moto zero
by Transitions Lab

01

MODULE 1

Foundations: the machine, its anatomy and the workshop

How the motorcycle evolved, how its systems divide and connect, the physics that governs it, and the safe working methods, tools and measurements every later module depends on.



A technical course on how motorcycles work
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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 1.1

A short history and the motorcycle as a system

LEARNING OBJECTIVES

- Place the main technical milestones of the motorcycle, from the steam velocipedes of 1868–69 to battery swapping, in sequence and explain what each one solved.
- Divide any motorcycle, scooter or electric two-wheeler into its functional systems and name the main components of each.
- Trace the flow of energy from fuel tank or battery to the tyre contact patch and estimate where it is lost.
- Explain why emissions and safety regulation drove the shift from two-strokes and carburettors to fuel-injected four-strokes, ABS and electric drive.

From steam velocipede to mass production

The motorcycle needed four inventions to arrive at roughly the same time: a compact engine, the pneumatic tyre (Dunlop 1888, Michelin 1895), the bush roller chain (Renold 1880) and a frame geometry able to carry a rider and a power unit (the Starley safety bicycle of 1886), a sequence Charles Falco sets out in his essay for the Guggenheim's *The Art of the Motorcycle*. The first powered two-wheelers used steam: Louis Guillaume Perreaux patented a small steam engine on 26 December 1868 that was fitted to a Michaux iron-framed velocipede with a pulley drive to the rear wheel by 1871, and Sylvester Roper built a comparable machine in the United States around 1867–69. Nikolaus Otto ran a four-stroke engine in 1876, and in 1885 Gottlieb Daimler and Wilhelm Maybach mounted a small high-speed petrol engine in a wooden frame with outrigger wheels, the *Reitwagen*, built as an engine test bed rather than a product.

The first machine sold in series and called a "motorrad" was the **Hildebrand & Wolfmüller of 1894**: a water-cooled 1,489 cc twin whose connecting rods drove cranks on the rear wheel directly, as on a locomotive, with no flywheel or gearbox. Falco records roughly one thousand built before the company failed in 1897, which proved demand while showing that a flywheel-less direct drive could neither idle nor pull away cleanly. The 1897 Werner carried its engine above the front wheel, which raised the centre of mass and made the front wheel prone to slide; the **1901 New Werner** moved the engine down to the bottom-bracket position between the wheels, and by about 1903 that layout, engine low and central with the tank above it, was established practice.

Indian (1901) and Harley-Davidson (1903) were the two American makers to survive the 1930s, and the interwar years brought overhead valves, chain final drive and Edward Turner's 1937 Triumph Speed Twin, a parallel twin copied for half a century. Alfred Scott's water-cooled two-stroke twins won the Isle of Man Senior TT in 1912 and 1913, and DKW's loop-scavenged RT125, copied after 1945 as the BSA Bantam, the Harley-Davidson Hummer and Yamaha's first product, the YA-1, became the template for cheap motorised transport. The hydraulically damped telescopic fork became general just after the Second World War.

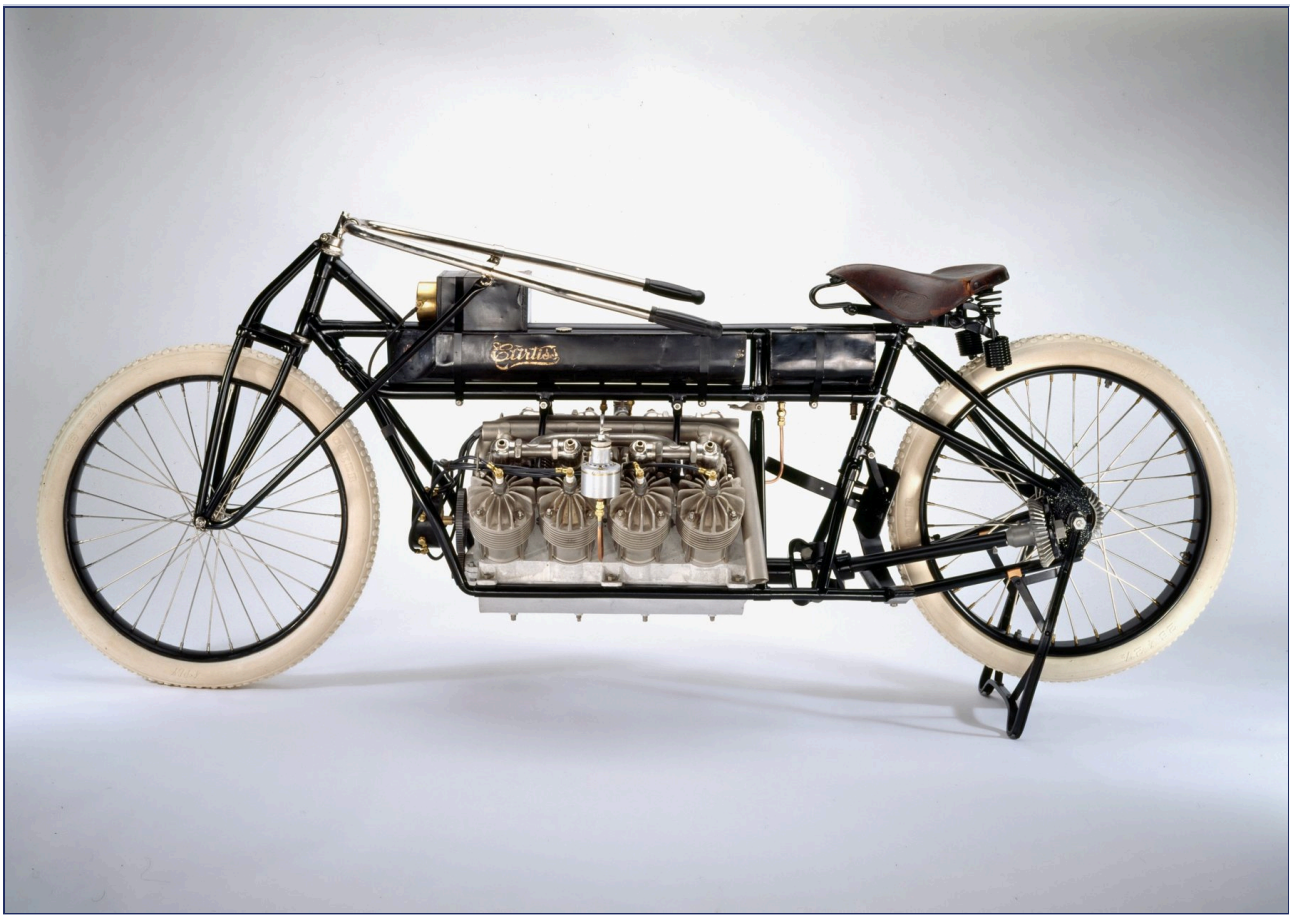


FIGURE 1.1 An early Curtiss racing motorcycle with an air-cooled multi-cylinder engine slung low in a bicycle-derived diamond frame, belt-free direct drive and a sprung saddle: the layout that the first decade of motorcycling inherited from the safety bicycle. Photograph: Transitions Lab collection

From the late 1950s Japanese mass production changed the economics of the motorcycle. Honda's C100 **Super Cub** of 1958, a step-through with a 49 cc overhead-valve four-stroke and an automatic centrifugal clutch, passed **100 million units in October 2017** and is generally described as the most-produced motor vehicle in history; the CB750 of 1969 brought an overhead-camshaft inline-four and a front disc brake to the mass market. Two-stroke development by Suzuki, Kawasaki and Yamaha (reed valves, exhaust power valves, expansion chambers) produced very high specific outputs, but a ported two-stroke loses part of its fresh charge into the exhaust during scavenging and burns its lubricating oil, so its hydrocarbon emissions are many times those of a four-stroke. Emission limits from the US EPA rules of the late 1970s to Euro 3 (2006) and Bharat Stage II and III in India (2005–2010) pushed road two-strokes out of most markets; they survive in off-road competition, some direct-injection designs and older fleets.

The same pressure ended the carburettor. Euro 4 (2016), Euro 5 (2020) and India's BS-VI (April 2020) require the mixture to be held at **stoichiometric (14.7:1 for petrol)** so that a three-way catalytic converter can work, which in practice means electronic fuel injection with an oxygen sensor, now fitted even to 100–125 cc commuters such as the K-Light 125 used as this course's worked example. Under Regulation (EU) No 168/2013, **ABS** became compulsory on new motorcycles above 125 cc (new types from 2016, all new registrations from 2017), with ABS or a **combined braking system (CBS)** on the 125 cc class; India required ABS above 125 cc and CBS at or below 125 cc on new models from April 2018 and on all models from April 2019.

The current transition is electric. China's fleet of electric two-wheelers is commonly estimated at more than 300 million, India's electric two-wheeler sales passed one million a year in the mid-2020s, and in East Africa, where motorcycle taxis (boda bodas in Kenya and Uganda, motos in Rwanda) carry a large share of urban trips, firms such

as Roam, Spiro and Ampersand build or import electric motorcycles and run **battery-swapping** networks, a model taken to scale by Gogoro in Taiwan from 2015. Swapping separates battery cost from vehicle cost and replaces hours of charging with a two-minute stop.

The motorcycle as a set of systems

A motorcycle is easier to inspect and repair when divided into functional systems, each with a defined input, output and set of failure modes. A misfire, for example, can originate in the spark plug, plug cap, ignition coil, pickup coil, ECU, ignition switch or wiring, and a technician who sees the ignition system as a chain from trigger to spark can test those links in order.

System	Function	Main components (internal-combustion)	Electric equivalent	Module
Power unit	Converts stored energy into shaft torque	Cylinder head, valves, cylinder, piston, connecting rod, crankshaft, crankcase, lubrication and cooling	Motor (stator, rotor, magnets, bearings), inverter	2, 5
Fuel and air	Meters fuel and air in and expels exhaust	Tank, pump, injector or carburettor, throttle body, air filter box, exhaust header, catalytic converter, silencer	Battery pack and BMS	2, 3
Ignition and electrical	Fires the charge at the right crank angle and supplies all loads	Pickup coil, ECU or CDI, ignition coil, spark plug, alternator, regulator/rectifier, battery, starter, lighting	Traction pack, DC-DC converter to 12 V, VCU, CAN bus	3, 5
Transmission	Matches engine speed and torque to road speed and load	Primary drive, clutch, gearbox, chain, belt or shaft; CVT on scooters	Usually a single fixed reduction	2, 4
Chassis	Carries loads, steers, absorbs road inputs, transmits traction and braking	Frame, steering head, front fork, swingarm, rear shock absorbers, wheels, tyres, brakes	Same; battery often structural	4
Controls and instruments	Let the rider command and monitor the machine	Throttle, levers, gear lever, brake pedal, switch clusters, instruments	Throttle, regen control, ride modes, state-of-charge display	1, 3

Many faults sit at system boundaries: a loose engine mounting bolt on a stressed-engine frame causes vibration resembling wheel imbalance, and a failing regulator/rectifier starves the fuel pump and injector and presents as a fuelling fault.

How energy flows from tank or battery to tyre

Petrol stores about **43 MJ/kg (32 MJ/L)**, so the 11.8 L tank of the K-Light 125 holds about 380 MJ, or 105 kWh. A small air-cooled four-stroke converts at best about 28–32 % of this into crankshaft work, and nearer 15–22 % in stop-start riding, where pumping losses at part throttle are high; the rest leaves as heat in the exhaust and through the fins and oil. The **primary drive** (about 98 % efficient), the **gearbox** (about 97–98 % per meshing gear pair, two pairs per ratio) and the **chain** (95–98 % when clean, lubricated and correctly tensioned, much less when dry or rusted) give an overall transmission efficiency of 85–92 %, and the tyre loses a little more in rolling resistance and slip.

$$\eta_{total} = \eta_{engine} \times \eta_{primary} \times \eta_{gearbox} \times \eta_{chain} \times \eta_{tyre}$$

$$\eta_{total} \approx 0.25 \times 0.98 \times 0.96 \times 0.96 \times 0.97 \approx 0.22$$

where η_engine is brake thermal efficiency averaged over a riding cycle; roughly a fifth of the fuel energy reaches the road as propulsive work.

An electric drive replaces the first factor with battery discharge (95–98 %), inverter (95–98 %), permanent-magnet motor (90–95 %) and reduction drive (95–98 %), giving **80–88 % battery to wheel**, and regenerative braking returns part of the kinetic energy. The penalty is energy density: a lithium-ion pack stores about **0.12–0.20 kWh/kg** including housing and BMS against about 12 kWh/kg for petrol, so even with a fourfold efficiency advantage an electric motorcycle carries several times more energy-storage mass per kilometre of range, which is why electric two-wheelers succeeded first in short urban trips and why swapping suits high-mileage taxi work. All propulsive force finally acts at the rear tyre **contact patch**, roughly 20–40 cm² on a commuter tyre, whose friction limits every acceleration, cornering and braking force (Chapter 1.4).

