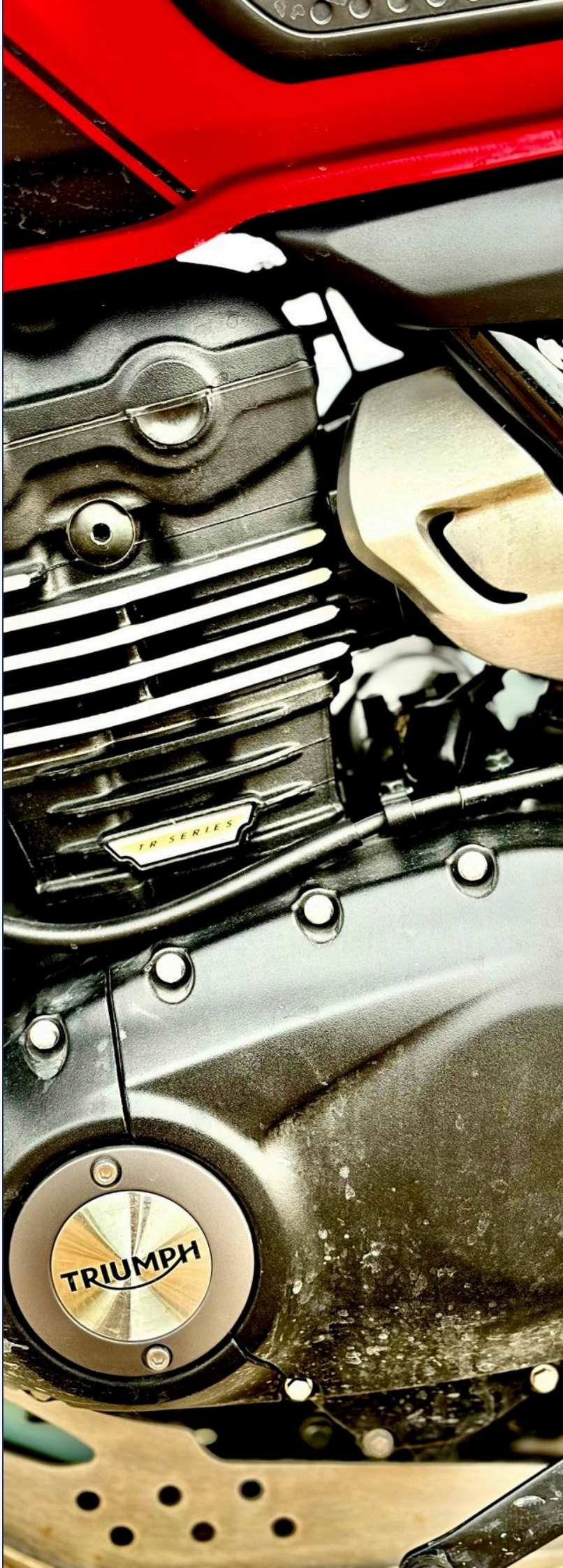
moto zero
by Transitions Lab

02

MODULE 2

The engine: four-stroke and two-stroke

How a reciprocating petrol engine turns fuel into torque, how its four-stroke and two-stroke variants are built, lubricated and cooled, and how a technician measures, diagnoses and repairs them.



A technical course on how motorcycles work
Transitions Lab · Edition 1.0 · November 2026
Open licence CC BY-SA 4.0

Contents

2.1 Engine fundamentals and key numbers 3

2.2 The four-stroke cycle 9

2.3 The two-stroke cycle 13

2.4 The top end 20

2.5 The bottom end 26

2.6 Lubrication and cooling 31

2.7 Engine diagnosis and service 35

Glossary 42

Further reading 43

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 2.1

Engine fundamentals and key numbers

LEARNING OBJECTIVES

- Explain how combustion pressure becomes crankshaft torque and why the ideal Otto efficiency depends only on compression ratio.
- Calculate displacement, compression ratio, bore/stroke ratio and mean piston speed from bore, stroke and combustion chamber volume.
- Calculate brake mean effective pressure (BMEP) and specific output from published torque and power figures, and use them to compare engines of different size and type.
- Define volumetric efficiency and estimate it from airflow.
- Read a torque and power curve and relate its shape to engine design choices.

From fuel to force

A motorcycle petrol engine is a heat engine that burns air and fuel inside a sealed, variable-volume chamber. Petrol has a lower heating value of about **43 MJ/kg**, and when it burns at the chemically correct (**stoichiometric**) ratio of **14.7 kg of air per kg of fuel**, the gas temperature in the chamber rises from roughly 600 K at the end of compression to a peak of 2,300–2,600 K, and cylinder pressure rises from about 1.5–2 MPa to a peak of 4–7 MPa in a typical road engine. That pressure acts on the piston crown, and the connecting rod and crank convert the resulting linear force into torque at the crankshaft.

Combustion is not an explosion: the spark starts a flame kernel and a turbulent flame front crosses the chamber at 15–40 m/s, consuming the charge over roughly 40–60° of crank rotation. The spark therefore fires before **top dead centre (TDC)**: the K-Light 125 manual specifies **15° BTDC** at its 1,500 rpm idle, and the ECU advances this as speed rises, aiming to place peak pressure at roughly 10–15° after TDC where the crank has leverage. Firing too early wastes work against the rising piston and risks **detonation** (spontaneous ignition of the unburnt end gas, heard as knock or pinking); firing too late sends heat out of the exhaust rather than into the crank.

The ideal Otto cycle

The air-standard **Otto cycle** is the idealised model of a spark-ignition engine. It replaces the real working gas with air, treats compression and expansion as reversible and adiabatic (no friction, no heat loss), and treats combustion as instantaneous heat addition at constant volume at TDC. Under those assumptions the thermal efficiency depends only on the compression ratio r and the ratio of specific heats γ of the gas:

```
η = 1 − 1/r^(γ−1)
```



FIGURE 2.1 Exterior of a horizontal single-cylinder four-stroke commuter engine with carburettor, starter motor, clutch cover and kickstart.

Render: Transitions Lab, CC BY-SA 4.0

where η is the ideal thermal efficiency (fraction of fuel energy converted to work), r is the compression ratio, and γ is the ratio of specific heats (1.4 for cold air, about 1.25–1.3 for a real hot fuel-air mixture).

The physical reason is that a higher compression ratio also gives a higher expansion ratio, so the burnt gas gives up more of its energy to the piston before the exhaust valve releases it.

> ▤ **REFERENCE DATA** **K-Light 125 key engine data (K-Light 125 manual)**
>
> Engine type QJ157FMI, single cylinder, air-cooled, two-valve, spherical combustion chamber. Bore × stroke 56.5 × 49.5 mm, displacement 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, idle 1,500 ± 100 rpm. Ignition timing 15° BTDC at idle (ECU controlled), electronic fuel injection with a 30 mm throttle body. Lubrication by pressure and splash, oil capacity 1.1 L at a change. The same 56.5 × 49.5 mm dimensions are used by the Honda CG125, of which the 157FMI family is a derivative.

For the K-Light 125 at r = 9 and γ = 1.4, η = 1 − 9^(−0.4) = 1 − 0.415 = 0.585, or 58.5 %. With a more realistic γ = 1.3 the figure falls to 1 − 9^(−0.3) = 1 − 0.517 = 48.3 %. A real small air-cooled engine reaches a peak **brake thermal efficiency** of only about **28–32 %**, because of heat loss to the walls, finite combustion time, pumping work and friction (10–20 % of indicated work at full load, much more at part load).

The Otto formula also explains why compression ratio is capped. Raising r from 9 to 12 lifts the ideal efficiency (γ = 1.3) from 48.3 % to 52.5 %, but it also brings the end gas closer to knock; fuel octane, chamber shape, bore size, cooling and knock-sensor timing control set the usable limit. Air-cooled commuter singles typically run 9–10:1, liquid-cooled four-valve sport engines 12–14:1.

Displacement, compression ratio and the geometry of the cylinder

Swept volume (displacement) is the volume the piston crown sweeps between bottom dead centre (BDC) and TDC, multiplied by the number of cylinders:

$$V = \pi/4 \times B^2 \times S \times n$$

where V is displacement, B is bore (cylinder diameter), S is stroke (piston travel from TDC to BDC, equal to twice the crank throw), and n is the number of cylinders.

For the K-Light 125, working in centimetres so the answer comes out in cm³: V = 0.7854 × 5.65² × 4.95 × 1 = 0.7854 × 31.92 × 4.95 = 124.1 cm³, which the manual rounds to 124 cm³.

The **compression ratio** compares the total cylinder volume with the piston at BDC to the volume left above the piston at TDC:

$$r = (Vs + Vc) / Vc$$
$$Vc = Vs / (r - 1)$$

where Vs is the swept volume of one cylinder and Vc is the **clearance volume** (combustion chamber in the head, plus any volume in the piston crown dish, the head gasket thickness and the space above the top ring land).

At r = 9, the K-Light's clearance volume is Vc = 124.1 / 8 = **15.5 cm³**, which shows how sensitive r is to small changes. Skimming 0.10 mm from the head face removes π/4 × 5.65² × 0.010 = 0.25 cm³ from Vc, raising r to (124.1 + 15.26) / 15.26 = 9.13. Fitting a head gasket 0.20 mm thicker adds 0.50 cm³, giving r = (124.1 + 16.0) / 16.0 = 8.76. Carbon deposits also reduce Vc, which is why the K-Light 125 manual lists excessive carbon among the causes of compression pressure that is too high.

This geometric ratio differs from the **effective (dynamic) compression ratio**, because the four-stroke inlet valve and the two-stroke exhaust port both close well after BDC and real compression starts only then. Two-stroke makers often quote a trapped ratio; Yamaha lists the YZ125 at 8.2–10.1:1, the range reflecting power valve position.

> EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy
>
> **Displacement and compression on the explorer**
>
> Open transitionslab.org/motorcycle-anatomy and set the bore slider to 56.5 mm and the stroke slider to 49.5 mm, then calculate the displacement (124 cm³) and compare it with what the explorer shows. Increase the bore to 62 mm with the stroke unchanged and recalculate (about 149 cm³). Move the compression slider from 9:1 to 11:1 and work out the change in ideal Otto efficiency at γ = 1.3 (48.3 % to 51.3 %), then set a short and a long stroke at 9,000 rpm and compare the mean piston speeds.

