, then switch on. If the tool will not communicate, check fuse and earth, the ECU connector, and test the tool on another motorcycle. On machines with blink codes, bridge the service connector and count the MIL flashes instead.

3. Record all stored codes and freeze-frame data before clearing anything. Note whether each code is current or historic.
4. Read live data: battery voltage, engine and intake temperatures (they should agree with ambient on a cold engine), MAP (atmospheric, about 100 kPa, engine stopped) and TPS percentage.
5. For a TPS code, back-probe the TPS connector with the key on. Measure reference to sensor earth: 5 ± 0.1 V. No reference indicates a harness or ECU fault; a low reference shared by several sensors suggests another sensor shorting the 5 V supply.
6. Measure signal to sensor earth (pins 1 and 3 on the K-Light TPS) with the throttle closed: 0.5–0.9 V. Open the throttle slowly to full: the voltage should rise smoothly to about 3.5–4.0 V with no dropouts. Watch a bar graph or min/max reading for momentary jumps.
7. With the connector unplugged and the key off, check continuity from TPS signal pin to ECU pin 29 (must be continuous) and from the signal pin to earth (must be open).
8. Repair, clear the codes, perform any TPS or idle relearn the manufacturer requires, and road-test until the MIL stays off and no code returns.

Pass criteria: no current codes after repair and road test, TPS reference within 5 ± 0.1 V, signal 0.5–0.9 V closed rising smoothly to about 3.5–4.0 V open, and correct harness continuity and insulation.

Troubleshooting tables

The following tables condense the K-Light 125 fault-diagnosis trees into the standard format.

Engine will not start or starts with difficulty

Symptom	Likely cause	Check	Remedy
No spark or weak spark	Carbon-bridged plug, plug cap, coil, trigger, ECU, ignition switch circuit	Job sheet 3.6.3 in order	Clean or replace plug; replace faulty part
Good spark, plug dry	No fuel delivered: tank vent blocked, pump or filter fault, empty tank	Tank vent; pump runs 3 s at key-on; fuel pressure 300 kPa	Clear vent; replace filter or pump; refuel
Good spark, plug wet	Flooding, leaking injector, starter device fault	Clear-flood procedure; injector leak test	Dry and retry; replace injector
Good spark and fuel, low compression	Valve clearance too small, valve seat leak, worn or stuck rings, intake leak	Compression test; valve clearance	Adjust valves; top-end repair
Engine starts then stops	Blocked air filter, throttle body by-pass blocked	Filter; by-pass passage	Clean or replace

Battery and charging

Symptom	Likely cause	Check	Remedy
Battery cannot be charged	Stator winding shorted or open, wire to regulator open, regulator fault	Stator resistance; continuity regulator to battery; regulator diode test	Replace stator, repair wire, replace regulator
Battery undercharged	Brake light switch stuck on, parasitic drain above 1 mA, sulphated or shorted battery, shorted stator	Brake light off; drain test; battery test	Adjust switch; locate drain; replace battery or stator

Symptom	Likely cause	Check	Remedy
Battery voltage too high, bulbs burn out	Regulator not limiting, poor regulator earth, poor battery connection	Charging voltage at 5000 rpm; voltage drop on regulator earth	Replace regulator; repair earth or terminal
All lights out	Main fuse blown, battery flat, open circuit between battery and ignition switch, ignition switch fault	Fuse; battery voltage; switch continuity table	Replace fuse after finding short; charge battery; repair
Lights weak	Low regulated voltage, poor connector or earth in lighting circuit, wrong or aged bulb	Charging voltage with lights on; voltage drop to lamp	Repair connections; replace regulator or bulb

Starter, signals and horn

Symptom	Likely cause	Check	Remedy
Starter does not turn, horn weak	Battery flat or terminal loose	Battery voltage and terminals	Charge; clean and tighten
Starter does not turn, no relay click	Brake or clutch switch, neutral switch or diode, start button, relay coil, fuse	Relay coil voltage and earth; switch continuity	Repair switch or wiring; replace relay
Relay clicks, starter does not turn	Burned relay contacts, worn brushes, open armature	Relay contact voltage drop; bridge relay heavy terminals	Replace relay; overhaul or replace starter
Starter spins, engine does not turn	Starter clutch slipping, reduction gear damaged	Inspect starter clutch	Replace starter clutch
Turn signals all out	Flasher (scintillator) failed, supply from ignition switch open, battery flat	Bridge flasher terminals; supply voltage at flasher	Replace flasher; repair supply
Turn signals out on one side	Bulbs failed, switch contact, lampholder earth	Bulbs; voltage at lampholder; switch continuity	Replace bulb; clean contact or earth
Horn silent	Horn supply open, button contact, horn failed	Spark test on supply wire; bridge button side to earth	Repair supply or button; adjust or replace horn