REVIEW QUESTIONS

1. Name the four inventions that Falco identifies as preconditions for a practical motorcycle, with approximate dates.
2. Why was the Hildebrand & Wolfmüller layout, with connecting rods acting directly on the rear wheel, a technical dead end?
3. What did the 1901 New Werner change, and why did that change improve handling?
4. Explain, in terms of the scavenging process, why a carburetted two-stroke emits far more unburnt hydrocarbons than a four-stroke.
5. Why does meeting Euro 5 or BS-VI limits in practice require electronic fuel injection with an oxygen sensor?
6. State the EU and Indian braking requirements for new motorcycles above 125 cc and for the 125 cc class.
7. A rider reports that the headlight and the engine's idle became erratic at the same time. Which system boundary would you suspect first, and why?
8. Calculate the chemical energy in a full 11.8 L tank of petrol, in MJ and kWh, taking 32 MJ/L.
9. Using the efficiency chain in this chapter, how much of that energy reaches the road as propulsive work?
0. An electric motorcycle has a 4 kWh pack and 85 % battery-to-wheel efficiency. How much propulsive work is available, and what mass of petrol, used at 22 % overall efficiency, gives the same work?
1. Give two operational reasons why battery swapping suits motorcycle taxi fleets in East Africa.

ANSWERS

1. A compact engine (practical petrol engines from about 1885), the pneumatic tyre (Dunlop 1888, Michelin 1895), the bush roller chain (Renold 1880) and a suitable frame geometry (Starley safety bicycle 1886).
2. With no flywheel, clutch or gearbox the engine could not idle with the machine stationary or pull away smoothly, torque reached the wheel in large pulses, and engine speed could not be matched to road speed.
3. It moved the engine from above the front wheel to a low position between the wheels, lowering the centre of mass, loading the driven rear wheel and reducing front-wheel slides, while leaving room for the tank above.
4. Fresh charge enters through the transfer ports while the exhaust port is still open, so part of the fuel–air–oil mixture short-circuits straight into the exhaust, and the oil mixed with the fuel is burnt, partly incompletely. A four-stroke, with separate strokes and a wet sump, largely avoids both.
5. A three-way catalyst converts HC, CO and NOx together only in a narrow window around λ = 1. Holding that window at all loads and temperatures requires measuring exhaust oxygen and correcting fuel quantity every few cycles, which an ECU-controlled injector can do and a fixed-jet carburettor cannot.

6. EU: ABS above 125 cc (new types 2016, all new registrations 2017), ABS or CBS in the 125 cc class (L3e-A1). India: ABS above 125 cc and CBS at or below 125 cc, new models from April 2018 and all models from April 2019.
7. The charging system (regulator/rectifier, battery, earth connections), because both loads share the supply voltage and on an EFI machine an unstable supply also disturbs the fuel pump and injector.
8. 11.8 × 32 = 377.6 MJ; 377.6 / 3.6 = 104.9 kWh.
9. 104.9 × 0.22 ≈ 23 kWh (about 83 MJ).
10. 4 × 0.85 = 3.4 kWh = 12.24 MJ. Fuel energy needed: 12.24 / 0.22 = 55.6 MJ, and 55.6 / 43 ≈ 1.3 kg of petrol (about 1.8 L).
11. Any two of: a swap takes one to two minutes, so the vehicle keeps earning; the rider pays per swap instead of financing a battery that can be a third or more of the vehicle cost; the operator manages battery health and charging centrally; stations need only modest grid capacity spread over the day.

CHAPTER 1.2

Types and configurations

LEARNING OBJECTIVES

- → Classify a two-wheeler by use category and by its legal class under EU Regulation 168/2013, and relate that class to the licence needed to ride it.
- → Compare single, parallel twin, V-twin, boxer, triple and inline-four engines in terms of firing interval, balance and typical application.
- → Compare four-stroke, two-stroke and electric power units on specific power, efficiency, emissions, maintenance and cost.
- → Identify the main frame types and explain why each suits its category.

Categories by use

Pedelecs and e-bikes. A **pedelec** is a bicycle whose motor assists only while the rider pedals; in the EU one with no more than **250 W** continuous rated power and assistance ending at **25 km/h** is legally a bicycle, tested to EN 15194, while 45 km/h "speed pedelecs" are approved as L1e-B mopeds.

Mopeds. Mopeds are limited to **45 km/h** with up to 50 cc or 4 kW electric; many are scooters, some small geared motorcycles.



FIGURE 1.2 An electric scrambler: the battery pack fills the space of tank and engine, a mid-mounted motor drives the rear wheel, and the controller and DC-DC converter sit under the seat.

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FIGURE 1.4 A classic air-cooled four-stroke roadster with twin shocks and wire wheels, one of the three reference machines modelled for this course.

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FIGURE 1.3 A two-stroke motocross machine with perimeter frame, USD fork, linkage monoshock, expansion chamber and knobby tyres.

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Step-throughs and underbones. The Super Cub and its many derivatives have a low pressed-steel or tubular spine (the **underbone**) with a near-horizontal 50–125 cc four-stroke single beneath it, 17-inch wheels, a semi-automatic gearbox with centrifugal clutch and leg shields, so riders mount without lifting a leg over a tank and can carry heavy loads on a rack.

Scooters. Scooters have 10–14 inch wheels, a flat floorboard and enclosing bodywork, and in modern form a **unit-swing engine**: engine, **continuously variable transmission (CVT)** with a rubber V-belt between two variable pulleys, and rear wheel form one assembly that pivots on the frame as the swingarm, so the rider only twists the throttle. The Honda PCX (125–160 cc) is typical, and the heavy pivoting assembly gives a high **unsprung mass**, the main handling compromise of the layout.

Commuter and standard motorcycles. The commuter class (Honda CG125, Bajaj Boxer, Hero Splendor, K-Light 125) uses an air-cooled two-valve 100–150 cc single, a four- or five-speed gearbox with manual wet clutch, chain drive, a tubular steel frame, a telescopic fork and twin rear shocks. It dominates world sales and the taxi trade because it is cheap, uses 1.5–2.5 L/100 km and can be repaired with hand tools; larger standards or naked bikes (300–1000 cc) keep the upright position with more power.

Sport, touring, adventure and cruiser. Sport bikes place the rider forward over a high-revving engine (typically a 600 cc or 1000 cc four, triple or V-twin) in an aluminium twin-spar frame, with steep steering geometry, adjustable suspension, four-piston radial calipers and a full fairing. Touring machines prioritise load, comfort, range and weather protection, often with shaft drive; adventure bikes add long-travel suspension, a 19- or 21-inch front wheel and high ground clearance for unpaved roads. Cruisers have a low seat, forward footpegs, a long, raked-out front end and usually a slow-revving V-twin tuned for low-speed torque.

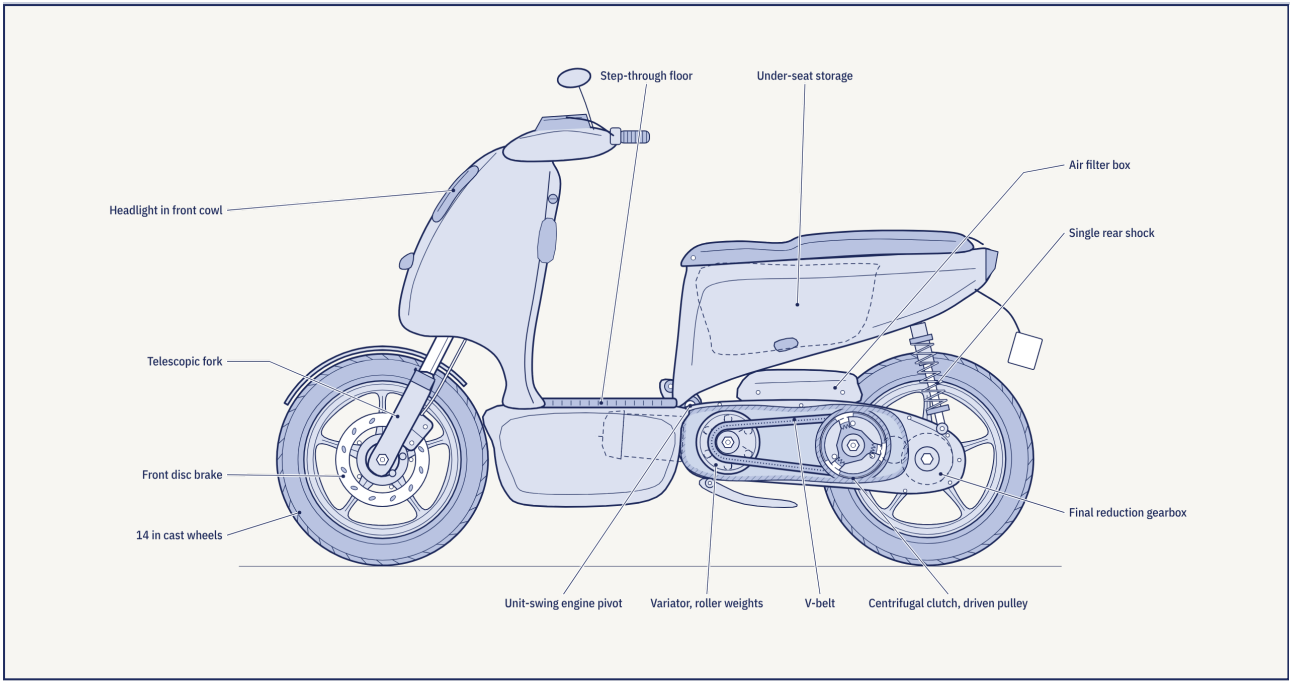


FIGURE 1.5 Automatic scooter with the CVT cover cut away, showing the unit-swing engine, variator, V-belt and driven pulley.

Off-road: motocross, enduro and trials. Motocross bikes are closed-circuit competition machines: about 90–105 kg for a 125 cc two-stroke such as the Yamaha YZ125, about 300 mm of suspension travel, 21-inch front and 19-inch rear knobby tyres and no lights, with a 125 cc two-stroke or a 250/450 cc four-stroke. Enduro bikes add lights, quieter exhausts and wider gear ratios for road-legal events; trials bikes have almost no seat, very low gearing and soft low-pressure tyres for climbing obstacles at walking pace.

Electric motorcycles. These range from 2–5 kW hub-motor commuters through 7–15 kW mid-drive machines such as the Roam Air to 80–110 kW performance machines from Zero and Energica. A **mid-drive** places a permanent-magnet synchronous motor (PMSM) in the frame and drives the rear wheel by belt or chain, keeping unsprung mass low, whereas a **hub motor** is simpler and cheaper but adds several kilograms to the wheel; the 2–15 kWh pack occupies the space of the tank and engine.

Regulatory classes and licences

The EU classifies two- and three-wheeled vehicles and quadricycles as **L-category** under Regulation (EU) No 168/2013, which also sets the emission stage (Euro 5 from 2020, with Euro 5+ durability and diagnostic requirements phased in from 2024–2025), definitions shared by many UNECE countries.

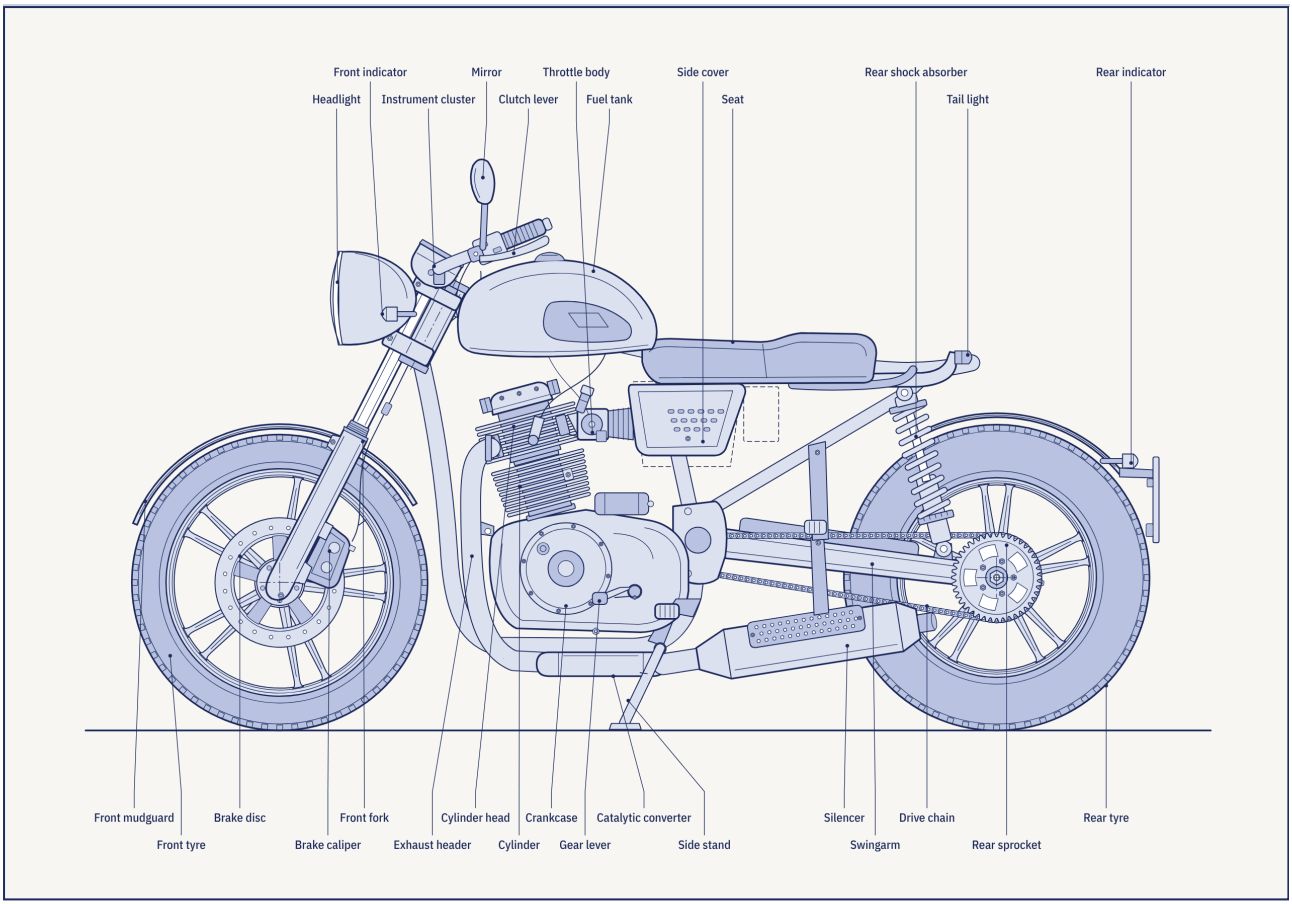


FIGURE 1.6 Four-stroke standard road motorcycle with an air-cooled single-cylinder engine, left side elevation.