Bore/stroke ratio

The **bore/stroke ratio** B/S describes the shape of the cylinder: above 1 is **over-square** (short-stroke), 1 is square, and below 1 is **under-square** (long-stroke). The K-Light 125 at 56.5/49.5 = 1.14 is moderately over-square, the Yamaha YZ125 at 54.0 × 54.5 mm (B/S = 0.99) is essentially square, and a modern 1,000 cm³ superbike four runs B/S around 1.4–1.6.

The trade-offs follow from geometry and piston speed:

Property	Over-square (short stroke)	Under-square (long stroke)
Mean piston speed at a given rpm	Lower, so higher rpm is possible	Higher, which limits rpm
Valve area available	Larger bore gives room for bigger or more valves	Smaller bore restricts valve size
Combustion chamber	Wide and flat, longer flame path, higher surface/volume ratio	Compact, short flame path, tolerates higher compression
Torque character	Tends toward high-rpm power	Tends toward low-rpm torque and good part-load efficiency
Crank throw and rod loads	Shorter throw, lower inertia loads per rpm	Longer throw, higher inertia loads

Mean piston speed

The piston covers two strokes per revolution, so its **mean piston speed** is:

$$cm = 2 \times S \times N / 60$$

where cm is mean piston speed in m/s, S is stroke in metres, and N is crankshaft speed in rev/min.

For the K-Light 125 at its peak power speed, cm = 2 × 0.0495 × 9,000 / 60 = 14.9 m/s, and at peak torque (7,500 rpm) 12.4 m/s. The YZ125 two-stroke at about 11,500 rpm gives 2 × 0.0545 × 11,500 / 60 = 20.9 m/s. It indexes mechanical stress and wear, because inertia forces scale with speed squared and ring friction with sliding velocity. As rough guides, long-life commuter engines run 13–16 m/s at peak power, sports road engines 18–22 m/s, and racing engines 24–26 m/s with special materials and short service intervals.

Torque, power, BMEP and specific output

Torque is the turning moment at the crankshaft, measured on a dynamometer in N·m; **power** is torque multiplied by angular speed:

$$P = T \times \omega = T \times 2\pi \times N / 60$$

$$P\ (kW) = T\ (N \cdot m) \times N\ (rpm) / 9{,}549$$

For the K-Light 125, 8.9 N·m at 7,500 rpm gives 8.9 × 7,500 / 9,549 = 6.99 kW, and the quoted peak of 7.8 kW at 9,000 rpm implies a torque at that speed of 7.8 × 9,549 / 9,000 = 8.28 N·m. Power peaks above the torque peak because, beyond the torque peak, torque falls more slowly than rpm rises; power peaks where the percentage fall in torque per extra rpm equals the percentage rise in speed.

To compare engines of different size, **brake mean effective pressure (BMEP)** is the constant pressure that, acting on the piston over each power stroke, would produce the measured brake torque:

$$BMEP\ (four\text{-}stroke) = 4\pi \times T / Vd$$

$$BMEP\ (two\text{-}stroke) = 2\pi \times T / Vd$$

where T is brake torque in N·m and Vd is total displacement in m³ (result in Pa; divide by 10^5 for bar).

The K-Light 125 at peak torque gives $4\pi \times 8.9 / 124.1 \times 10^{-6} = 9.01 \times 10^{5}$ Pa, or 9.0 bar, and at peak power 8.4 bar. Typical BMEP values at the torque peak are 8–10 bar for naturally aspirated two-valve air-cooled road engines, 11–13 bar for liquid-cooled four-valve sports engines, and 6–9 bar for carburetted road two-strokes. BMEP is proportional to the air trapped per cycle and the efficiency with which it burns, so it is the cleanest single measure of breathing and combustion quality.

Volumetric efficiency

Volumetric efficiency (ηv) is the mass of fresh air actually inducted per cycle divided by the mass that would fill the swept volume at reference (usually ambient) density:

```
ηv = ṁair / (ρair × Vd × N / 120)  (four-stroke)
```

where $\dot{m}_{air}$ is measured air mass flow (kg/s), ρ_{air} is air density (about 1.18 kg/m³ at 25 °C and sea level), V_d is displacement (m³) and N is rpm. The divisor 120 converts rpm to intake strokes per second; the two-stroke equivalent, the delivery ratio, uses N/60.

At 7,500 rpm the K-Light's ideal air flow is $1.18 \times 124.1 \times 10^{-6} \times 7{,}500 / 120 = 9.15$ g/s. If a flow meter measured 7.8 g/s, $\eta_v = 0.85$. Small two-valve road engines reach 80–90 % at their torque peak; tuned four-valve engines exceed 100 % over a narrow band because intake and exhaust pressure waves push extra charge in, and fall well below 100 % elsewhere. The torque curve tracks volumetric efficiency closely, which is why the shape of the torque curve is largely determined by valve timing, port and runner dimensions and exhaust length.

The airflow also allows a quick energy check. At 7.8 g/s of air and an air-fuel ratio of 14.7, fuel flow is 0.53 g/s, which carries $0.53 \times 43 = 22.8$ kW of chemical energy. With 7.0 kW at the crank, brake thermal efficiency is about 31 %, consistent with the real-engine figure given earlier.

Reading torque and power curves

On a full-throttle dyno plot, the rpm of peak torque marks the speed of highest volumetric efficiency, set by cam timing and intake and exhaust tuning; the K-Light 125 (torque peak 7,500 rpm, power peak 9,000 rpm) is tuned for a broad curve that pulls from 3,000–4,000 rpm, while a tuned two-stroke with an expansion chamber gives high power in a band perhaps 2,000–3,000 rpm wide. Dips in the curve usually come from pressure waves arriving at the wrong moment, and the fall above peak power from flow limits and rising friction. Manufacturers quote crankshaft power corrected to standard conditions (for example under UN Regulation No. 85); rear-wheel figures from a chassis dynamometer are typically **8–15 % lower**.

> EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy **Torque and RPM on the explorer**
>
> On the explorer, set the RPM slider to 3,000, 6,000 and 9,000 rpm in turn with the four-stroke model selected, and calculate the mean piston speed and the number of power strokes per second (rpm/120). Switch to the two-stroke model at the same RPM values and confirm that the power-stroke frequency doubles. Use these numbers to explain why a 125 cm³ two-stroke can produce two to three times the power of a 125 cm³ commuter four-stroke.

REVIEW QUESTIONS

1. State the four simplifying assumptions of the air-standard Otto cycle and explain why a real engine falls short of the efficiency it predicts.
2. Calculate the ideal Otto efficiency at r = 10.5 for γ = 1.4 and γ = 1.3.

3. A single-cylinder engine has a bore of 52.4 mm and a stroke of 57.8 mm. Calculate its displacement and bore/stroke ratio, and classify it.
4. A 124 cm³ engine has a clearance volume of 13.8 cm³. What is its compression ratio? What clearance volume would give 10:1?
5. Calculate the change in compression ratio of the K-Light 125 if 0.25 mm is machined from the cylinder head face during resurfacing.
6. A 150 cm³ four-stroke single produces 12.8 N·m at 6,500 rpm. Calculate the power at that speed and the BMEP.
7. A 250 cm³ two-stroke produces 38 N·m at 8,500 rpm. Calculate its BMEP and power, and explain why its BMEP is lower than a four-stroke's even though its torque per litre is higher.
8. At 6,000 rpm a 124 cm³ four-stroke inducts 5.6 g/s of air at an air density of 1.18 kg/m³. Calculate its volumetric efficiency.
9. A rider reports that, after a top-end rebuild using a thinner aftermarket head gasket, the engine pinks under load on hills. Explain the likely mechanism.

ANSWERS

1. The working fluid is air with constant specific heats; compression and expansion are reversible and adiabatic; heat is added instantaneously at constant volume at TDC; and heat is rejected at constant volume at BDC, replacing the exhaust and intake strokes. A real engine loses heat to the walls, burns over 40–60° of crank angle, has real gas properties with lower γ, spends pumping work on gas exchange and loses work to friction, so peak brake efficiency is about 28–35 % rather than 50–60 %.
2. γ = 1.4: η = 1 − 10.5^(−0.4) = 1 − 0.390 = 0.610 (61.0 %). γ = 1.3: η = 1 − 10.5^(−0.3) = 1 − 0.494 = 0.506 (50.6 %).
3. V = 0.7854 × 5.24² × 5.78 = 0.7854 × 27.46 × 5.78 = 124.6 cm³. B/S = 52.4/57.8 = 0.91, so the engine is undersquare (long stroke).
4. r = (124 + 13.8) / 13.8 = 9.99, effectively 10:1. For exactly 10:1, Vc = 124 / 9 = 13.78 cm³.
5. Volume removed = 0.7854 × 5.65² × 0.025 = 0.627 cm³. New Vc = 15.51 − 0.63 = 14.88 cm³. New r = (124.1 + 14.88) / 14.88 = 9.34:1, a rise of about 0.34. Head resurfacing beyond the 0.05 mm flatness limit is a sign the head should be replaced rather than heavily machined.
6. P = 12.8 × 6,500 / 9,549 = 8.71 kW. BMEP = 4π × 12.8 / 150 × 10^{-6} = 160.8 / 1.5 × 10^{-4} = 1.07 × 10^{6} Pa = 10.7 bar, a good figure for a two-valve road single.
7. BMEP = 2π × 38 / 250 × 10^{-6} = 238.8 / 2.5 × 10^{-4} = 9.55 × 10^{5} Pa = 9.6 bar. P = 38 × 8,500 / 9,549 = 33.8 kW. Torque per litre is 152 N·m/L against about 72 N·m/L for the K-Light, but the two-stroke fires every revolution, so the work per power stroke (and hence per unit of swept volume per firing) is what BMEP measures; the two-stroke traps less charge per firing because some of the cycle is spent scavenging, but fires twice as often.
8. Ideal flow = 1.18 × 124 × 10^{-6} × 6,000 / 120 = 7.32 g/s. ηv = 5.6 / 7.32 = 0.77 (77 %).
9. A thinner gasket reduces clearance volume and raises the compression ratio, increasing end-gas temperature and pressure at the end of compression. With unchanged ignition timing and fuel octane, the unburnt end gas can auto-ignite before the flame front reaches it (detonation), heard as pinking at high load and low speed. The fix is the correct gasket thickness, after checking the chamber for carbon.