REVIEW QUESTIONS

1. Why should a resistance test on a stator winding be preceded by shorting the meter probes?
2. A brake light circuit draws 1.75 A. You measure 0.7 V between the battery positive and the lamp's supply terminal. Calculate the resistance responsible and the power wasted.
3. During cranking you measure 0.9 V between battery positive post and starter terminal, and 0.15 V across the relay heavy terminals. Where is the fault?
4. Parasitic drain measures 18 mA on a bike with a 6 Ah battery. How long until the battery is at 50 %, and how would you find the cause?
5. Why must an ammeter never be connected across the battery terminals?
6. The charging voltage stays at 12.6 V at 5000 rpm. Stator pairs read 0.8, 0.9 and 0.8 Ω and are isolated from earth. What do you test next?
7. A trigger coil measures 152 Ω but its cranking peak is 0.8 V. What is the probable cause?
8. A TPS reads 5.0 V at all throttle positions. Which code is likely, and which wiring faults could cause it?

9. A continuity test shows a wire to be continuous, yet the lamp it feeds is dim. Explain and state the correct test.
10. Why is the battery charged before any charging system or starter test?

ANSWERS

1. Probe and lead resistance (0.1–0.3 Ω) is a large fraction of a 0.8 Ω reading; shorting the probes and using REL subtracts it.
2. R = V ÷ I = 0.7 ÷ 1.75 = 0.4 Ω; P = V × I = 0.7 × 1.75 ≈ 1.2 W wasted, which exceeds a typical 0.2 V limit by a wide margin.
3. Positive side drop is 0.9 V, above the 0.5 V limit, but the relay accounts for only 0.15 V, so the remaining 0.75 V is in the cables, fuse holder or terminals; move the probes section by section to find it.
4. 3 Ah ÷ 0.018 A ≈ 167 h, about 7 days. Pull fuses one at a time while watching the ammeter; the fuse that removes the drain identifies the circuit, then disconnect components in that circuit.
5. An ammeter has almost zero resistance, so connecting it across the battery is a short circuit: hundreds of amps flow, blowing the meter fuse or damaging the meter and battery.
6. Stator resistance and insulation are good, so measure AC output between each pair with the engine running, then check the wiring between stator, regulator and battery (red wire voltage, black earth), and finally diode-test the regulator.
7. The resistance is in specification, so the winding is intact; a low peak means the air gap between trigger and reluctor is too large, the reluctor is damaged, or the cranking speed is too low.
8. P0123 (above 4.9 V). Causes: open sensor earth wire, signal shorted to the 5 V reference, or the reference shorted to the signal inside the connector.
9. Continuity requires only a minute current, so a wire with one strand left or a corroded terminal passes the test but drops voltage at load current. Measure voltage drop with the circuit operating.
10. A discharged battery pulls charging voltage down and masks a faulty regulator, and its low voltage under cranking load imitates starter or relay faults; all reference values assume a charged battery.