Category	Description	Main limits
L1e-A	Powered cycle	Assistance to 25 km/h, up to 1 kW (pedelecs of 250 W or less are excluded)
L1e-B	Two-wheel moped	Up to 45 km/h; 50 cc spark ignition or 4 kW electric
L2e	Three-wheel moped	Moped limits on three wheels
L3e-A1	Low-performance motorcycle	Up to **125 cc, 11 kW and 0.1 kW/kg**
L3e-A2	Medium-performance motorcycle	Up to **35 kW and 0.2 kW/kg**, not derived from a vehicle of more than double the power
L3e-A3	High-performance motorcycle	Any L3e above A2
L4e	Motorcycle with sidecar	L3e base vehicle plus one sidecar
L5e	Powered tricycle	Three wheels, up to 1,000 kg in running order
L6e	Light quadricycle	Up to 45 km/h, 425 kg, 4 kW (6 kW enclosed)
L7e	Heavy quadricycle	Up to 450 kg (passenger) or 600 kg (goods), 15 kW on road

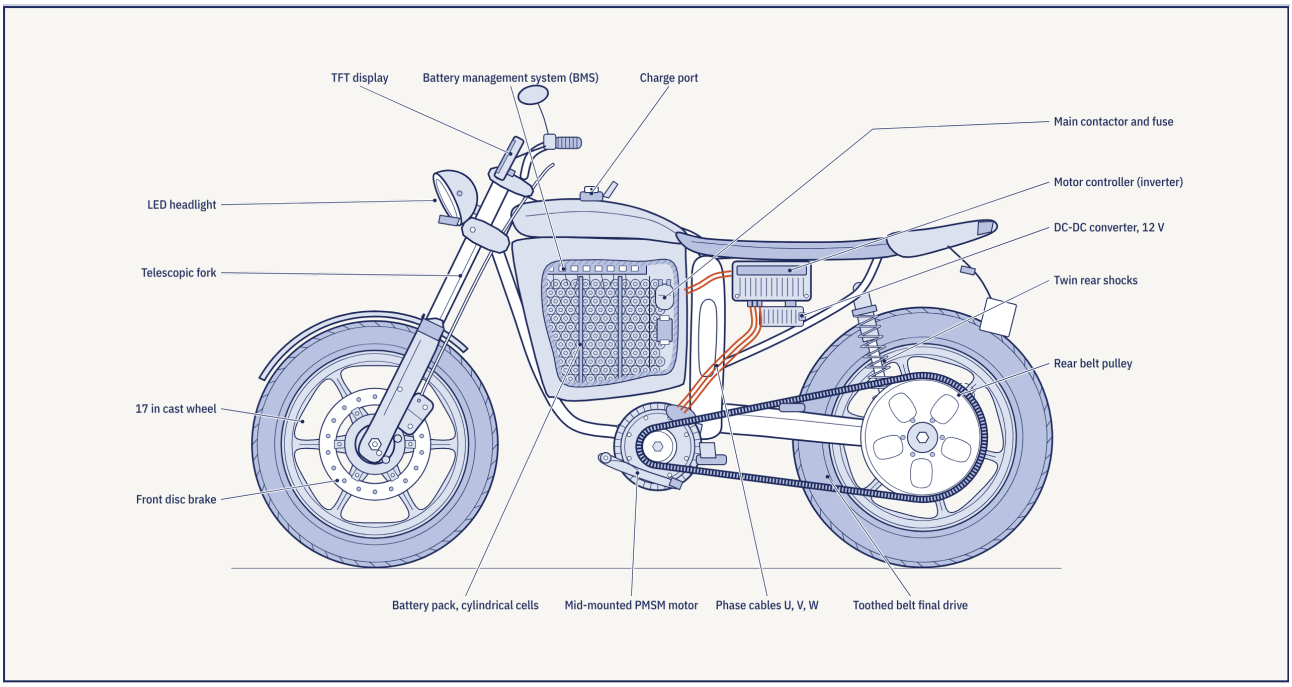


FIGURE 1.8 Electric motorcycle with the battery pack, mid-drive motor and controller shown in hidden lines inside the frame.

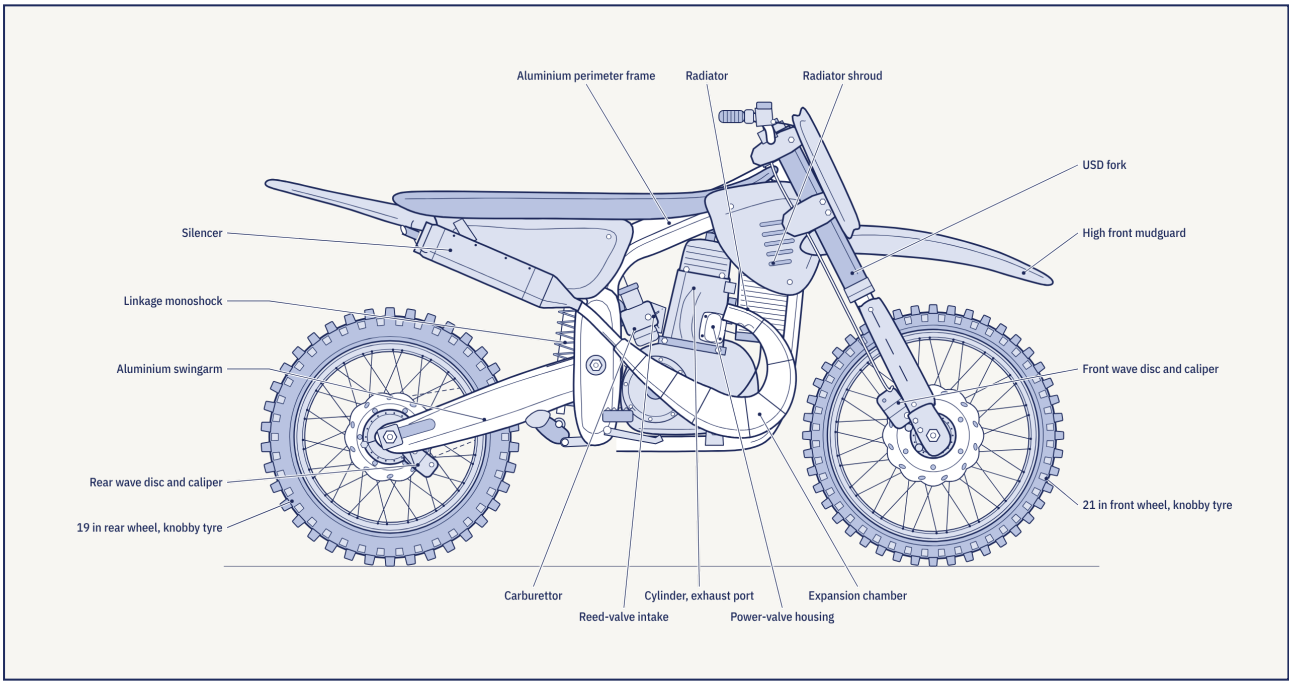


FIGURE 1.7 Two-stroke motocross motorcycle, right side elevation, showing the expansion chamber and long-travel suspension.

Directive 2006/126/EC sets matching licences: **AM** for mopeds (minimum age 14–16 nationally), **A1** for L3e-A1 machines (from 16), **A2** up to 35 kW and 0.2 kW/kg (from 18), and **A** unrestricted (from 24, or 20 after two years on A2). The K-Light 125, at 124 cc, 7.8 kW and 145 kg kerb mass (0.054 kW/kg), is an L3e-A1 machine for an A1 licence. India's Central Motor Vehicles Rules use L1 (up to 50 cc and 45 km/h) and L2 categories, with low-speed e-scooters of 250 W and 25 km/h or less exempt from registration; Kenya's 2016 licence rules separate mopeds, motorcycles and commercial motorcycle taxis, and its boda boda fleet is mostly 100–150 cc commuter singles plus a growing number of electric machines.

Engine configurations and balance

The reciprocating piston and small end produce a **primary inertia force** at crankshaft frequency and a smaller **secondary force** at twice crankshaft frequency, caused by connecting-rod angularity. Counterweights on a single can only move part of the primary force from the vertical to the horizontal plane, so larger singles add a **balance shaft**, and the cylinder arrangement of multis is chosen partly to cancel these forces.

Layout	Firing interval (four-stroke)	Balance	Character and use
Single	720°	Primary partly countered by counterweights; balancer common above about 200 cc	Narrow, light, cheap, easy to air-cool; commuters, off-road
Parallel twin, 360°	360°, 360°	Pistons move together; shakes like a large single	Even firing, simple; classic British twins
Parallel twin, 180°	180°, 540°	Primary cancels; rocking couple remains	Higher revving 250–500 cc twins
Parallel twin, 270°	270°, 450°	Partly cancelled; couple balanced by shaft	V-twin-like firing in a narrow package; mid-size bikes
V-twin, 90°	270°, 450°	Perfect primary balance with shared crankpin	Narrow, long; cruisers, Ducati
Boxer twin	360°, 360°	Primary cancels; small couple from offset	Low centre of mass, cylinders in airflow; BMW
Inline triple, 120°	240°	Primary and secondary forces balanced; couple usually shaft-balanced	Torque of a twin, revs of a four
Inline four, 180°	180°	Primary balanced; secondary force unbalanced	Smooth, high revving, wide; sport and touring

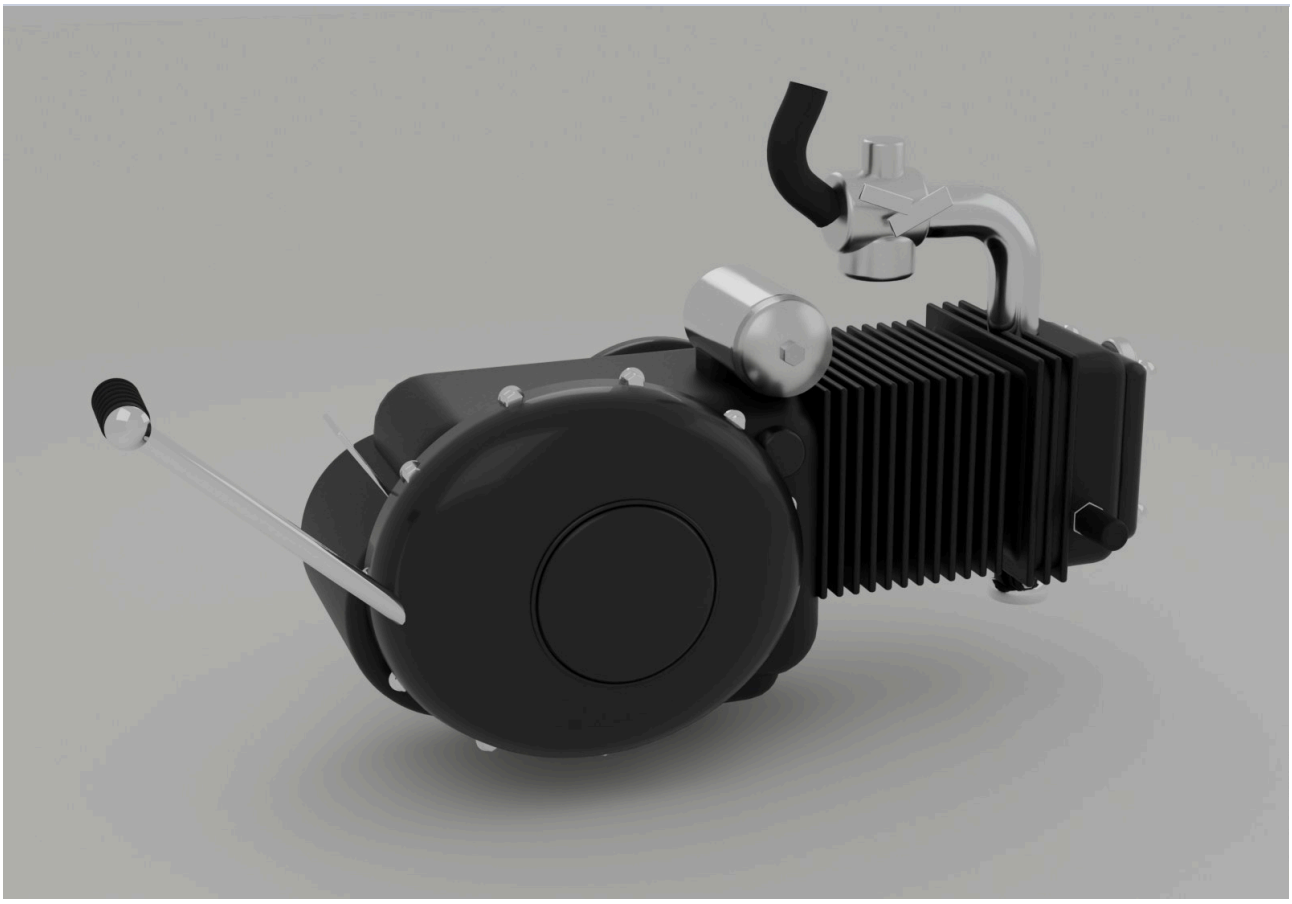


FIGURE 1.9 A horizontal single-cylinder engine of the type fitted to step-throughs and commuter motorcycles across Asia and Africa: finned cylinder and head pointing forward, carburettor and intake on top, electric starter behind the cylinder, the large clutch cover on the right and the kickstart lever at the rear.