CHAPTER 2.2

The four-stroke cycle

LEARNING OBJECTIVES

- Describe each of the four strokes in terms of valve positions, piston motion, pressure and gas flow.
- Read a valve timing diagram and calculate valve duration, overlap and cam lobe centre angles.
- Explain why valves open before and close after the dead centres, and how timing differs between commuter and sports engines.
- Relate firing order and crank layout to firing intervals, smoothness and character in twins, triples and fours.

The cycle in 720 degrees

A **four-stroke** engine completes one working cycle in two crankshaft revolutions (**720°**), so the camshaft turns at **half crankshaft speed**. Each cylinder fires once every second revolution, so a single needs a large flywheel effect in its alternator rotor and crank webs to coast through three idle strokes.

Intake (0–180°). The piston descends from TDC with the inlet valve open. The cylinder volume grows faster than air can enter, so cylinder pressure falls to perhaps 0.85–0.95 bar absolute at full throttle (much lower at part throttle, where the throttle valve restricts flow). Because the incoming air column moves at 50–100 m/s at full load, its inertia carries it on into the cylinder after the piston has passed **bottom dead centre (BDC)**.

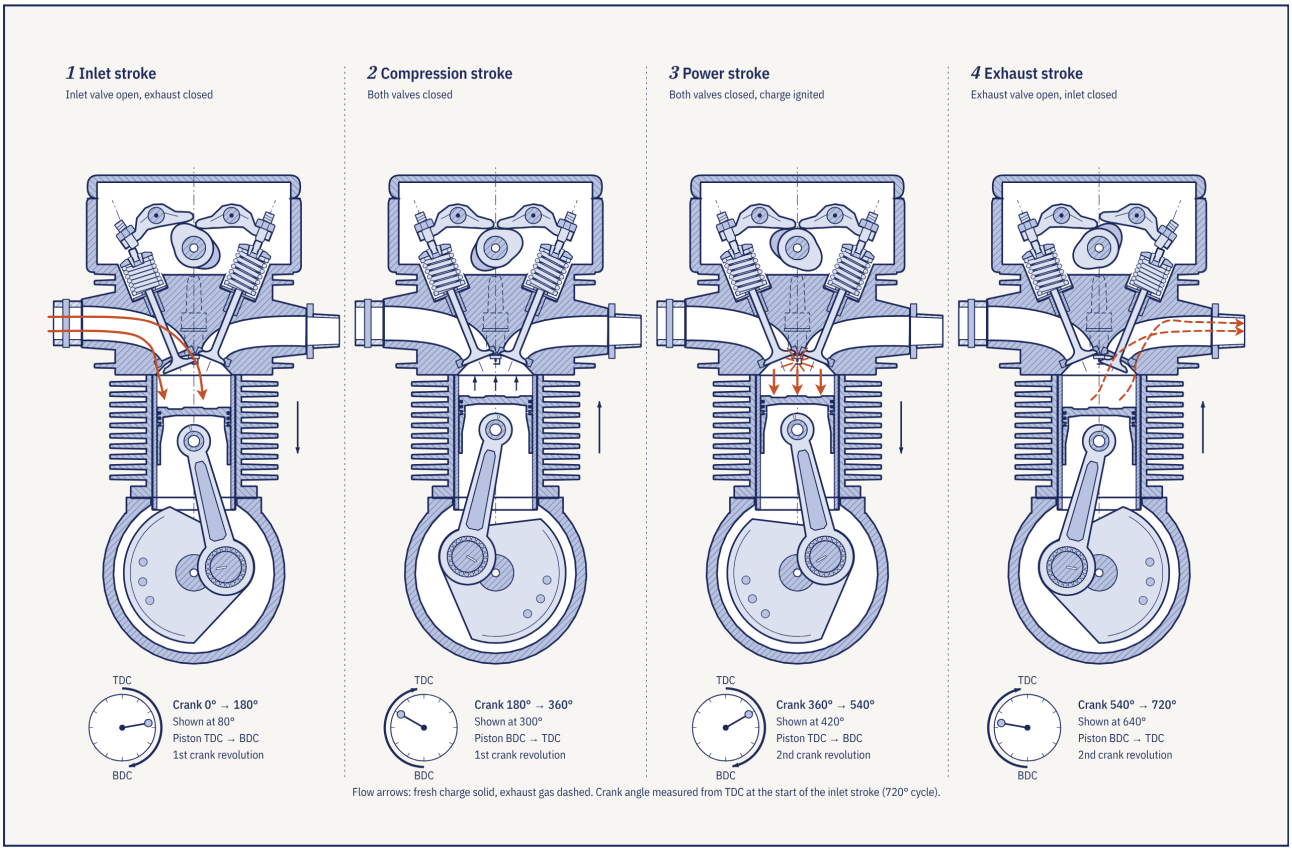


FIGURE 2.2 The four-stroke cycle of a single-cylinder overhead-camshaft engine, showing valve positions, piston travel, crank angle and gas flow in the intake, compression, power and exhaust strokes.

Compression (180–360°). Once the inlet valve closes, the piston rises and compresses the trapped charge. In the K-Light 125 the cranking compression pressure is **1.0–1.2 MPa** (K-Light 125 manual). Compression heats the mixture and evaporates remaining fuel, and the spark fires near the end of the stroke, 10–40° BTDC depending on speed and load.

Power (360–540°). The flame front crosses the chamber, pressure peaks shortly after TDC, and the gas expands, pushing the piston down. Most of the useful work is done in the first 60–90° of the stroke.

Exhaust (540–720°). The exhaust valve opens before BDC, and the first rush of high-pressure gas (**blowdown**) leaves at near sonic velocity; the rising piston displaces most of the rest, leaving 5–15 % **residual gas** in the clearance volume.

Valve timing

Because gases have inertia and valves take time to lift, cams open each valve early and close it late. The four **valve timing** events are named by the valve and the dead centre they relate to:

Event	Abbreviation	Typical commuter single	Typical sports four (four-valve)
Inlet valve opens	IVO	5–15° BTDC	25–40° BTDC
Inlet valve closes	IVC	30–45° ABDC	55–70° ABDC
Exhaust valve opens	EVO	30–45° BBDC	55–70° BBDC
Exhaust valve closes	EVC	5–15° ATDC	25–40° ATDC
Valve overlap	IVO + EVC	10–30°	50–80°

These ranges are typical, not specifications; service data usually quote timing at a defined lift such as 1 mm, because cam ramps are gradual and zero-lift timings are much longer.

Inlet duration is IVO + 180 + IVC. A commuter engine with IVO 10° BTDC and IVC 40° ABDC has 10 + 180 + 40 = 230° duration; exhaust duration with EVO 40° BBDC and EVC 10° ATDC is likewise 230°. The **inlet lobe centre**, the point of maximum lift, falls at (IVC − IVO + 180)/2 after TDC, here (40 − 10 + 180)/2 = 105° ATDC. Engine builders "degree" a camshaft by checking that the measured lobe centre matches the specification.

The reasons for each event are:

- **Early inlet opening (IVO before TDC).** The valve needs 20–40° to reach useful lift, so opening before TDC means it is well open when the piston descends, and the departing exhaust helps start the inlet flow.
- **Late inlet closing (IVC after BDC).** At speed the inlet column keeps ramming in after BDC; at low speed charge is pushed back into the port instead, so a late-closing cam loses low-speed torque and cranking compression.
- **Early exhaust opening (EVO before BDC).** This sacrifices a little expansion work but lets blowdown empty the cylinder before the piston rises, saving far more pumping work.
- **Late exhaust closing (EVC after TDC).** The outgoing gas has momentum and continues to draw residual gas out after TDC.
- **Overlap.** The period around TDC when both valves are open is **valve overlap**. Long overlap, combined with tuned intake and exhaust lengths, lets an exhaust pressure wave scavenge the chamber and pull in fresh charge at high rpm, but at idle exhaust flows back into the inlet, giving rough idle and high hydrocarbon emissions, so emission-certified commuter engines use short overlap.

Variable valve timing systems address this compromise. Examples include Honda's HYPER VTEC on the VFR800 and CB400 (switching from two to four valves per cylinder at a set rpm), Kawasaki's variable inlet cam timing on the 1400GTR, Suzuki's centrifugal inlet cam phaser on the GSX-R1000, Ducati's DVT (which phases both inlet and exhaust camshafts), and Yamaha's VVA on the 155 cm³ R15 and MT-15, which switches the inlet valve between two cam lobes.

Firing order and crank layouts

In a multi-cylinder engine the **firing order** and the **firing interval** between firings shape smoothness, vibration and rear-tyre loading. Even firing in a four-stroke requires an interval of 720° divided by the number of cylinders.

Layout	Crank arrangement	Firing intervals	Examples and character
Single	One throw	720°	Commuters, trail bikes; strong pulses, large flywheel effect
Parallel twin, 360°	Both pistons rise together	360°, 360°	Classic British twins, many A2-licence twins; even firing, strong primary shake
Parallel twin, 180°	Pistons move opposite	180°, 540°	Older Japanese twins; primary forces cancel, rocking couple remains
Parallel twin, 270°	Crank pins 90° apart	270°, 450°	Yamaha MT-07, Triumph and Honda twins; mimics a 90° V-twin
90° V-twin	Single shared crankpin	270°, 450°	Ducati, Suzuki SV650; perfect primary balance with correct counterweights
45° V-twin	Single shared crankpin	315°, 405°	Harley-Davidson; uneven, needs balancers or rubber mounts
Inline triple	Throws at 120°	240° even	Triumph, Yamaha MT-09; balanced primary forces, end-to-end rocking couple
Inline four, flat-plane	Throws at 0°, 180°, 180°, 0°	180° even (order 1-2-4-3)	Most Japanese fours; primary balance, secondary vertical shake
Inline four, crossplane	Throws at 90° intervals	270°, 180°, 90°, 180° (Yamaha R1)	Cancels inertial torque fluctuations, leaves combustion torque pulses

In a flat-plane four, pistons 1 and 4 move together, as do 2 and 3. Yamaha's **crossplane** R1 crank places the pins at 90° intervals so that the inertial torque of the accelerating and decelerating pistons cancels across the four cylinders, leaving the rear tyre to feel only combustion torque.

> EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy **Cycle animation**
>
> Run the four-stroke cycle animation on the explorer at a slow RPM setting. Pause it at the points where the inlet valve begins to lift and where the exhaust valve closes, read the crank angle display, and calculate the overlap. Then step through 720° and confirm that the camshaft has turned through 360°.

REVIEW QUESTIONS

1. Why does the camshaft of a four-stroke turn at half crankshaft speed?
2. Describe the pressure in the cylinder during the intake stroke at full throttle and at idle, and explain the difference.

3. A cam has IVO 12° BTDC, IVC 44° ABDC, EVO 46° BBDC and EVC 10° ATDC. Calculate inlet duration, exhaust duration, overlap and inlet lobe centre.
4. Why does the exhaust valve open well before BDC even though this wastes some expansion work?
5. A tuner fits a camshaft with longer duration and more overlap to a commuter 125. Predict the effects on idle quality, cranking compression, low-speed torque and peak power.
6. Explain why a 270° parallel twin sounds and feels like a 90° V-twin.
7. What is the purpose of the crossplane crank in the Yamaha R1, and what vibration penalty does it carry?
8. A single-cylinder engine is set on TDC with both rockers loose. On which stroke is it, and why does it matter for valve adjustment?

ANSWERS

1. Each valve must open once per cycle and the cycle takes 720° of crank rotation. A cam turning at half speed rotates 360° per cycle, so one lobe gives one opening per cycle.
2. At full throttle the throttle is fully open and cylinder pressure is only slightly below atmospheric (about 0.85–0.95 bar absolute), limited by port and valve restriction. At idle the throttle plate is nearly closed and manifold pressure is perhaps 0.3–0.4 bar absolute, so the cylinder fills with a small mass of charge; this is what lets the engine idle at low power, but the piston does pumping work against the vacuum.
3. Inlet duration = 12 + 180 + 44 = 236°. Exhaust duration = 46 + 180 + 10 = 236°. Overlap = 12 + 10 = 22°. Inlet lobe centre = (44 − 12 + 180)/2 = 106° ATDC.
4. By the last part of the power stroke the gas pressure has fallen and the crank has little leverage, so little work is lost by releasing it. Early opening lets blowdown empty the cylinder before the piston rises, so the exhaust stroke needs much less pumping work; the net effect is a gain, especially at high speed.
5. Idle becomes rough and higher idle speed is needed because exhaust gas dilutes the inlet charge during overlap; cranking compression falls because the later inlet closing pushes charge back into the port at low speed; low-speed torque falls; peak power rises and moves to higher rpm, provided the intake and exhaust can support it. Emissions also rise and the engine may no longer meet its type approval.
6. The 270° crank gives firing intervals of 270° and 450°, exactly the intervals of a 90° V-twin with a shared crankpin. The pistons also never stop simultaneously, which reduces primary shaking compared with a 360° twin, so the exhaust note and the torque pulses delivered to the tyre resemble the V-twin's.
7. With throws at 90° intervals, the inertia torques from accelerating and decelerating the pistons cancel, so crankshaft torque follows combustion rather than inertia; Yamaha claims this gives the rider a more direct link between throttle and rear-tyre torque. The crank creates a primary rocking couple that needs a balancer shaft, and the uneven firing order needs a heavier crank.
8. If both rockers are loose (both valves closed with clearance), the piston is at TDC at the end of the compression stroke. At TDC on the exhaust stroke the valves are in overlap and both are partly open, so the clearance cannot be measured; valve clearance must be checked at TDC compression.

CHAPTER 2.3

The two-stroke cycle

LEARNING OBJECTIVES

- Describe how a crankcase-scavenged two-stroke completes its cycle in one revolution, naming each port event.
- Compare piston-port, reed-valve and rotary-valve induction.
- Explain loop (Schnürle) scavenging, expansion chamber tuning and exhaust power valves.
- Calculate premix quantities and explain why two-strokes combine high specific output with high hydrocarbon emissions.
- Describe how direct and transfer-port injection reduce those emissions.

One power stroke per revolution

The motorcycle **two-stroke** uses the underside of the piston and a sealed crankcase as a scavenge pump, and replaces poppet valves with ports in the cylinder wall that the piston uncovers and covers, so the full cycle takes **360°**.



FIGURE 2.3 A 125 cc two-stroke single: finned cylinder with power-valve housing, reed-valve intake and carburettor, clutch and ignition covers.

Render: Transitions Lab, CC BY-SA 4.0

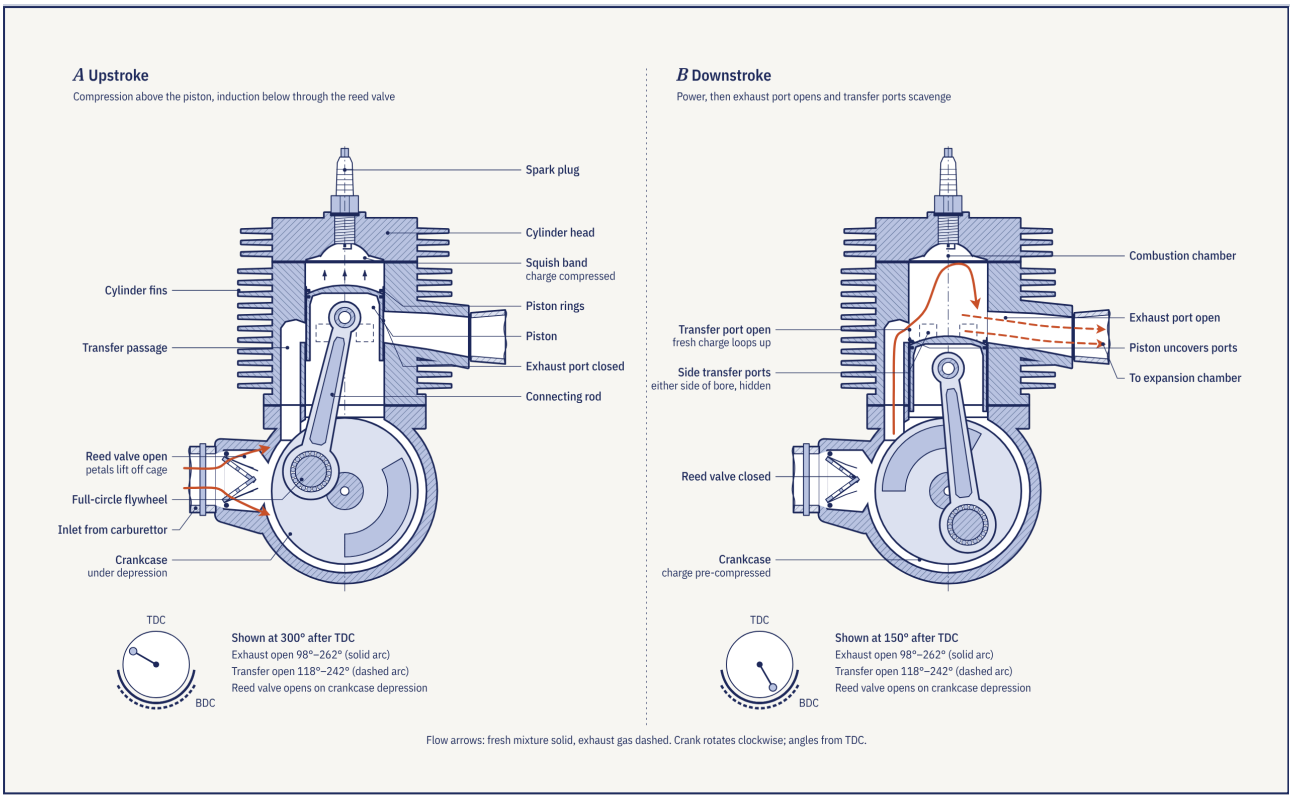


FIGURE 2.4 The two-stroke cycle in two panels: the upstroke compresses the charge above the piston while fresh mixture enters the crankcase through the reed valve; the downstroke delivers power, opens the exhaust port and then the transfer ports, which scavenge the cylinder.

Upstroke (BDC to TDC). Above the piston, the rising crown first closes the transfer ports and then the exhaust port, after which the trapped charge is compressed and ignited near TDC. Below the piston, crankcase volume increases and pressure falls to about 0.6–0.8 bar absolute, so fresh mixture is drawn into the crankcase through the inlet tract.

Downstroke (TDC to BDC). Combustion pressure drives the piston down. Below it, the inlet closes and the descending piston compresses the crankcase charge to about 1.3–1.5 bar absolute. Above it, the crown uncovers the exhaust port at roughly 80–100° before BDC, and blowdown drops cylinder pressure sharply. A few degrees later it uncovers the **transfer ports**, and the pressurised crankcase charge flows up into the cylinder, pushing burnt gas out of the exhaust. Port events are symmetrical about BDC because the piston both opens and closes them.

Typical **port durations** (crank degrees with the port open) indicate tuning:

Engine type	Exhaust duration	Transfer duration	Blowdown (exhaust lead)
Moped or road commuter	160–175°	115–122°	20–25°
Enduro or road sports	180–190°	122–128°	26–30°
Motocross 125	190–200°	128–134°	30–33°

Longer durations and more blowdown time favour high rpm, as long as the exhaust system can recover the charge that escapes.

Induction systems

Piston port. The piston skirt opens and closes an inlet port in the cylinder wall, giving symmetrical timing about TDC. It is the simplest arrangement (old Jawa, CZ and many mopeds), but a long inlet duration lets charge blow back at low speed.

Reed valve. A wedge-shaped **reed block** between carburettor (or throttle body) and crankcase carries flexible petals of spring steel or fibre composite that open only when crankcase pressure is below inlet pressure, so inlet timing becomes automatic and asymmetrical. Almost all modern two-strokes, including the Yamaha YZ125 and KTM models, use reeds. A chipped or warped petal costs low-speed torque and makes the engine spit fuel back through the inlet.

Rotary (disc) valve. A thin disc on the crankshaft, with a cut-out sector, covers an inlet port in the side of the crankcase. Timing is fixed by the cut-out and can be asymmetric (typically opening 130–145° BTDC and closing 60–80° ATDC). Rotary valves were common in Grand Prix racing (Aprilia RS125/250, Rotax tandem twins), but they widen the engine because the carburettor sits on the side of the crankcase.