Glossary

Air-fuel ratio (AFR): mass of air divided by mass of fuel in the mixture; 14.7:1 is stoichiometric for petrol. **Alpha-N**: fuel strategy that estimates engine load from throttle angle and rpm. **Alternator**: AC generator driven by the crankshaft; on most motorcycles a permanent-magnet rotor turning around a wound stator. **Ampere-hour (Ah)**: battery capacity, the product of discharge current and the hours it can be sustained (usually at the 10-hour rate). **AGM (VRLA)**: lead-acid battery with electrolyte held in absorbent glass-mat separators and sealed by a pressure valve. **Breakdown voltage**: voltage at which the gas in a spark gap ionises and conducts. **CAN bus**: two-wire differential network (ISO 11898) linking electronic control units, terminated by 120 Ω at each end. **Capacitor discharge ignition (CDI)**: ignition that discharges a charged capacitor into the coil primary through a thyristor. **Closed loop**: fuel control corrected continuously by oxygen-sensor feedback. **Cold cranking amps (CCA)**: current a battery delivers at −18 °C for 30 s while staying above 7.2 V. **Constant-velocity (CV) carburettor**: carburettor whose piston is lifted by venturi depression acting on a diaphragm, with a cable-operated butterfly. **Crankshaft position sensor (CKP)**: sensor reading reluctor teeth on the flywheel to give engine speed and crank angle; also called trigger or pulser. **Dwell**: crank angle or time during which the ignition coil primary carries current. **EVAP canister**: activated-charcoal container that stores fuel vapour from the tank for later burning in the engine. **Fault code (DTC)**: stored diagnostic trouble code identifying a detected fault, e.g. P0122. **Float level**: height of the carburettor float, which sets the fuel level in the bowl. **Fuse**: sacrificial link that opens when current exceeds its rating, protecting the wiring. **Heat range**: rate at which a spark plug insulator transfers heat; determines whether a plug runs hot or cold. **Idle air control (IAC)**: ECU-controlled valve or stepper motor that regulates by-pass air to hold idle speed. **Injector pulse width**: time for which the injector is held open in each cycle, in milliseconds. **Interlock**: switch that prevents starting or running in an unsafe condition (neutral, clutch, sidestand, brake). **Jet needle**: tapered needle hanging from the carburettor slide that meters fuel from 1/4 to 3/4 throttle. **Lambda (λ)**: actual AFR divided by stoichiometric AFR. **LiFePO4**: lithium iron phosphate battery chemistry; four 3.2 V cells make a 12.8 V starter battery. **Main jet**: calibrated orifice that limits fuel flow from about 3/4 to full throttle. **MAP sensor**: manifold absolute pressure sensor used to calculate engine load. **MIL**: malfunction indicator lamp, the engine warning lamp lit by the OBD system. **OBD**: on-board diagnostics; stage I monitors circuits, stage II monitors emission-relevant degradation against threshold limits. **Oxygen sensor**: exhaust sensor whose output indicates rich or lean mixture relative to λ = 1. **Parasitic drain**: current drawn from the battery with the ignition off. **Pilot jet**: small jet supplying fuel at idle and small throttle openings. **Regulator/rectifier**: unit that converts alternator AC to DC and limits charging voltage. **Resistor cap**: spark plug cap with a built-in suppressor resistor, typically about 5 kΩ. **Secondary air injection**: admission of air into the exhaust port to oxidise CO and HC (PAIR). **Shunt regulator**: regulator that limits voltage by short-circuiting the stator to earth. **Speed-density**: fuel strategy that calculates air mass from manifold pressure, temperature and rpm. **Starter clutch**: one-way (sprag or roller) clutch between starter gear and crankshaft. **Starter relay**: solenoid switch carrying starter motor current, operated by the start button through the interlocks. **Stoichiometric**: chemically correct mixture with exactly enough oxygen to burn all the fuel. **Three-way catalyst**: catalyst that oxidises CO and HC and reduces NOx simultaneously near λ = 1. **Throttle position sensor (TPS)**: potentiometer reporting throttle opening to the ECU. **Transistor-controlled ignition (TCI)**: inductive ignition in which a transistor switches the coil primary. **Turns ratio**: ratio of secondary to primary turns in an ignition coil, roughly 100:1. **Voltage drop**: voltage lost across a wire, connection or switch while current flows. **Wasted spark**: ignition arrangement in which one coil fires two plugs together, one cylinder on compression and the other on exhaust.

Further reading

- KS Motorcycles / Qianjiang, K-Light 125 maintenance manual (Manuel d'entretien K-Light 125): specifications p.18–19, fault-diagnosis trees p.20–46, electrical system p.72–104, electronic injection p.251–276, circuit diagram p.277.
- Mid-America Vocational Curriculum Consortium (1988), Motorcycle Mechanic, teacher edition: Unit VIII Battery and electrical service, Unit IX Carburetors and fuel systems, Unit XIV Starting systems, Unit XV Basic ignition tune-up. Stillwater, OK: MAVCC.
- Hero Honda, technician starter kit, Unit 2 "The Motorcycle" (systems overview with self-assessment questions).
- Solomon R. Guggenheim Museum (1998), The Art of the Motorcycle, New York: Guggenheim Museum Publications (Falco essay on technical evolution).
- Heywood, J. B. (2018), Internal Combustion Engine Fundamentals, 2nd edition, New York: McGraw-Hill (combustion, emissions formation, fuel metering).
- Robert Bosch GmbH, Bosch Automotive Handbook, current edition, Plochingen: Bosch (sensors, ignition, batteries, CAN).
- Bosch, Gasoline Engine Management: Systems and Components, Wiesbaden: Springer Vieweg.
- Jennings, G. (1973), Two-Stroke Tuner's Handbook, Tucson: H. P. Books (carburettor jetting and CDI on two-strokes).
- Haynes Publishing, Motorcycle Electrical Techbook and Motorcycle Carburettor Manual, Sparkford: Haynes.
- Regulation (EU) No 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles, and Delegated Regulation (EU) No 134/2014 (environmental performance requirements), as amended, including Regulation (EU) 2019/129 (Euro 5 application and OBD stage II).
- Ministry of Road Transport and Highways, India, Central Motor Vehicles Rules notifications on Bharat Stage VI for two-wheelers, including the amendments introducing OBD II.
- UNECE Regulation No 53 (installation of lighting on L3 vehicles), No 50 (position, stop and direction indicator lamps for L-category vehicles) and No 113 (headlamps).
- ISO 11898-2, Road vehicles: Controller area network (CAN), high-speed physical layer; ISO 15031-6 and SAE J2012, diagnostic trouble code definitions.

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Workshop procedures are general guidance. Specifications differ between machines: always confirm values and torque settings in the manufacturer's service manual, and observe the safety notes in Module 1 and Module 5.