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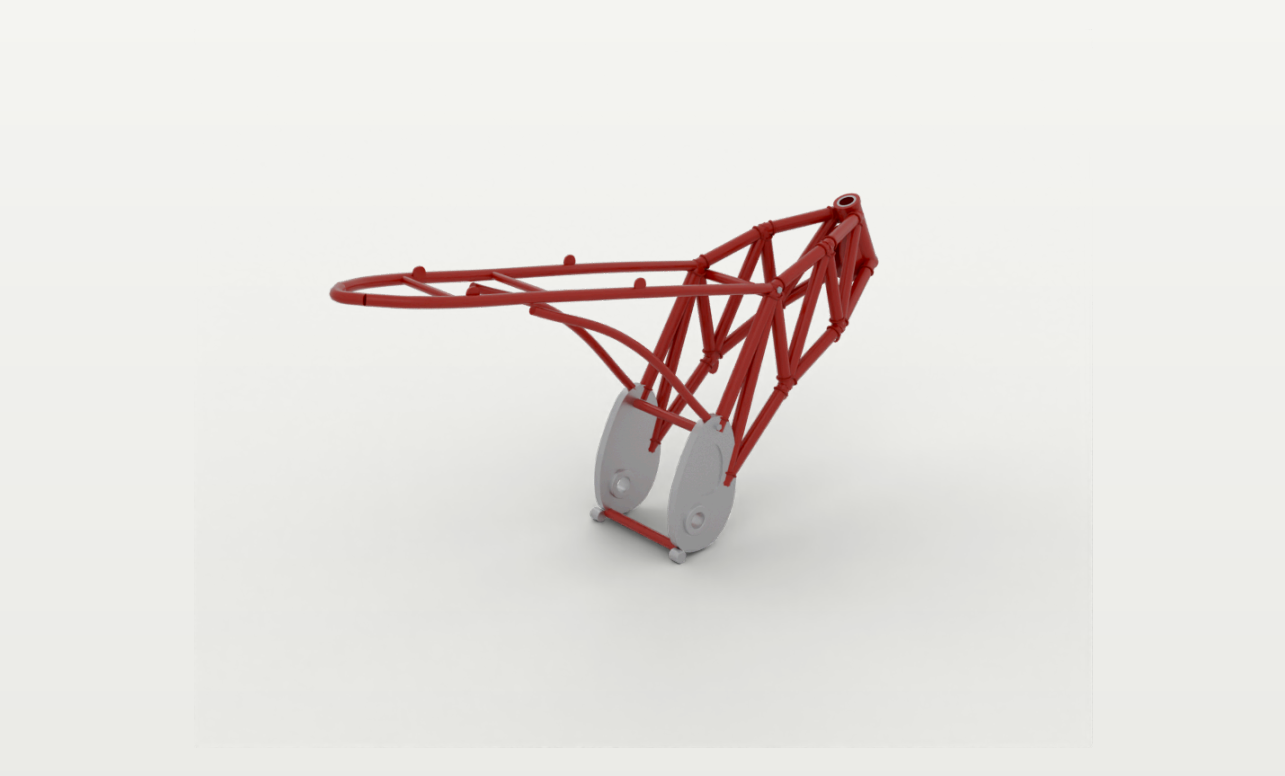
Air versus liquid cooling. About a third of the fuel energy leaves through the cylinder walls and head. An **air-cooled** engine sheds it from finned aluminium castings with no pump, radiator or coolant to fail, which suits the K-Light 125 and almost every commuter; because its temperature varies more with speed and load, clearances must be larger and compression lower (**9:1** on the K-Light 125). **Liquid cooling** holds the cylinder and head at about 80–100 °C, allowing tighter clearances, 11–13:1 compression and higher specific output at the cost of a pump, radiator, thermostat and hoses; oil-air cooling is an intermediate solution.

Property	Four-stroke	Two-stroke	Electric
Power delivery	One power stroke per two revolutions	One per revolution	Continuous torque from zero speed
Specific power	50–70 kW/L commuter; 130–170 kW/L sport	100–200 kW/L (YZ125 class about 25–30 kW)	Motor 2–5 kW/kg; limited by battery mass and heat
Peak efficiency (source to shaft)	28–35 %	20–28 % carburetted	85–92 %
Tailpipe emissions	Low with EFI and three-way catalyst	High HC and smoke unless direct injection	None at the vehicle
Routine maintenance	Oil and filter, valve clearance, spark plug, air filter, cam chain	Frequent piston and ring renewal, exhaust decarbonising, oil supply	Brakes, tyres, chain or belt, bearings, battery health, connectors

Property	Four-stroke	Two-stroke	Electric
Purchase and running cost	Moderate and moderate	Low purchase; high fuel and wear	High purchase (battery 30–50 % of cost) unless swapped; low running cost

Frame types and where they are used

The frame locates steering head, swingarm pivot and engine relative to each other, and its **torsional stiffness** between steering head and swingarm pivot affects handling more than any other property.



`FIGURE 1.10` A bare tubular steel trellis frame: triangulated tubes from steering head to swingarm pivot plates, with the bolted rear subframe.

Render: Transitions Lab, CC BY-SA 4.0

Frame type	Construction	Strengths	Typical use
Backbone and underbone	Single large tube or pressed-steel spine, engine hung below	Cheap to mass produce; step-through mounting	Super Cub derivatives, small commuters
Single cradle	One downtube splitting under the engine, top tube and seat rails	Simple, tolerant of rough use, easy engine removal	Commuter singles (K-Light 125), trail bikes
Double cradle	Two downtubes and lower rails around the engine	Stiffer, carries heavier engines	Classic standards, cruisers
Perimeter (twin spar)	Two large beams from steering head around the engine to the pivot	Highest torsional stiffness for its mass	Sport bikes, many modern mid-size machines
Trellis	Triangulated short straight steel tubes, engine often stressed	Stiff, light, tunable by tube size	Ducati, KTM
Monocoque or stressed engine	Engine, battery case or box structure carries loads; subframes bolt on	Fewest parts and least mass	Scooters (pressed steel), racing and electric bikes

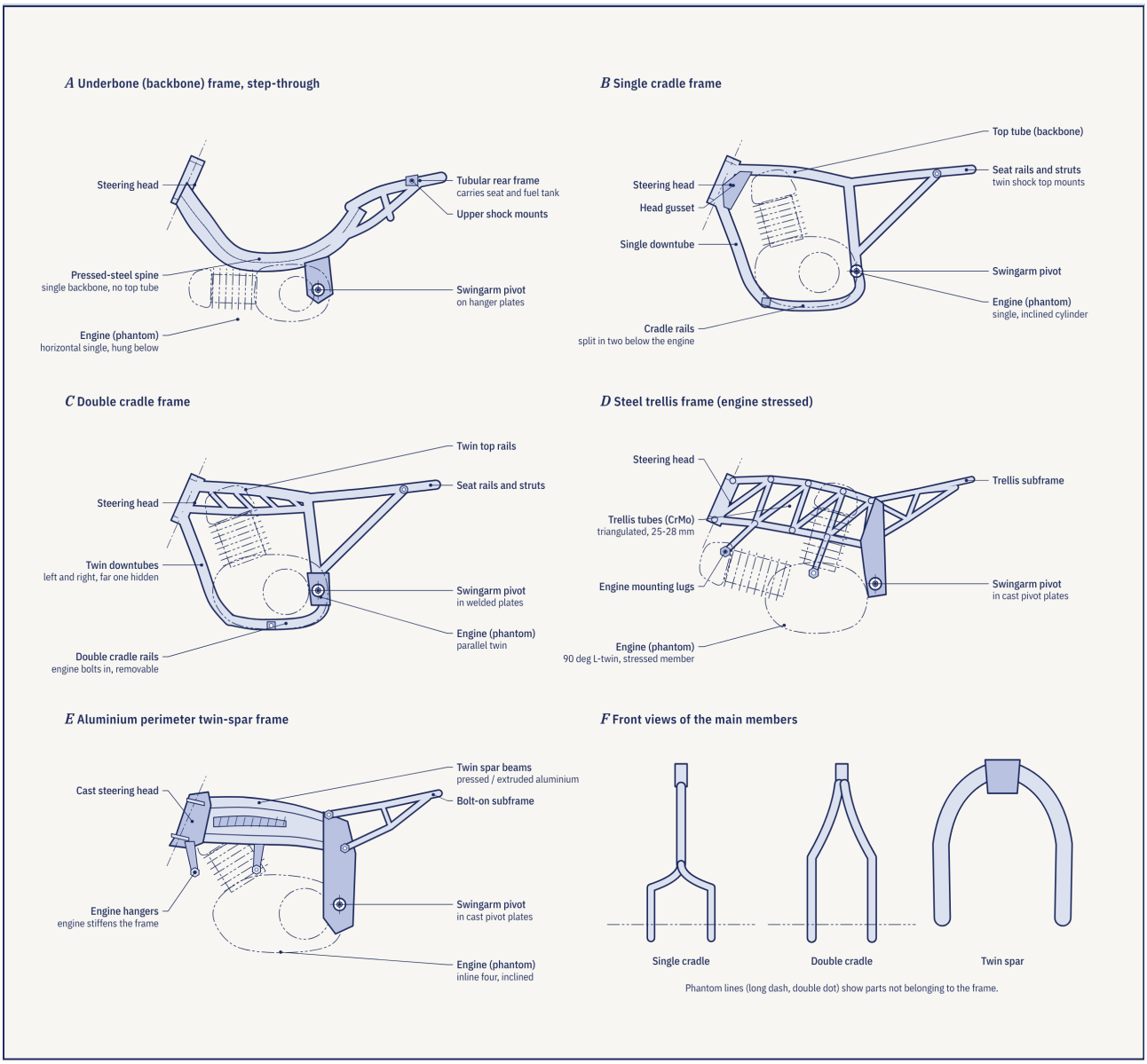


FIGURE 1.11 Frame types compared: underbone, single cradle, double cradle, steel trellis and aluminium twin-spar perimeter, each with steering head, swingarm pivot and engine position.

REVIEW QUESTIONS

1. State the limits that separate a pedelec from an L1e-B moped in the EU.
2. Calculate the power-to-mass ratio of the K-Light 125 and state its L3e subcategory and licence.
3. A 300 cc twin makes 30 kW and weighs 165 kg. Is it within the A2 limits? Show your working.
4. Why does a unit-swing scooter engine increase unsprung mass, and what is the effect on ride and grip?
5. Describe the firing intervals of 360°, 180° and 270° parallel twins and explain why the 270° twin sounds like a 90° V-twin.
6. Why does a flat-plane inline four still vibrate, and at what frequency relative to engine speed?
7. Give three reasons why the K-Light 125 is air-cooled rather than liquid-cooled.
8. Why can a two-stroke produce roughly twice the specific power of a four-stroke, and why is it not more efficient?

9. Name the frame type you would expect on (a) a Super Cub, (b) a CG125-type commuter, (c) a 600 cc sport bike, and explain why.

0. A boda boda operator wants the lowest cost per kilometre over five years at 120 km/day. List the factors to compare between a 125 cc four-stroke and an electric motorcycle on swapped batteries.