Scavenging

Scavenging is the replacement of burnt gas with fresh charge, and it is the central difficulty of the two-stroke because exhaust and transfer ports are open together. Early engines used cross-flow scavenging with a deflector piston; modern engines use **loop (Schnürle) scavenging**, patented by Adolf Schnürle in the 1920s: two or more pairs of transfer ports are angled away from the exhaust port, so the incoming streams strike the cylinder wall opposite the exhaust, rise toward the head, turn and descend toward the exhaust, sweeping burnt gas ahead of them in a loop. Modern cylinders have five to seven ports: a main exhaust (often with auxiliary exhaust ports), two pairs of transfers, and a **boost port** opposite the exhaust.

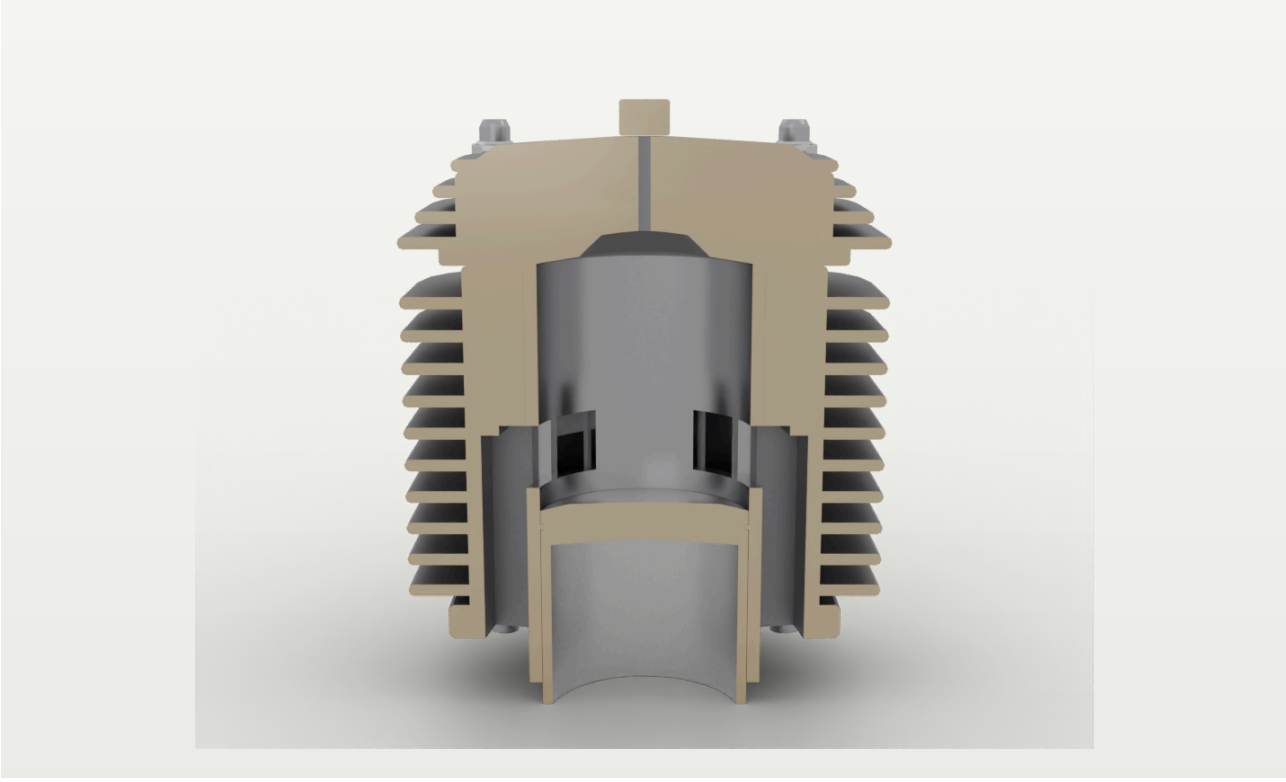


FIGURE 2.5 Two-stroke cylinder cut away through the transfer passages, showing how the channels lead from the crankcase to the windows in the liner.

Render: Transitions Lab, CC BY-SA 4.0

Some fresh charge always **short-circuits** straight out of the exhaust. In carburetted engines, where the charge already contains fuel, losses of **20–40 %** of the delivered charge are common at full throttle, and light-load misfiring ("four-stroking") adds more unburnt fuel, which is the origin of high **hydrocarbon (HC)** emissions and fuel consumption.

The expansion chamber

A tuned **expansion chamber** turns scavenging losses into a gain. When the exhaust port opens, a positive pressure pulse travels down the pipe at the local speed of sound (about 500–520 m/s in hot exhaust gas). In the divergent cone (diffuser) the pulse is reflected back as a negative (suction) wave that arrives at the port during the transfer phase and helps draw burnt gas out and pull fresh charge up the transfers. The convergent cone (baffle cone) at the end reflects the pulse as a positive wave that arrives just before the exhaust port closes and pushes the charge that has escaped into the header back into the cylinder.

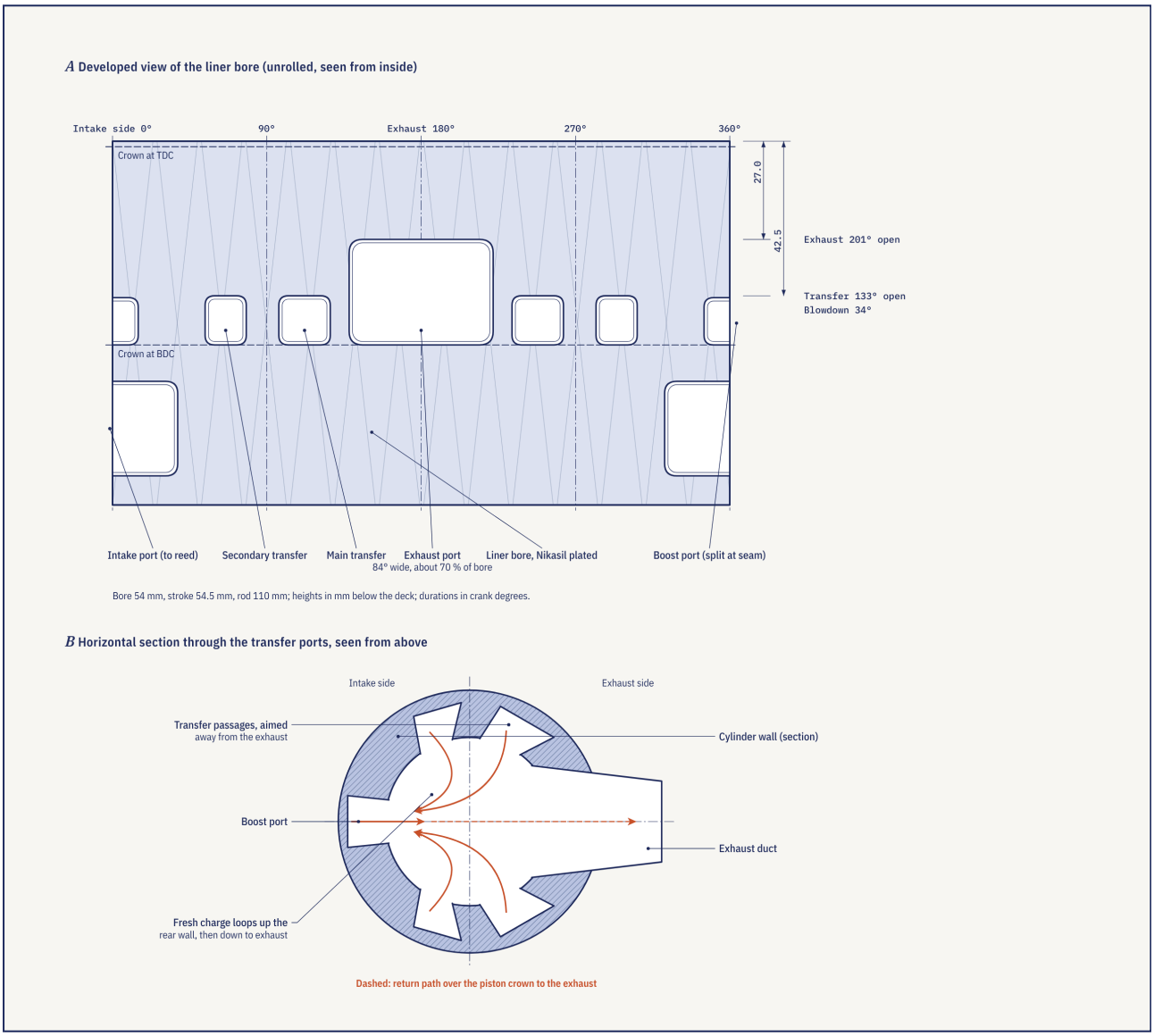


FIGURE 2.6 Two-stroke ports: the liner unrolled to show exhaust, transfer and boost ports with their timing heights, and a horizontal section showing loop scavenging.

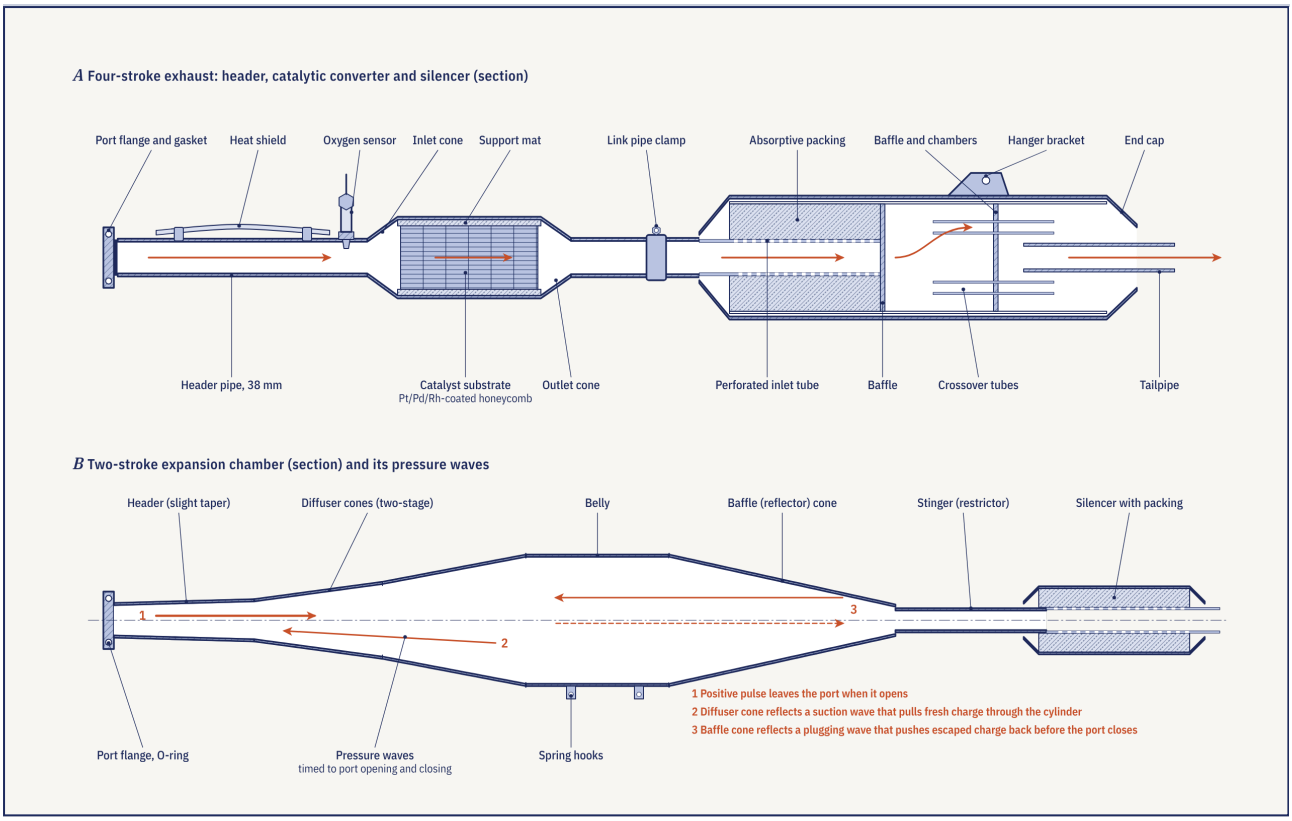


FIGURE 2.8 Exhaust systems in section: four-stroke header, catalytic converter and silencer, and the two-stroke expansion chamber with its diffuser, belly, baffle cone and stinger.



FIGURE 2.7 A two-stroke expansion chamber built from welded cone segments, ending in the stinger and silencer.
Render: Transitions Lab, CC BY-SA 4.0

A first estimate of the tuned length, from port to the mid-point of the baffle cone, follows from the time the port is open and the wave speed:

```
L ≈ a × θex / (12 × N)
```

where L is the tuned length in metres, a is the speed of sound in exhaust gas (about 500 m/s), θex is exhaust duration in degrees and N is rpm (the factor 12 combines the 6N degrees per second and the out-and-back travel).

For a 125 motocross engine with 194° exhaust duration tuned for 11,500 rpm, L ≈ 500 × 194 / (12 × 11,500) = 0.70 m. Because the reflection timing is fixed in milliseconds, the pipe only helps over a band of rpm, which is the main reason for the narrow powerband of a tuned two-stroke.

Power valves

A **power valve** changes the effective height (and so the timing) of the exhaust port, or the volume of the exhaust system, with rpm. At low rpm it lowers the port roof, giving a shorter exhaust duration, a higher trapped compression ratio and less charge loss; at high rpm it opens fully for maximum duration. Yamaha's YPVS uses a rotating spool in the port roof; KTM and others use sliding guillotine blades; Honda's HPP, Kawasaki's KIPS and Suzuki's AETC are other variants. Carbon from burnt oil seizes power valves, so they need regular cleaning: a valve **stuck closed** gives an engine that will not rev, one **stuck open** gives no bottom-end torque.

Lubrication by premix and oil injection

A two-stroke cannot hold an oil bath in its crankcase, which is part of the induction tract, so bearings and cylinder wall are lubricated by oil carried in with the charge, which then burns or leaves through the exhaust:

- **Premix.** Oil is mixed into the fuel in a fixed ratio, commonly **50:1** for modern synthetic oils in road and enduro engines, and 32:1 to 40:1 for racing. To make 5 L of 50:1 mix, add 5,000 / 50 = 100 mL of oil; at 32:1 the same fuel needs 156 mL.
- **Oil injection.** A separate tank feeds a small metering pump (Yamaha Autolube, Suzuki CCI, Kawasaki Superlube, and electronically controlled pumps on KTM's injected engines) that delivers oil to the inlet tract or directly to the main bearings in proportion to engine speed and throttle opening, typically between about 100:1 at idle and 30:1 at full load. A failed pump or **empty tank seizes the engine** within minutes.

Two-stroke oils are classified by JASO M345 (grades FA, FB, FC and FD, increasing in detergency and in reduced smoke) and ISO-L-EGB/EGC/EGD.

Why two-strokes make more power and more pollution

The two-stroke fires every revolution and has no valve train to limit rpm, so at equal displacement it can produce **1.5 to 2 times** the power of a four-stroke with fewer parts and less weight. Its weaknesses follow from the same features: short-circuiting charge, burnt oil (blue smoke and particulates), unstable part-load combustion and hot pistons that never get a cooling gas-exchange stroke. Under Euro emission rules carburetted two-strokes largely left road use from the early 2000s, surviving in competition, enduro and older commuter fleets in Asia and Africa.

Injected two-strokes

Injecting fuel after the exhaust port has nearly closed means that only air short-circuits, which removes most of the HC penalty. Air-assisted direct injection derived from Orbital's system was used in scooters such as the Aprilia DiTech and Peugeot TSDI. KTM introduced **Transfer Port Injection (TPI)** on its 250 and 300 EXC enduro models for the 2018 model year: injectors in the rear transfer ports spray fuel into the scavenging flow, far from the exhaust port, while an ECU uses throttle, crankcase pressure and temperature sensors, and an electronically controlled pump meters oil from a separate tank into the inlet tract. From the 2023–2024 model years KTM moved to Throttle Body Injection (TBI), which places the injectors in the throttle body and was introduced to give a more carburettor-like response at low rpm.

> EXPLORER EXERCISE · transitionslab.org/motorcycle-anatomy **Two-stroke toggle**
>
> Switch the explorer to the two-stroke model and run the cycle animation slowly. Pause when the exhaust port starts to open and when the transfer ports start to open, estimate both crank angles, and calculate the blowdown period. Then raise the RPM slider and note how many power strokes per second the two-stroke delivers compared with the four-stroke at the same speed.

REVIEW QUESTIONS

1. Describe what happens above and below the piston of a two-stroke during the upstroke.
2. Why are the port events of a piston-port two-stroke symmetrical about BDC, and why can a rotary valve engine have asymmetric inlet timing?
3. An exhaust port opens 97° before BDC. What is the exhaust duration? If the transfers open 64° before BDC, what is the blowdown period?
4. Explain loop scavenging and why a boost port is placed opposite the exhaust.
5. Calculate the approximate tuned length of an expansion chamber for an engine with 188° exhaust duration tuned for 9,500 rpm (wave speed 500 m/s).
6. How much oil is needed to make 12 L of fuel at 40:1, and at 50:1?
7. A YZ125 will rev but has no low-speed pulling power after a rebuild. The rider says it "comes on with a bang" at 9,000 rpm. Suggest two causes connected with this chapter.
8. Why do carburetted two-strokes emit more HC than four-strokes, and how does transfer-port injection reduce it?

ANSWERS

1. Above the piston the transfer and then exhaust ports close and the trapped charge is compressed toward ignition near TDC. Below, the crankcase volume grows, pressure falls below atmospheric, and fresh mixture enters through the reed valve or inlet port.
2. The piston uncovers each port at a certain distance from BDC on the way down and covers it at the same distance on the way up, so opening and closing are equally spaced about BDC. A rotary valve is a separate disc whose cut-out sector can be positioned and sized independently of piston position.
3. Exhaust duration = 2 × 97 = 194°. Blowdown = 97 − 64 = 33°.
4. Transfer ports aim the fresh charge away from the exhaust, so it travels across and up the far wall, turns at the head and descends toward the exhaust, pushing burnt gas ahead in a loop. A boost port opposite the exhaust adds flow up the rear wall, filling the region that the main transfer streams would otherwise leave stagnant.

5. L ≈ 500 × 188 / (12 × 9,500) = 94,000 / 114,000 = 0.82 m.
6. 40:1: 12,000 / 40 = 300 mL. 50:1: 12,000 / 50 = 240 mL.
7. A power valve stuck open or incorrectly assembled (so the port is always at full height), or chipped or broken reed petals letting charge blow back; a leaking exhaust joint upsetting the pipe's suction wave is another possibility.
8. Carburetted charge already contains fuel, so whatever short-circuits from the transfers to the exhaust during scavenging leaves unburnt, together with fuel from part-load misfires. With transfer-port injection, fuel is sprayed into the transfer flow late in the scavenge process and directed away from the exhaust, so mostly air short-circuits.

CHAPTER 2.4

The top end

LEARNING OBJECTIVES

- → Identify the parts of a four-stroke cylinder head and explain the function, material and wear modes of each.
- → Compare combustion chamber shapes and the reasons for two-, three- and four-valve layouts.
- → Distinguish OHV push-rod, SOHC rocker and DOHC bucket or finger-follower valve trains and their adjustment methods.
- → Explain cam chain drive and tensioning, decompression devices, and why valve clearance closes up with wear.

Cylinder head and combustion chamber

The **cylinder head** closes the cylinder, carries the valves, ports, spark plug and (in overhead-cam engines) the camshafts, and conducts heat to the fins or water jacket. Heads are cast in heat-treated aluminium-silicon alloy with harder inserted valve seats and guides. The head face must be flat to seal the gasket: the K-Light 125 manual allows 0.03 mm standard and a **0.05 mm** flatness limit.

The **combustion chamber** shape determines flame travel, turbulence, surface-to-volume ratio and knock resistance:

- **Hemispherical or spherical.** A dome with valves inclined on either side gives large valves and a central plug. The K-Light 125 manual lists its chamber as spherical, the common choice in two-valve singles.
- **Pent-roof.** Two flat inclined faces meeting at a ridge, standard in four-valve heads. It accommodates four valves at a narrow included angle (20–25° in modern sports engines against 60–90° in older two-valve designs), keeps the chamber compact and places the plug at the centre for a short flame path.
- **Squish band.** A flat area near the cylinder wall where the piston comes within **0.8–1.5 mm** of the head at TDC, squeezing gas toward the centre to create turbulence and cool the end gas, which raises the knock limit. Squish clearance is a key two-stroke tuning dimension.