ANSWERS

1. A pedelec assists only while pedalling, up to 250 W continuous, and stops assisting at 25 km/h. More power, a throttle working without pedalling or assistance above 25 km/h (up to 45 km/h) makes it an L1e-B moped.
2. 7.8 / 145 = 0.054 kW/kg. With 124 cc and 7.8 kW it meets all L3e-A1 limits (125 cc, 11 kW, 0.1 kW/kg) and needs an A1 licence.
3. 30 kW is below 35 kW, and 30 / 165 = 0.18 kW/kg is below 0.2 kW/kg, so it qualifies for A2 provided it is not derived from a version of more than 70 kW.
4. Engine, CVT and wheel pivot together, so 20–35 kg moves with the wheel instead of being isolated by the shock. The wheel follows bumps less closely, contact-patch load fluctuates more, ride is harsher and grip on broken surfaces falls.
5. 360°: pistons rise together, firing every 360°. 180°: pistons opposite, firing at 180° then 540°. 270°: firing at 270° then 450°, the same pattern as a 90° V-twin with a shared crankpin, so pulse spacing and torque delivery match.
6. Primary forces cancel, but the secondary force acts in the same direction for all four pistons, giving vertical shaking at twice crankshaft frequency; large fours use a balance shaft at twice engine speed or rubber mounts.
7. Any three of: 7.8 kW of heat can be shed by fins; no pump, radiator, hoses or coolant reduces cost, mass and failure points; it is easier to repair where parts are scarce; the 9:1 compression and two-valve head do not need tight temperature control.
8. It fires every revolution instead of every second one. Efficiency is no better (often worse) because some charge escapes during scavenging, ports shorten the effective compression and expansion strokes, and residual exhaust dilutes the charge.
9. (a) Underbone: step-through mounting and low engine position at minimum cost. (b) Single cradle: cheap steel tube, engine supported below, easy removal. (c) Aluminium twin-spar perimeter: the stiffest direct path between steering head and pivot for the least mass under high cornering and braking loads.
10. Purchase and finance cost; energy cost per km (about 2 L/100 km of fuel against swap fees); service and parts per km; battery subscription terms; daily downtime and station distance; vehicle life and resale value; payload and gradient performance on the routes; grid reliability; tax and import duty.

CHAPTER 1.3

Anatomy and controls

LEARNING OBJECTIVES

- → Identify the 30 major assemblies of a standard road motorcycle by the names used in the exploded diagram and the online explorer.
- → State the function, main sub-components, usual materials and typical failure of each assembly.
- → Describe the standard layout of the primary controls and the function of each switch.
- → Carry out and explain the sequence of control inputs for an upshift, a downshift and an emergency stop.

The 30 assemblies of a road motorcycle

The exploded diagram separates a fuel-injected single-cylinder road motorcycle of the K-Light 125 type into 30 assemblies, numbered as in the figure and named as on the explorer; later modules treat each in detail.

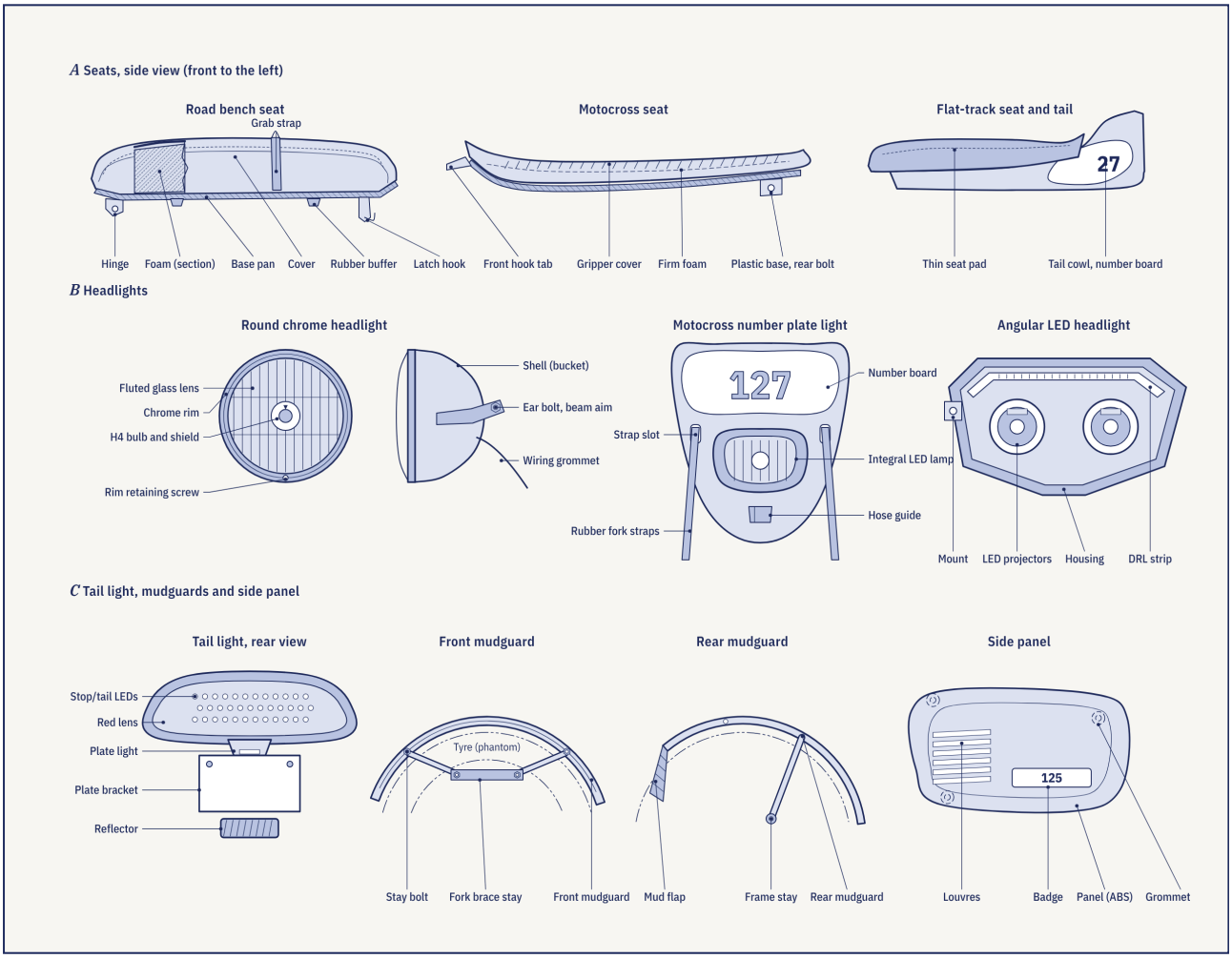


FIGURE 1.12 Body parts by type: bench, motocross and flat-tracker seats; round chrome, number-plate and LED headlights; tail light, mudguards and side panel.

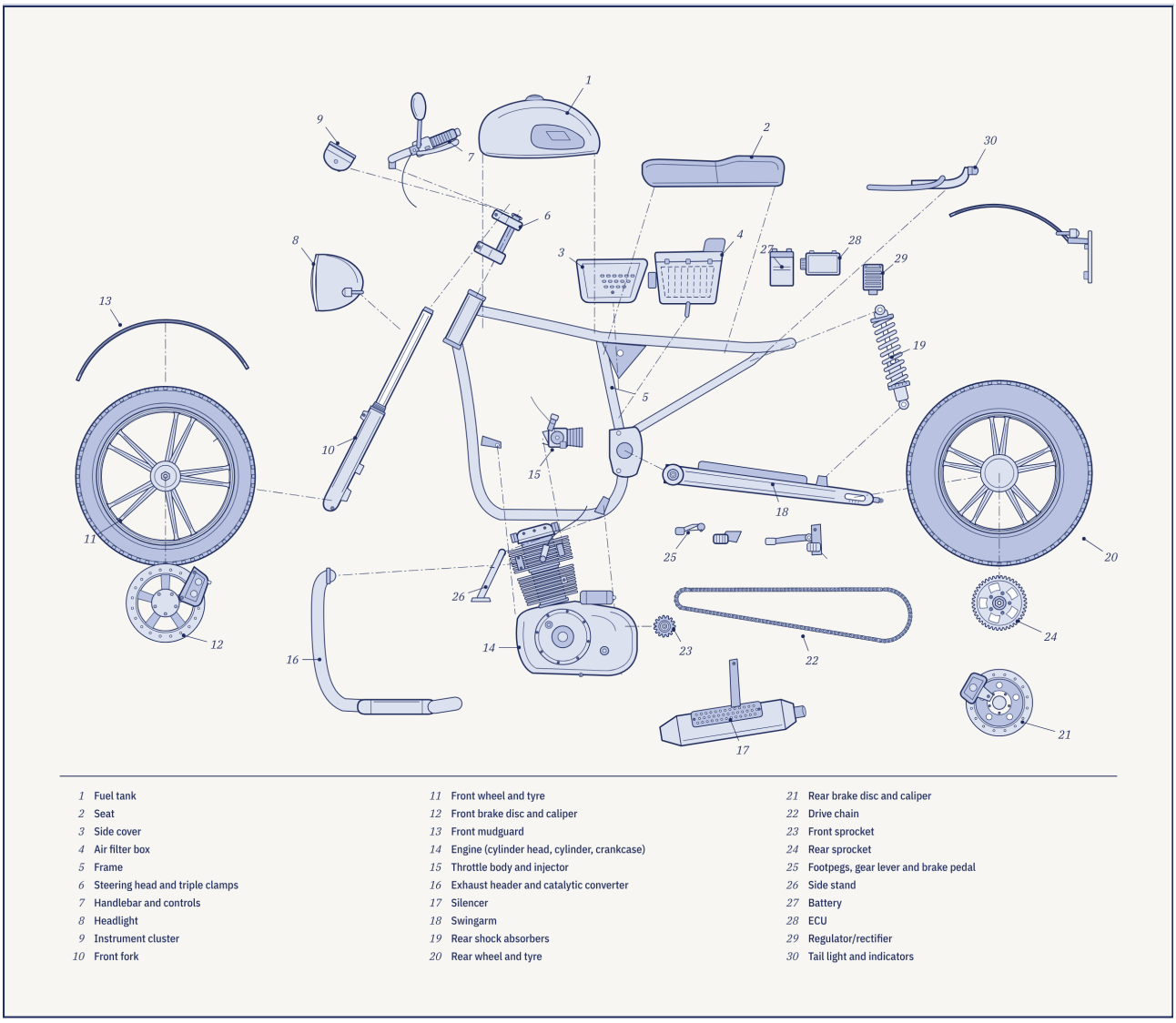


FIGURE 1.13 Exploded diagram of the standard road motorcycle with numbered callouts 1 to 30 and a parts legend.

No.	Part	Function	Sub-components and materials	Typical failure
1	Fuel tank	Stores fuel; houses the pump on EFI models	Pressed steel or HDPE shell, vented cap, in-tank pump, level sender	Rust blocking the pump strainer; blocked vent starving the engine
2	Seat	Supports rider and passenger; covers battery and tools	Polypropylene or steel base, foam, vinyl cover, lock catch	Torn cover soaking the foam; broken catch
3	Side cover	Encloses battery, electrics and filter box	ABS or polypropylene moulding, rubber grommets	Broken tabs; lost grommets causing rattles
4	Air filter box	Filters and silences intake air	Polypropylene housing, sponge element on the K-Light 125, intake duct, crankcase breather	Clogged element (rich running, power loss); split duct admitting dirt
5	Frame	Carries loads; locates steering head, engine and swingarm pivot	Welded steel tube (single cradle on the K-Light 125), engine mounts, VIN stamp	Weld cracks near the steering head or mounts; crash damage

No.	Part	Function	Sub-components and materials	Typical failure
6	Steering head and triple clamps	Hold the fork and let it rotate about the steering axis	Upper and lower clamps, stem, cup-and-cone or taper roller bearings, adjusting nuts	Notched bearings; wrong preload causing wobble or heavy steering
7	Handlebar and controls	Give steering leverage and carry the hand controls	Steel or aluminium bar, grips, levers, switch housings, cables, master cylinder	Bent bar; dry or frayed cables; cracked lever
8	Headlight	Lights the road and makes the bike visible	Reflector, lens, LED module or H4 halogen bulb, beam adjuster	Failed bulb or driver; water ingress; misaim
9	Instrument cluster	Shows speed, revs, fuel, gear and warning lamps	LCD or analogue gauges, speed sensor, LEDs	Water ingress; broken sensor wire
10	Front fork	Steers, suspends and damps the front wheel	Chromed steel stanchions, aluminium sliders, springs, damper rods, oil, seals, bushes	Leaking seals from grit or pitted chrome; bent stanchions
11	Front wheel and tyre	Front support, steering and braking grip	Cast aluminium 1.85 × 17 rim, 90/90-17 tubeless tyre, axle, sealed bearings	Low pressure, worn or cut tyre; rim runout over **2.0 mm**; worn bearings
12	Front brake disc and caliper	Converts kinetic energy to heat	280 mm stainless disc, **4.0 mm** thick (limit **3.0 mm**), caliper, pistons, seals, pads	Pads below **3 mm**; runout over **0.15 mm**; sticking pistons
13	Front mudguard	Stops spray and stones	Polypropylene moulding, fork brackets	Cracked mounts
14	Engine (cylinder head, cylinder, crankcase)	Produces crankshaft torque; houses clutch and gearbox	Aluminium head with valves, cam and rockers; cylinder with iron liner; split crankcase with crank, balancer, clutch, gears	Worn rings and bore; valve clearance drift; cam chain tensioner wear; gasket leaks
15	Throttle body and injector	Meters air and fuel under ECU control	Aluminium body, butterfly, TPS, idle air control, MAP and IAT sensor, injector	Carbon causing poor idle; clogged injector; faulty TPS
16	Exhaust header and catalytic converter	Carries exhaust and converts HC, CO and NOx	Steel header, oxygen sensor boss, metallic catalyst substrate with platinum-group coating	Cracked header; leaking port gasket; poisoned or broken catalyst
17	Silencer	Reduces noise	Steel shell, baffles, perforated tubes, fibre packing, heat shield	Internal corrosion; blown packing
18	Swingarm	Locates the rear wheel	Steel box or tube, pivot spindle, bushes or needle bearings, chain adjusters	Worn pivot bushes giving rear play
19	Rear shock absorbers	Support and damp the rear	Coil springs, hydraulic dampers, preload adjusters, bushes (twin shocks on the K-Light 125)	Oil leak and lost damping; worn bushes
20	Rear wheel and tyre	Carries most load; transmits drive	Cast rim, 130/90-15 tyre, sprocket carrier with cush drive rubbers, bearings	Squared-off tread; worn cush rubbers causing snatch
21	Rear brake disc and caliper	Rear braking; on CBS also part of the front	240 mm disc, single-piston sliding caliper, pads, master cylinder	Seized slide pins; uneven pad wear

No.	Part	Function	Sub-components and materials	Typical failure
22	Drive chain	Transmits torque between sprockets	Side plates, pins, bushings, rollers; O-ring or plain	Ten-link length over **127 mm**; slack outside **20–40 mm**; rust
23	Front sprocket	Drives the chain from the gearbox output	Hardened steel, splined, retaining plate	Hooked teeth from a worn chain
24	Rear sprocket	Turns the rear wheel	Steel, 41 teeth on the K-Light 125, bolted to the carrier	Tooth wear; loose nuts (**45–50 N·m**)
25	Footpegs, gear lever and brake pedal	Support the feet and carry the foot controls	Pegs, gear lever and linkage, pedal with return spring	Bent lever; worn pivot; weak spring
26	Side stand	Supports the parked bike	Steel leg, pivot bolt, return springs, side-stand switch	Weak spring; failed interlock switch
27	Battery	Powers starting, ECU, pump and lighting	12 V 6 Ah AGM (YTX7A-BS): lead plates, glass mat, sulphuric acid	Sulphation after deep discharge; hard starting
28	ECU	Sets injection and ignition timing; stores fault codes	Microcontroller, injector, coil and pump drivers, sealed housing	Corroded pins; damage from reversed polarity
29	Regulator/rectifier	Converts alternator AC to DC and limits voltage	Diode bridge, thyristor shunt regulator, finned heat sink	Overheating, then overcharging or no charge
30	Tail light and indicators	Signal position, braking and turning	LED or bulb units, lenses, flasher relay, brake light switches	Failed bulbs; misadjusted brake switch

EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy

Find the assemblies on the exploded diagram

Open the exploded motorcycle view on transitionslab.org/motorcycle-anatomy and click, in order, Drive chain, Front sprocket, Rear sprocket, Swingarm and Rear wheel and tyre, and write down the order in which drive torque passes through them. Then click Throttle body and injector, ECU, Battery and Regulator/rectifier and sketch the connections you expect between them before checking against Module 3.

The primary controls and how they are used

The layout of the **primary controls** on a manual-gearbox motorcycle has been standard since the 1970s, when US rule FMVSS 123 fixed it and other markets converged on it: the right hand works the **throttle grip** (twist towards the rider to open) and the **front brake lever**, the left hand the **clutch lever**, the left foot the **gear lever** and the right foot the **rear brake pedal**. Scooters with a CVT have no clutch or gear lever, so the left lever works the rear brake (on CBS scooters also part of the front).

The right switch cluster carries the start button, the **engine stop (kill) switch** and often the headlight switch; the left carries the dip/main beam switch, flasher, horn and the indicator switch, usually pushed in to cancel. The ignition switch and steering lock sit on the top yoke. The instruments show speed, odometer, fuel, neutral, indicator and main-beam warnings, and on EFI machines a **malfunction indicator lamp (MIL)** that lights briefly at key-on as a bulb check and stays lit when the ECU stores a fault. On the K-Light 125 the front brake lever **free play** is **10–20 mm** at the lever tip, the rear pedal free play **20–30 mm** and the throttle cable free play **3–5 mm** (K-Light 125 manual).

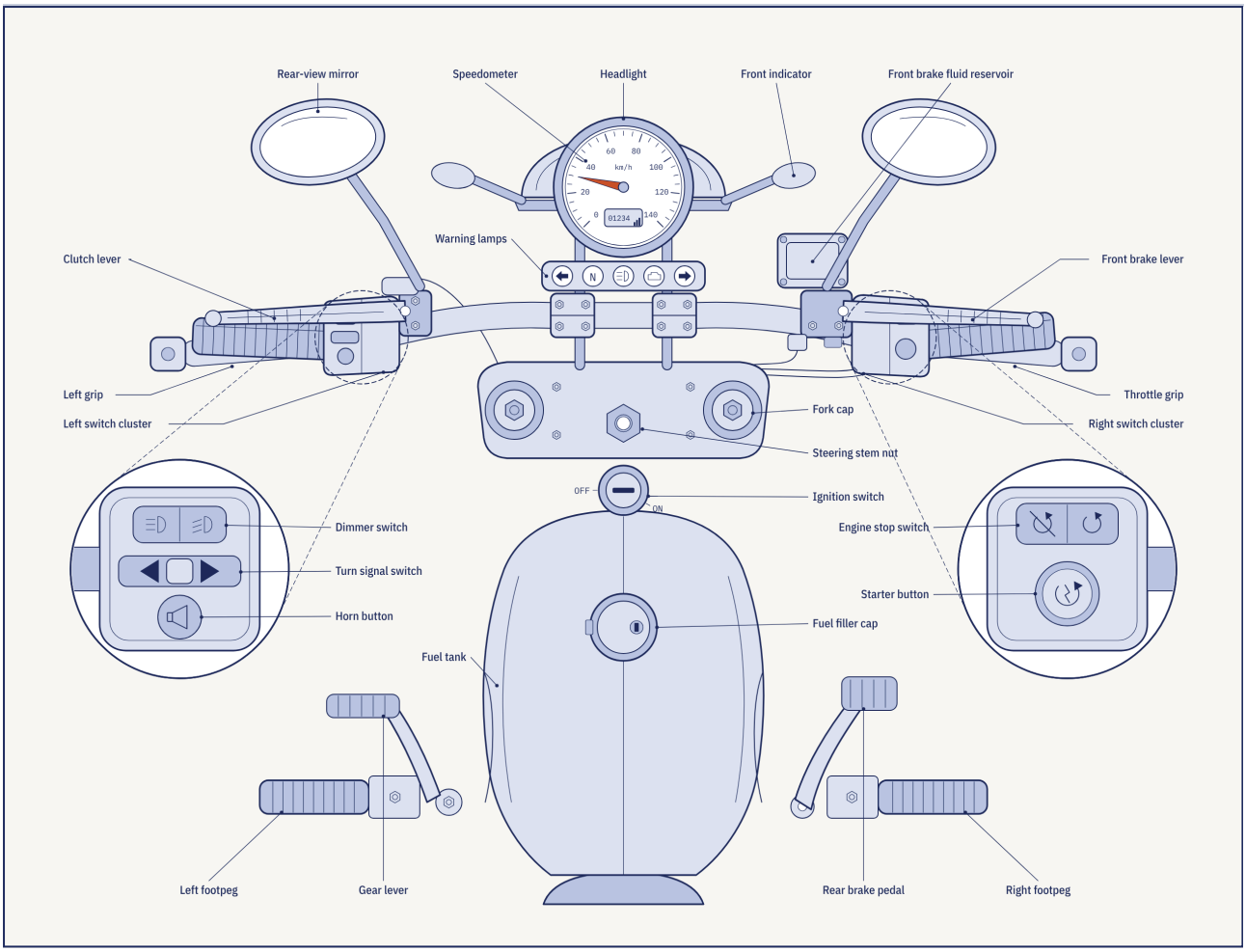


FIGURE 1.14 Handlebar and controls viewed from the rider's seat, with the left and right switch clusters called out.

Most road gearboxes use a **one-down, four-up** pattern: from neutral, pressing the lever down selects first and each lift selects the next gear, with neutral a half-lift between first and second. For an upshift, close the throttle, pull the clutch in briskly, lift the lever through its full travel and release the clutch while reopening the throttle; the throttle is closed because the **dogs** on the gear wheels disengage cleanly only when unloaded. For a downshift, pull in the clutch, press the lever down, blip the throttle to raise engine speed to match the lower gear and release the clutch smoothly, since an abrupt release at low engine speed can lock the rear wheel.

A stop from speed uses both brakes, with the front doing most of the work because load transfers forwards (Chapter 1.4). Close the throttle, squeeze the front lever progressively over about half a second so the fork compresses and tyre load builds before maximum force, apply the rear pedal with less force, pull the clutch in below about 15–20 km/h to avoid stalling, select first while stopping and put the left foot down. With ABS, full lever force can be held; without it the rider must modulate just below wheel lock, and CBS reduces the risk of a locked rear wheel by sending part of the pedal effort to the front caliper.

REVIEW QUESTIONS

1. Which numbered assemblies make up the final drive, and in what order does torque pass through them?
2. List the sensors and actuators that belong to the Throttle body and injector assembly.
3. A K-Light 125 front disc measures 3.1 mm thick with 0.18 mm runout. Is it serviceable?

4. A drive chain measures 128.5 mm over 10 links after stretching by hand. What do you do, and what else must be inspected?
5. Why must the engine be unloaded at the moment of an upshift?
6. Describe the one-down, four-up pattern and where neutral is found.
7. A rider reports that the battery boils and bulbs blow regularly. Which assembly is the likely cause, and what test confirms it?
8. The engine cuts out every time the side stand is lowered in gear. Is this a fault?
9. Why should the front brake be applied progressively, even with ABS?
0. A machine weaves at the rear under power over bumps. Which assemblies would you inspect first, and for what?



FIGURE 1.15 The handlebar assembly from the rider's seat: grips, throttle, clutch and brake levers with perches, switch cubes, twin clocks and mirrors.

Render: Transitions Lab, CC BY-SA 4.0

ANSWERS

1. Engine (14), Front sprocket (23), Drive chain (22), Rear sprocket (24), Rear wheel and tyre (20) through its cush drive, with the Swingarm (18) locating the axle and adjusters.
2. Throttle valve, throttle position sensor, idle air control valve, MAP and intake air temperature sensor, and the injector.
3. No. Thickness is above the 3.0 mm limit, but 0.18 mm exceeds the 0.15 mm runout limit; after confirming bearings, disc bolts and hub face are in order, replace the disc, normally with new pads.
4. 128.5 mm exceeds the 127 mm limit, so replace the chain, and inspect both sprockets for hooked teeth and normally replace them too, because mixing new and worn parts accelerates wear.

5. Loaded dogs are locked together by friction; unloading them lets the fork slide them apart with little force and engage the next gear cleanly, reducing dog and fork wear.
6. Down once from neutral for first; each lift selects second to fifth. Neutral is a half-lift from first or a half-press from second.
7. The Regulator/rectifier (29). Measure battery voltage at 5,000 rpm: the K-Light 125 should give 14.5 ± 0.5 V, and above about 15 V confirms a failed regulator.
8. No. The side-stand switch is an interlock that prevents riding away with the stand down.
9. It lets the fork compress and load transfer to the front tyre before maximum force arrives, so grip rises before it is demanded; a snatched lever exceeds the grip of the still lightly loaded tyre, and even with ABS the stop is longer and the chassis unsettled.
10. The Rear shock absorbers (19), for oil leaks and lost damping (the rear bouncing more than once when pushed down), and the Swingarm (18) pivot, for bush play when the wheel is levered sideways.

CHAPTER 1.4

Physics of riding

LEARNING OBJECTIVES

- → Convert between torque, power and engine speed, and calculate wheel torque and tractive force through a gear train.
- → Estimate rolling resistance, aerodynamic drag and gradient resistance and use them to predict top speed, acceleration and climbing ability.
- → Calculate load transfer under braking and acceleration and explain why the front brake does most of the work.
- → Explain the friction circle, the gyroscopic effect, countersteering and the lean angle needed for a given corner.

Force, torque and power

A force F acting at a radius r produces a **torque** T = F·r, measured in newton-metres (N·m). **Power** is the rate of doing work; for a rotating shaft it is torque multiplied by angular speed, with ω in radians per second, so engine speed in rev/min must be converted.

$$P = T \times \omega$$

$$\omega = 2\pi \times n / 60$$

$$T = P / \omega$$

where P is power in watts, T torque in N·m, ω angular speed in rad/s and n engine speed in rev/min. One kilowatt is 1,000 W; one metric horsepower (PS) is 0.7355 kW.

> ▤ REFERENCE DATA **K-Light 125 performance data (K-Light 125 manual)**
>
> Engine QJ157FMI, single cylinder, air-cooled, 56.5 × 49.5 mm, 124 cm³, compression ratio 9:1. Maximum power 7.8 kW at 9,000 rpm; maximum torque 8.9 N·m at 7,500 rpm; maximum speed 90 km/h. Kerb mass 145 kg (69 kg front, 76 kg rear); wheelbase 1,440 mm. Five-speed gearbox, chain drive, rear sprocket 41 teeth; tyres 90/90-17 front, 130/90-15 rear.

At maximum power, ω = 2π × 9,000 / 60 = 942.5 rad/s, so the torque at that speed is T = 7,800 / 942.5 = 8.28 N·m, lower than the 8.9 N·m peak. At the peak-torque speed of 7,500 rpm (785.4 rad/s) the power is 8.9 × 785.4 = 6.99 kW. Peak power occurs above peak torque because power keeps rising with speed until torque falls faster than speed rises, which happens once the valves and ports can no longer fill the cylinder in the shorter time per cycle.