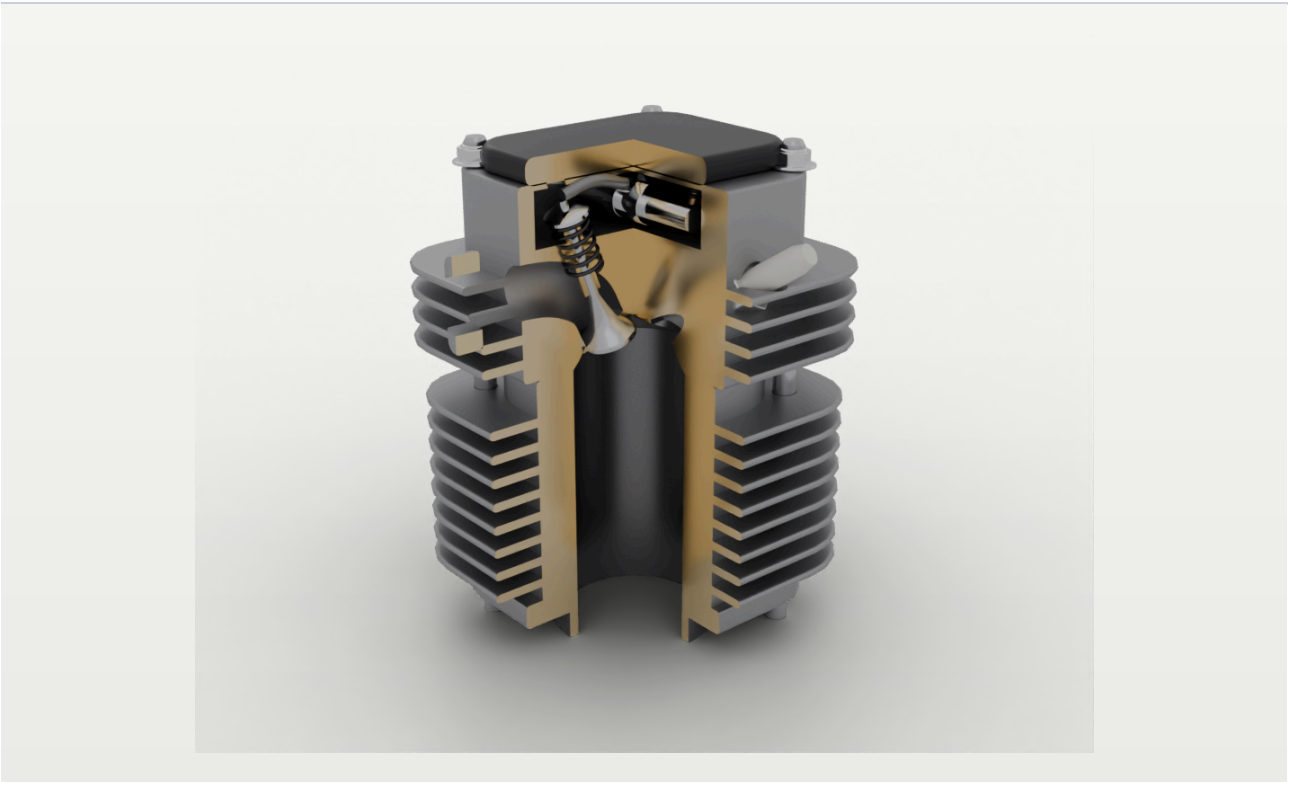


FIGURE 2.9 Cylinder and head in quarter section: liner, combustion chamber, inlet valve and port, and the cooling fins.
Render: Transitions Lab, CC BY-SA 4.0

Two valves per cylinder are cheaper and give high port velocity at low rpm, which suits commuter engines. Four valves provide about 30–40 % more curtain area than two in the same bore, allow higher rpm because each valve is lighter, and place the plug centrally. Three-valve and five-valve (Yamaha Genesis) layouts have also been built.

Valves, seats, guides and springs

Inlet valves are usually martensitic or austenitic steel; exhaust valves, whose heads run at **650–800 °C**, use austenitic steel (for example 21-4N), nickel alloy or a bimetallic construction, and high-performance engines use coated titanium valves.

Each valve closes onto a **valve seat** ring of sintered iron or bronze alloy shrunk into the head. The seat has a 45° sealing face flanked by 30–32° and 60° correcting cuts; the K-Light 125 manual specifies a contact width of 0.8–1.0 mm with a 1.6 mm limit, and describes recutting with 45°, 32° and 60° cutters.

The **valve guide** is a bronze or cast-iron tube pressed into the head that keeps the valve concentric with its seat. A **valve stem seal** on top of the guide meters a little oil to the stem and prevents oil being drawn down the inlet guide by manifold vacuum. Typical K-Light 125 values (K-Light 125 manual): inlet stem diameter 5.44–5.45 mm (limit 5.40), guide bore 5.475–5.485 mm (limit 5.50), stem-to-guide clearance 0.025–0.045 mm inlet (limit 0.08) and 0.03–0.05 mm exhaust (limit 0.10).



FIGURE 2.10 An exhaust valve with a window cut in the stem to show the sodium filling that carries heat from the head to the guide.

Render: Transitions Lab, CC BY-SA 4.0

Valve springs close the valve and keep the follower on the cam. Most engines fit two concentric springs wound in opposite directions, which reduces coil surge and gives a margin if one breaks; progressively wound springs go with the close coils toward the head (K-Light 125 manual). Free-length limits for the K-Light are 30 mm inner (standard 33.5 mm) and 39.5 mm outer (standard 40.9 mm). The springs are retained by a top collar and two split **collets** (cotters) in a groove in the stem. If spring force is inadequate at high speed, the follower leaves the cam (**valve float**) and the valve bounces on its seat and may touch the piston.

Camshaft and valve train types

OHV push-rod. In an **OHV** engine the camshaft sits low in the crankcase, gear-driven from the crankshaft, and operates tappets (cam followers) that push long rods up to rocker arms in the head. The Honda CG125 and its many derivatives use this layout, including the K-Light 125's QJ157FMI engine: its manual describes a cam gear and cam followers in the crankcase and cylinder block, push rods, and rockers on shafts in the head (rocker shaft 11.98–11.988 mm, limit 11.95). It is cheap and tolerant of poor maintenance; push-rod mass and flexibility limit revs, which does not matter in a commuter engine peaking at 9,000 rpm.

SOHC rocker. A **single overhead camshaft (SOHC)** in the head, driven by a chain, operates the valves through rockers with screw-and-locknut adjusters. This is the common layout in modern 100–250 cm³ singles and many scooters.

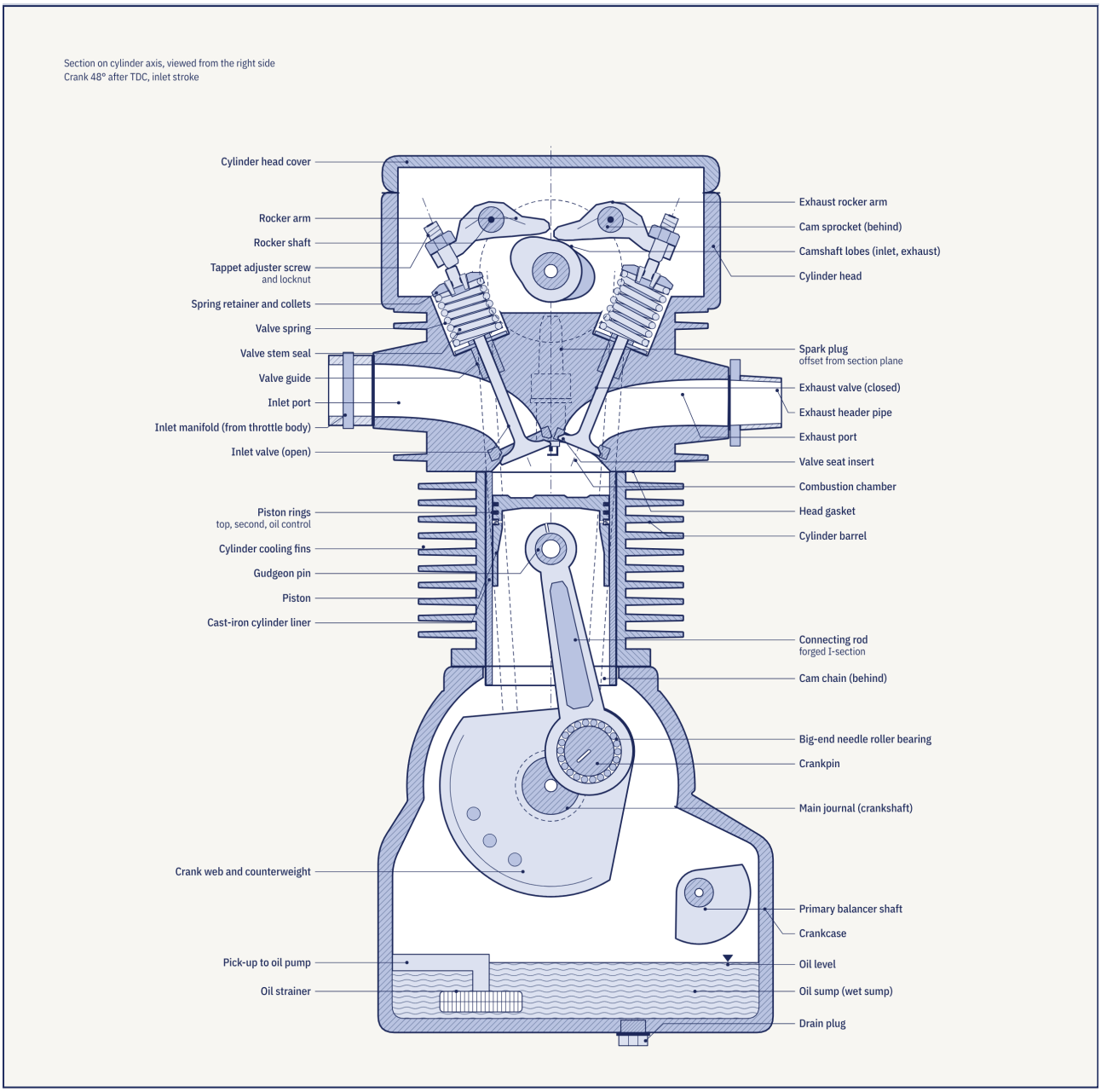


FIGURE 2.11 Sectional view of a single-cylinder four-stroke engine through the cylinder, showing cam chain, camshaft, rockers, valves and springs, spark plug, piston and rings, gudgeon pin, connecting rod, crankshaft, balancer, crankcase, oil sump and cylinder fins.