Gearing and wheel torque

The transmission multiplies torque and divides speed by the **overall ratio** i, the product of the primary reduction, the selected gear ratio and the final drive ratio (rear teeth divided by front teeth). The K-Light 125 manual gives the 41-tooth rear sprocket but not the other ratios, so the example below assumes typical values for this class: primary 3.40, first gear 2.75, fifth gear 1.10, and a 15-tooth front sprocket (final drive 41/15 = 2.733).

```
i_1 = 3.40 × 2.75 × 2.733 = 25.56
i_5 = 3.40 × 1.10 × 2.733 = 10.22
T_wheel = T_engine × i × η_t
F_t = T_wheel / r_w
```

where η_t is transmission efficiency (taken as 0.90) and r_w the rolling radius of the rear tyre. A 130/90-15 tyre has a section height of 0.90 × 130 = 117 mm, so its unloaded diameter is 15 × 25.4 + 2 × 117 = 615 mm; under load the rolling radius is about 0.30 m. In first gear at peak torque, T_wheel = 8.9 × 25.56 × 0.90 = 205 N·m and the tractive force is F_t = 205 / 0.30 = 682 N.

Resistance to motion

Three forces oppose the tractive force on level and sloping roads:

```
F_roll = C_rr × m × g
F_aero = ½ × ρ × C_d × A × v²
F_grade = m × g × sin θ
```

where C_rr is the **rolling resistance coefficient** (0.015–0.025 for motorcycle tyres on asphalt at correct pressure, higher when under-inflated), m the total mass, ρ air density (1.2 kg/m³ at sea level and 20 °C), C_d A the **drag area** (about 0.5–0.7 m² for an unfaired commuter with an upright rider, 0.3–0.4 m² for a tucked rider on a faired sport bike), v speed in m/s and θ road gradient angle.

For the K-Light 125 with a 75 kg rider, m = 220 kg; taking C_rr = 0.02 and C_d A = 0.60 m² gives F_roll = 0.02 × 220 × 9.81 = 43 N, while at 90 km/h (25 m/s) F_aero = 0.5 × 1.2 × 0.60 × 625 = 225 N. Drag grows with the **square of speed** and the power to overcome it with the **cube**, so small machines are drag-limited at modest speeds.

Top speed, acceleration and climbing

Top speed is reached where the power available at the wheel equals the power absorbed by resistance, $P_{wheel} = (F_{roll} + F_{aero}) \times v$. With $7.8 \times 0.90 = 7.02$ kW at the wheel:

$$0.36 \times v^3 + 43 \times v = 7{,}020$$

$$v \approx 25.4 \text{ m/s} \approx 91 \text{ km/h}$$

This agrees with the manual's 90 km/h. In fifth gear 25.4 m/s is a wheel speed of $25.4 / (2\pi \times 0.30) \times 60 = 809$ rpm and an engine speed of $809 \times 10.22 \approx 8{,}270$ rpm, just below the power peak; shorter gearing would trade top speed for acceleration and climbing.

Initial acceleration in first gear is $a = (F_t - F_{roll}) / (m \times k)$, where k (about 1.1–1.2 in first gear) accounts for the extra force needed to accelerate the rotating crankshaft, flywheel, gears and wheels. With $k = 1.15$, $a = (682 - 43) / (220 \times 1.15) = 2.5$ m/s², about 0.26 g. The steepest gradient that can be climbed at steady low speed in first gear is found from $\sin\theta = (F_t - F_{roll}) / (m\,g) = 639 / 2{,}158 = 0.296$, so $\theta = 17.2°$, a gradient of about **31 %**; with a passenger and load it falls to roughly 22 %, which is why taxi motorcycles in hilly towns are often fitted with a larger rear sprocket.

Load transfer under braking and acceleration

When the motorcycle decelerates at a, an inertial force $m \cdot a$ acts at the centre of mass at height h, and its moment about the contact patches causes **load transfer** from the rear tyre to the front:

$$\Delta N = m \times a \times h / L$$

where L is the wheelbase. Take the K-Light 125 with rider: static loads 971 N front and 1,187 N rear (machine 69/76 kg, rider 30/45 kg), $h = 0.65$ m, $L = 1.44$ m. At a deceleration of 0.8 g (7.85 m/s²), $\Delta N = 220 \times 7.85 \times 0.65 / 1.44 = 780$ N, so the front tyre carries 1,751 N (81 %) and the rear only 407 N. With a tyre friction coefficient of about 1.0 on dry asphalt, the rear can contribute at most 407 N of the 1,727 N braking force needed, so the front brake must provide **at least three quarters** of it. The deceleration at which the rear wheel lifts is $a = g \times b / h$, where b is the horizontal distance from the centre of mass to the front contact patch (here $1.44 \times 1{,}187 / 2{,}158 = 0.79$ m), giving 1.22 g; on a short, tall sport bike the limit falls close to 1 g, so stoppies rather than front-tyre slides become the limiting case. Under acceleration the transfer reverses and loads the rear tyre, so a powerful bike is limited by wheelie tendency rather than rear grip.

The friction circle

A tyre can generate a total horizontal force (braking or driving plus cornering) no larger than μ times its vertical load, so the combined force must lie inside the **friction circle** of radius μN:

$$\sqrt{(F_x^2 + F_y^2)} \le \mu \times N$$

A rider using 0.6 g of cornering force on a surface with $\mu = 1.0$ has $\sqrt{(1 - 0.6^2)} = 0.8$ g left for braking; braking hard while leaned over therefore needs the lean angle to be reduced first. On wet asphalt μ falls to about **0.5–0.7**, and on painted lines, metal covers or gravel to **0.2–0.4**.

Gyroscopic effect, countersteering and lean angle

A spinning wheel has angular momentum H = I × ω_w. Rolling the motorcycle at a rate Ω makes the front wheel precess, producing a steering torque T = I × ω_w × Ω about the steering axis that turns the wheel into the lean. For a front wheel with I ≈ 0.4 kg·m² at 50 km/h (ω_w ≈ 48 rad/s), a roll rate of 0.5 rad/s gives about 9.6 N·m, which helps the steering follow the lean but is small beside the tyre and trail forces.

To start a turn above walking pace, a rider applies **countersteering**: a brief push on the right handlebar steers the front wheel slightly left, the contact patches move out from under the centre of mass to the left, and the machine rolls to the right; once the required lean is reached, the steering settles into the turn direction. In a steady turn, balance requires the resultant of weight and centrifugal force to pass through the contact patches:

$$\tan \theta = v^2 / (g \times r)$$

where θ is **lean angle** from vertical and r the turn radius. At 50 km/h (13.9 m/s) on a 40 m radius, tan θ = 193 / 392 = 0.49 and θ = 26°. A wide tyre needs a few degrees more lean than this ideal value because the contact patch moves across its profile, and maximum lean is set by friction (tan θ = μ, about **45°** for μ = 1.0) or by ground clearance, whichever comes first.

The motorcycle's tendency to stay upright and to steer itself into a lean comes mainly from **trail**, the distance on the ground by which the front contact patch lies behind the point where the steering axis meets the road; commuter machines typically have rake of 25–28° and trail of 90–110 mm. Module 4 treats steering geometry, trail, wobble and weave in detail.

REVIEW QUESTIONS

1. Calculate the torque of an engine producing 30 kW at 10,000 rpm.
2. What power does the K-Light 125 produce at its peak-torque speed?
3. Using the assumed gearing, calculate the rear-wheel torque and tractive force in fifth gear at 8,000 rpm, taking engine torque as 8.5 N·m.
4. Calculate the aerodynamic drag on the K-Light 125 with rider at 60 km/h and the power needed to overcome it.
5. Why does doubling engine power not double top speed?
6. A rider and passenger (total 290 kg with the machine) need to climb a 20 % gradient in first gear. Is this possible with 682 N of tractive force and C_rr = 0.02?
7. Calculate the load transfer at 1.0 g deceleration for the K-Light 125 with rider, and the resulting front and rear loads.
8. A rider is cornering at 0.7 g on a surface with μ = 0.9. What is the maximum braking deceleration available without reducing lean?
9. Calculate the ideal lean angle at 80 km/h on a 100 m radius curve.
0. Describe what a rider does with the handlebar to change lanes to the left at 80 km/h, and why.

ANSWERS

1. ω = 2π × 10,000 / 60 = 1,047 rad/s; T = 30,000 / 1,047 = 28.6 N·m.
2. ω = 2π × 7,500 / 60 = 785.4 rad/s; P = 8.9 × 785.4 = 6,990 W ≈ 7.0 kW.

3. T_wheel = 8.5 × 10.22 × 0.90 = 78.2 N·m; F_t = 78.2 / 0.30 = 261 N.
4. v = 16.7 m/s; F_aero = 0.5 × 1.2 × 0.60 × 16.7² = 100 N; P = 100 × 16.7 = 1.67 kW.
5. Aerodynamic power rises with the cube of speed, so doubling power increases top speed (where drag dominates) only by about the cube root of two, roughly 26 %.
6. 20 % gradient: θ = arctan 0.20 = 11.3°, sin θ = 0.196. F_grade = 290 × 9.81 × 0.196 = 558 N; F_roll = 0.02 × 290 × 9.81 = 57 N; total 615 N, below 682 N, so the climb is just possible at low steady speed, with little margin for acceleration.
7. ΔN = 220 × 9.81 × 0.65 / 1.44 = 974 N. Front 971 + 974 = 1,945 N; rear 1,187 − 974 = 213 N.
8. Available total 0.9 g; braking = √(0.9² − 0.7²) = √0.32 = 0.57 g.
9. v = 22.2 m/s; tan θ = 22.2² / (9.81 × 100) = 0.503; θ = 26.7°.
10. A brief push forward on the left handlebar steers the front wheel momentarily right, moving the contact patches to the right of the centre of mass so the machine rolls left; the rider then relaxes the pressure and the bike tracks left.

CHAPTER 1.5

Workshop safety, tools and measurement

LEARNING OBJECTIVES

- Identify the main workshop hazards (exhaust gas, fuel, battery acid and hydrogen, hot parts, brake dust, lifting, high-voltage packs) and apply the controls for each.
- Select and use hand tools and metric fasteners correctly, including property classes, torque, tightening sequence and threadlockers.
- Read a vernier caliper, an outside micrometer and a dial gauge, and use bore gauges, feeler gauges, Plastigauge and a multimeter.
- Distinguish **standard values** from **service limits** in a service manual and decide whether a part is serviceable.
- Measure a piston pin and disc runout, repair a damaged thread and remove a broken bolt following the job sheets.

Workshop hazards and their controls

Carbon monoxide (CO) is colourless, odourless and binds to haemoglobin about 200 times more strongly than oxygen, and a small engine idling in a closed garage can reach dangerous levels within minutes, so **never** run an engine indoors without an extraction hose venting outside. **Petrol** vapour is heavier than air, collects in pits and drains and ignites at concentrations as low as about **1.4 %**; drain fuel only into approved containers, keep a CO_2 or dry-powder extinguisher at hand and disconnect the battery before opening fuel lines. Lead-acid batteries contain **sulphuric acid** and give off **hydrogen** while charging, explosive between about **4 % and 75 %** in air; charge in a ventilated area, connect the charger before switching it on, and remove the negative terminal first and refit it last so a spanner touching the frame cannot short the positive. Exhaust headers reach **300–600 °C** and stay hot for half an hour.

Brake and clutch dust is a fine respirable particulate (older pads contained asbestos), so clean brakes wet or with brake cleaner and **never** with compressed air. Support the machine on a centre stand, paddock stand or strapped lift before removing a wheel, and lift heavy parts with a straight back or with help. **Personal protective equipment (PPE)** for general work is safety glasses, nitrile gloves and safety footwear.

> SAFETY **High-voltage electric motorcycles**
>
> Traction packs commonly run at 48–120 V and on larger machines up to about 400 V DC; anything above **60 V DC** is classed as high voltage, can cause fatal shock and cannot be switched off inside the pack. Only trained technicians should open orange-cabled circuits: switch off, remove and lock out the service disconnect, wait for the controller capacitors to discharge as the manual specifies, and **verify absence of voltage** with a rated meter before touching anything, using tools insulated to IEC 60900 (1,000 V).

Hand tools and metric fasteners

A metric thread is designated by diameter and **pitch**, for example **M8 × 1.25** (ISO coarse) or M8 × 1.0 (fine, used on axles and some studs). Common sizes on a 125 cc machine are 8, 10, 12, 14, 17 and 19 mm; use a six-point socket or ring spanner on tight fasteners, because an open-ended spanner grips only two flats and rounds the head. The **property class** on a bolt head gives its strength: class **8.8** has 800 MPa tensile and 640 MPa yield strength, class **10.9** has 1,000 MPa and 900 MPa, and a replacement must be of at least the original class.

A tightened bolt is a stiff spring whose stretch produces a **clamp load** on the joint. Since 80–90 % of the applied torque is lost to friction under the head and in the thread, the relation is approximate:

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T = K × d × F
F = T / (K × d)
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where T is torque, d nominal diameter, F clamp load and K the nut factor (about 0.20 dry, 0.15 oiled). An M8 bolt at 25 N·m dry clamps with 25 / (0.20 × 0.008) = 15.6 kN, but oiled it reaches 20.8 kN, close to the 22 kN proof load of an M8 class 8.8 bolt, so follow the manual's instruction on whether to oil a thread. Tighten multi-fastener joints in a crisscross **tightening sequence** in two or three stages so the part is pulled down evenly; the K-Light 125 cylinder head nuts take **25–28 N·m** and the disc bolts **10–12 N·m** (K-Light 125 manual). Medium-strength (blue) **threadlocker** suits bolts that must come out with hand tools; high-strength (red) needs about 250 °C to release and is used only where specified.

Pull a click-type **torque wrench** smoothly at the handle grip, at right angles, and stop at the click; never use it to loosen, store it at its lowest setting and have it calibrated (typical accuracy ±4 %). Japanese machines use **JIS** cross-head screws, marked with a dot, whose flatter recess makes a Phillips driver cam out and strip the head, so use a JIS driver and press firmly.

Precision measuring tools

Vernier and dial calipers read to 0.02 or 0.05 mm for spring length, chain length and pad and disc thickness. An **outside micrometer** reads to **0.01 mm**: the sleeve has 1 mm divisions above the index line and 0.5 mm divisions below it, the thimble has 50 divisions of 0.01 mm, and the reading is sleeve plus thimble plus the base of the range (0–25, 25–50 mm and so on), as the MAVCC curriculum sets out. A **dial gauge** on a magnetic base measures movement and **runout**, the total indicator reading as a part rotates, to 0.01 mm. Bores are measured with a **telescopic gauge** or small hole gauge transferred to a micrometer, or with a **dial bore gauge** zeroed on one. **Feeler gauges** measure gaps such as valve clearance and ring end gap, and **Plastigauge**, a calibrated plastic thread crushed between journal and bearing, gives oil clearance from its squashed width. A **multimeter** measures voltage in parallel on a live circuit, current in series within its fuse rating, and resistance or continuity only on a **de-energised** circuit; the K-Light 125 charging test expects **14.5 ± 0.5 V** at 5,000 rpm.

Reading a service manual

A manual gives a **standard value** (the dimension of a new part) and a **service limit** (allowable or operating limit) at which the part must be replaced or reconditioned. The K-Light 125 piston pin has a standard outer diameter of **12.994–13.000 mm** and a limit of **12.96 mm**; its piston bore is 13.002–13.008 mm with a limit of 13.04 mm (K-Light 125 manual). A part near its limit at a major service is often replaced anyway because the labour to reach it again costs more than the part; record every measurement on the job card.

Job sheet 1.5.1: Reading an outside micrometer and measuring a piston pin

Tools and materials	Reference values
0–25 mm outside micrometer, lint-free cloth, piston pin, job card	K-Light 125 pin OD standard 12.994–13.000 mm, limit 12.96 mm

1. Clean the anvil and spindle and close them with the ratchet; the thimble zero must align with the index line, or the sleeve must be adjusted with the spanner supplied.
2. Clean the pin and let it reach room temperature, since a pin warmed in the hand expands measurably.
3. Hold the micrometer by the frame, close it on the pin with the ratchet slipping two or three times for constant force, rock it slightly to find the true diameter and lock the spindle.
4. Read the whole millimetres on the sleeve (for example 12), add 0.5 mm if a lower line shows beyond them, and add the thimble division on the index line (for example 49 = 0.49 mm): 12 + 0.5 + 0.49 = 12.99 mm.
5. Measure at both piston-boss positions and the small-end position, each at two orientations 90° apart, and record all six readings; a step between them shows local wear.

Pass criteria: zero checked, six readings within 0.002 mm of the instructor's, and a correct decision to replace the pin if any reading is below 12.96 mm.

Job sheet 1.5.2: Measuring disc and axle runout with a dial gauge

Tools and materials	Reference values
Dial gauge with magnetic base, V-blocks, stand, micrometer	K-Light 125: disc runout limit 0.15 mm; disc 4.0 mm (limit 3.0 mm); axle bend limit 0.2 mm

1. Raise the front wheel on the centre stand and rock it to check for bearing play, which would make runout readings meaningless.
2. Mount the gauge on the fork leg with the plunger square to the disc face 5–10 mm inside its edge, preloaded by about half a needle turn.
3. Turn the wheel slowly, zero the bezel at the lowest reading, then turn one full revolution and note the highest reading: this is the runout. Above 0.15 mm, check the disc bolts (10–12 N·m) and hub face before condemning the disc.
4. Measure disc thickness at four points; variation over about 0.015 mm causes judder even when runout is in limit.
5. Remove the axle, support it on V-blocks at its journals, rotate it under the gauge at its centre and compare with the manual's definition of bend; replace it above 0.2 mm.

Pass criteria: gauge preloaded and zeroed, runout and thickness recorded at the correct positions, and a correct decision with the cause of any excess identified.

Job sheet 1.5.3: Repairing a damaged thread with a thread insert

Tools and materials	Reference values
Thread insert kit for the size (drill, special tap, inserts, insertion and tang tools), drill, safety glasses, cutting fluid	The kit drill and tap are oversize; a standard tap **cannot** be used

1. Wear safety glasses, identify thread size and depth, and check there is at least about 2 mm of material around the hole for the larger drill.
2. Drill out the old thread with the kit drill, square to the surface, to full depth of a blind hole or right through an open one, keeping to the original centreline.
3. Tap with the kit tap and cutting fluid, backing off half a turn every turn to break chips, and blow the hole clear, never towards yourself.
4. Wind an insert in on the insertion tool, tang leading, until its top coil is 0.25–0.5 turn below the surface, then break off and remove the tang.
5. Run the original bolt in by hand and tighten it to specification.

Pass criteria: insert just below the surface, tang removed, hole square, and the bolt reaches its torque without the insert turning.

Job sheet 1.5.4: Removing a broken bolt

Tools and materials	Reference values
Safety glasses, file, centre punch, hammer, drills, screw extractor set, penetrating oil, heat gun, thread insert kit	The extractor chart gives the drill per bolt size, typically 4–5 mm for M8

1. Soak the bolt in penetrating oil for at least 15 minutes; if a stub projects, try locking pliers or file two flats first.
2. File the end flat, punch its exact centre and check the mark before deepening it to about 2 mm, since an off-centre hole damages the component's thread.
3. Drill a pilot hole along the bolt axis and enlarge it to the chart size; a left-hand drill sometimes unscrews the bolt.
4. Tap the extractor in and turn it anticlockwise with steady force; extractors are hard and brittle, and a broken one **cannot** be drilled with ordinary bits.
5. If it will not turn, heat the casting (not the bolt) to about 100–150 °C so it expands away from the bolt, and try again.
6. Inspect the thread and clean it with a tap of the original size or fit an insert (Job sheet 1.5.3).

Pass criteria: bolt removed without damage or a broken extractor, thread serviceable, and a replacement of the correct property class torqued to specification.

REVIEW QUESTIONS

1. Why must an engine **never** be run in a closed workshop, and what control allows it to run indoors?
2. Why is hydrogen a hazard when charging a lead-acid battery? Give two precautions.
3. Why should brake dust not be blown off with compressed air?
4. What do the markings 8.8 and 10.9 on a bolt head mean?
5. Calculate the clamp load of an M10 bolt tightened to 40 N·m with oiled threads (K = 0.15).
6. Why are cylinder head nuts tightened in sequence and in stages?
7. A 25–50 mm micrometer shows 7 mm and the lower 0.5 mm line on the sleeve, with thimble line 23 on the index. What is the reading?
8. A dial gauge on a disc reads from −0.04 mm to +0.09 mm over one turn. What is the runout?
9. Distinguish a standard value from a service limit, using the K-Light 125 piston pin.
0. Why does a Phillips screwdriver damage a JIS screw?
1. A technician measures ignition coil primary resistance with the ignition on. What is wrong?
2. A screw extractor breaks off inside a crankcase bolt hole. What are the options?

ANSWERS

1. Exhaust carbon monoxide is odourless and can reach lethal concentration in minutes in an enclosed space; an extraction hose from the silencer vented outdoors allows engines to be run indoors.

2. Charging releases hydrogen, explosive between about 4 % and 75 % in air and ignitable by a terminal spark. Charge with ventilation, switch the charger on only after connecting it, and keep flames and sparks away.
3. The dust reaches deep into the lungs (and may contain asbestos on older parts), and compressed air spreads it through the workshop; clean wet or with brake cleaner.
4. 8.8: tensile strength 800 MPa, yield 640 MPa. 10.9: tensile 1,000 MPa, yield 900 MPa.
5. F = 40 / (0.15 × 0.010) = 26,700 N ≈ 26.7 kN.
6. To pull the head down evenly so the gasket is compressed uniformly and the head does not distort; tightening one nut fully first tilts the head and leaves leak paths.
7. 25 + 7 + 0.5 + 0.23 = 32.73 mm.
8. 0.09 − (−0.04) = 0.13 mm, within a 0.15 mm limit.
9. Standard value is the new dimension, 12.994–13.000 mm; the service limit, 12.96 mm, is the worn dimension at which the pin must be replaced.
10. The JIS recess has flatter flanks; a Phillips tip sits high in it and cams out under torque, stripping the head.
11. Resistance must be measured de-energised; with power on the reading is meaningless and the meter or ECU can be damaged. Switch off, disconnect the coil, then measure.
12. Spark erosion (EDM) at a machine shop, shattering it with a punch and picking out fragments, or carbide burrs, followed by a thread insert; failing these, replace the crankcase half.

Glossary

ABS (anti-lock braking system): a system that measures wheel speed and releases brake pressure momentarily when a wheel begins to lock, so that the tyre keeps rolling and steering control is retained. **CBS (combined braking system)**: a system in which one control applies both front and rear brakes in a set proportion. **Clamp load**: the tension in a tightened bolt and the equal compressive force it applies to the joint. **Contact patch**: the area of tyre in contact with the road, through which all driving, braking and cornering forces pass. **Countersteering**: a brief steering input opposite to the intended turn, which makes the motorcycle roll into the turn. **CVT (continuously variable transmission)**: a transmission using a belt between two variable-diameter pulleys to give a stepless range of ratios. **Drag area (C_d A)**: the product of drag coefficient and frontal area, which sets aerodynamic drag at a given speed. **ECU (engine control unit)**: the computer that controls fuel injection, ignition timing and diagnostics. **EFI (electronic fuel injection)**: a fuel system in which an ECU-controlled injector meters fuel into the intake. **Firing interval**: the crank angle between successive power strokes of a multi-cylinder engine. **Friction circle**: the limit of combined longitudinal and lateral force a tyre can generate, equal to μ times its vertical load. **Gyroscopic precession**: the steering torque produced when a spinning wheel is rolled. **JIS**: the Japanese Industrial Standard cross-head screw recess, marked with a dot and requiring a matching driver. **L-category**: the EU classification of two- and three-wheeled vehicles and quadricycles under Regulation (EU) No 168/2013. **Load transfer**: the shift of vertical tyre load between front and rear under braking or acceleration, equal to m × a × h / L. **MIL (malfunction indicator lamp)**: the instrument warning lamp lit when the ECU stores a fault. **Pedelec**: a bicycle with electric assistance only while pedalling, up to 250 W and 25 km/h in the EU. **Plastigauge**: a calibrated plastic thread used to measure bearing oil clearance. **Property class**: the strength grade of a metric bolt, such as 8.8 or 10.9. **Regulator/rectifier**: the unit that converts alternator AC to DC and limits charging voltage. **Rolling resistance**: the force opposing motion caused mainly by deformation of the tyre, C_rr × m × g. **Runout**: the total indicator reading of a rotating surface, showing how far it deviates from true. **Service limit**: the worn dimension or value at which a part must be replaced or reconditioned. **Standard value**: the specified dimension or setting of a new part. **Swingarm**: the pivoted arm that locates the rear wheel and allows it to move vertically. **Tractive force**: the driving force at the rear tyre contact patch, wheel torque divided by rolling radius. **Trail**: the distance on the ground between the front contact patch and the point where the steering axis meets the road. **Unit-swing engine**: a scooter engine and transmission that pivot as one unit and act as the swingarm. **Unsprung mass**: the mass not supported by the suspension springs, mainly wheels, brakes and part of the suspension.

Further reading

- KS Motorcycles / Qianjiang, *K-Light 125 maintenance manual* (manuel d'entretien), specification table and service data.
- Mid-America Vocational Curriculum Consortium (MAVCC), *Motorcycle Mechanic*, teacher edition, 1988, Units II–V (safety, tools and equipment, metric measurements, fasteners).
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- Foale, T., *Motorcycle Handling and Chassis Design: the Art and Science*, 2nd edn, Tony Foale Designs, 2006.
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- Jennings, G., *Two-Stroke Tuner's Handbook*, H. P. Books, 1973.
- Robert Bosch GmbH, *Bosch Automotive Handbook*, 11th edn, Wiley, 2022.
- Haynes, *Motorcycle Basics Techbook* and model-specific Haynes service and repair manuals.
- Regulation (EU) No 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles, and Directive 2006/126/EC on driving licences.
- UNECE Regulation No 78 (braking of category L vehicles) and UNECE Regulation No 136 (electric safety of L-category vehicles).
- ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel: bolts, screws and studs*.

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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.