DOHC. In a **double overhead camshaft (DOHC)** engine two camshafts act on the valves either directly through inverted buckets (with a shim under or on top of the bucket for adjustment) or through short finger followers pivoting on a shaft, which reduce moving mass and allow more aggressive lobe profiles. Almost all high-performance four-valve engines use DOHC.



FIGURE 2.12 A poppet valve with its spring set, assembled (left) and exploded along the stem (right): valve head with ground 45° seat face, spring seat washer, stem seal with garter spring, concentric outer and inner springs, top retainer and the two split collets that lock into the groove near the stem tip.

Render: Transitions Lab, CC BY-SA 4.0

Cam chain, tensioner and decompression

Overhead camshafts are driven at half crank speed by a roller or inverted-tooth **cam chain** running in a tunnel in the cylinder and head, with a fixed guide on one side and a slipper blade pressed by a **tensioner** on the other. Automatic tensioners use a spring-loaded ratchet or wedge plunger that can advance but not retreat. A worn chain or tensioner rattles at idle and on closing the throttle, retards cam timing and can jump teeth; the MAVCC course notes that the tensioner, guides, sprockets and chain wear together and are renewed as a set.

Large singles often have a **decompressor**: a lever, or a centrifugal flyweight on the camshaft that holds the exhaust valve slightly open at cranking speed and retracts once the engine runs. A stuck decompressor gives low compression readings and hard hot starting.

Valve clearance and why it closes up

A small **valve clearance** (lash) is left in the valve train when the valve is closed, to allow for thermal expansion and ensure the valve seats fully. Exhaust clearances are often larger, although the K-Light 125 uses **0.05–0.07 mm** for both. On most modern engines clearance **closes up** with wear. As the valve face and seat wear and are hammered into each other, the valve sits higher in the head (**valve recession**), lifting its stem tip toward the rocker or bucket. A valve with zero clearance no longer closes fully: it loses compression, leaks hot gas across its face, and burns the face and seat within a short time, starting with the exhaust valve. The usual sequence is hard hot starting, low compression and finally a burnt exhaust valve. Wear at the rocker tip, adjuster or cam lobe works the other way, opening clearance and causing ticking, which is more typical of OHV and older SOHC engines.

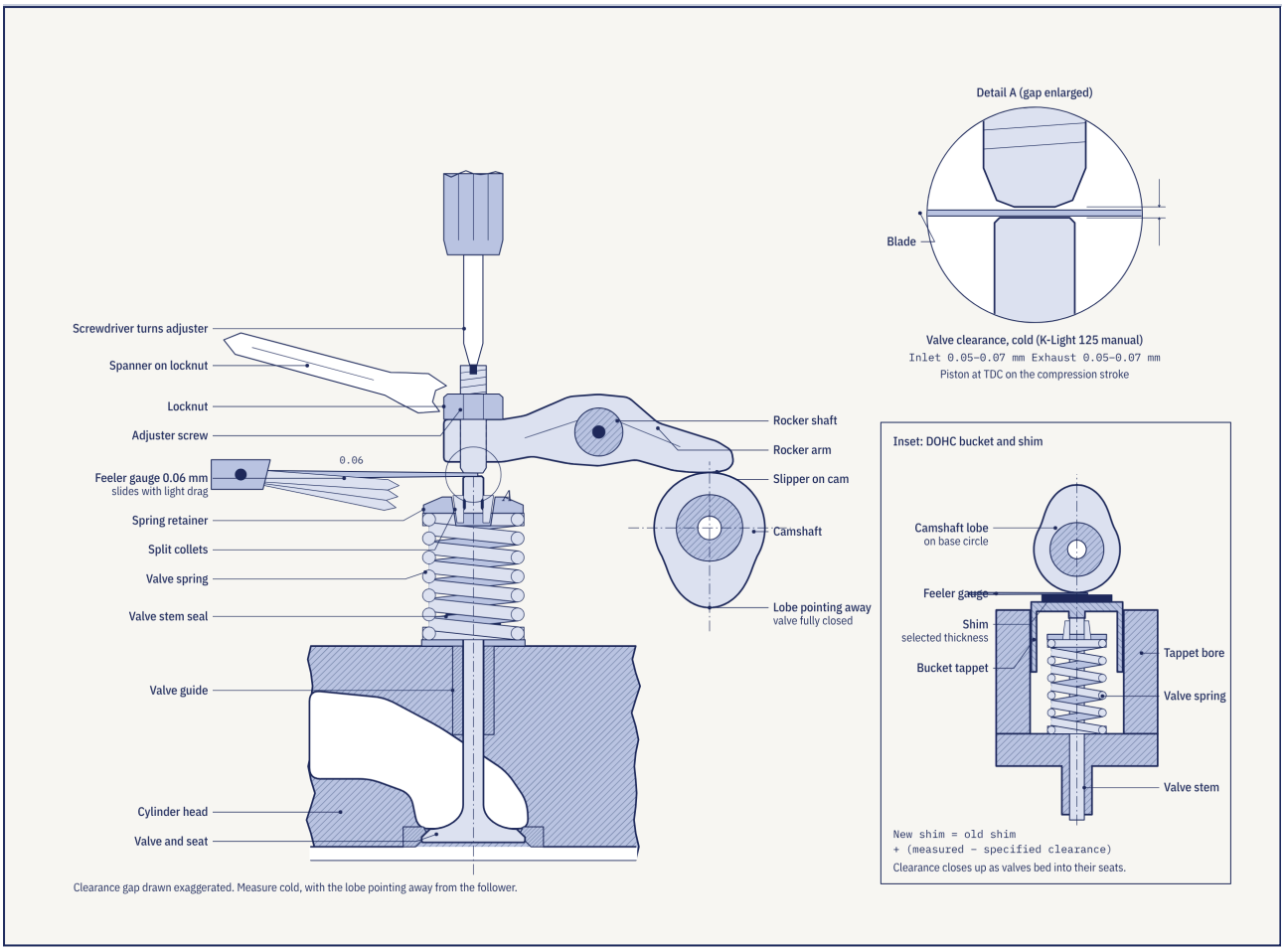


FIGURE 2.13 Valve train detail: SOHC rocker arm with screw-and-locknut adjuster and a feeler gauge measuring valve clearance, with an inset of a DOHC bucket-and-shim arrangement.

REVIEW QUESTIONS

1. Why is a squish band used in the combustion chamber, and what clearance is typical?
2. Give two advantages of four valves per cylinder over two.
3. Why are exhaust valves made from different materials from inlet valves?
4. A K-Light 125 inlet valve stem measures 5.42 mm and its guide 5.49 mm. Calculate the clearance and decide whether either part must be replaced.
5. Explain valve float and its consequences.
6. Name the valve train of the K-Light 125, and explain why it suits that engine.
7. A shim-under-bucket engine has 0.12 mm clearance on an exhaust valve with a specification of 0.22–0.27 mm and a 2.60 mm shim fitted. Which shim should be fitted to reach the middle of the range?
8. Explain why valve clearance usually closes up as a modern engine wears, and the consequence of ignoring it.

ANSWERS

1. The squish band forces gas toward the centre of the chamber as the piston approaches TDC, creating turbulence that speeds the flame and cooling the end gas, which raises the knock limit. Clearance is typically 0.8–1.5 mm.

2. Greater total valve curtain area and better flow for higher BMEP and rpm; lighter individual valves for higher safe rpm; a central spark plug location for a short flame path.
3. Exhaust valves run at 650–800 °C and must resist creep, oxidation and corrosion by hot exhaust gas, so heat-resistant austenitic steels or nickel alloys are used; inlet valves are cooled by incoming charge and can use cheaper steels.
4. Clearance = 5.49 − 5.42 = 0.07 mm, within the 0.08 mm inlet limit. The stem (5.42 mm) is above its 5.40 mm limit and the guide (5.49 mm) below its 5.50 mm limit, so both may be reused, but the margin is small and replacement is advisable during a full overhaul.
5. At high rpm the spring cannot keep the follower in contact with the closing flank of the cam, so the valve closes late and bounces on its seat. Power falls off, valves and seats are damaged, and in interference engines the valve can hit the piston.
6. OHV push-rod with rockers and screw adjusters, cam gear-driven in the crankcase. It is cheap, compact in height, durable and easy to adjust; its rpm limit is not a constraint for a commuter engine peaking at 9,000 rpm.
7. Required shim = existing shim + (measured clearance − target clearance) = 2.60 + (0.12 − 0.245) = 2.60 − 0.125 = 2.475 mm, so fit a 2.475 mm shim (shims are normally supplied in 0.025 mm steps).
8. The valve and seat wear and the valve recedes into the head, moving its stem tip toward the rocker or bucket, which reduces clearance. At zero clearance the valve stays slightly open, hot gas leaks across its face, compression is lost and the valve burns.

CHAPTER 2.5

The bottom end

LEARNING OBJECTIVES

- → Describe piston construction, the function of each ring and the role of the gudgeon pin.
- → Compare one-piece connecting rods with roller big ends and split rods with plain bearings, and pressed-up with one-piece crankshafts.
- → Calculate the primary inertia force of a single and explain balance factor and balancer shafts.
- → Identify main bearing types, crankcase split arrangements and seals, with their typical failure modes.

Piston and rings

Motorcycle pistons are aluminium-silicon alloy. **Cast pistons** (around 12 % Si, or hypereutectic 16–18 % Si for lower expansion) suit most road engines; **forged pistons** (2618 or 4032-type alloys) have better fatigue strength when hot and can be thinner and lighter, so they are used in sports and racing engines. The piston is **cam-ground** (slightly oval, smaller across the pin bosses where there is more metal to expand) and tapered (smaller at the crown, which runs hotter). This is why pistons are always measured across the skirt at **90° to the pin** at a specified height (MAVCC); the K-Light 125 manual specifies **11 mm** above the bottom of the skirt. Skirts are short, often slipper-cut and coated to reduce friction.

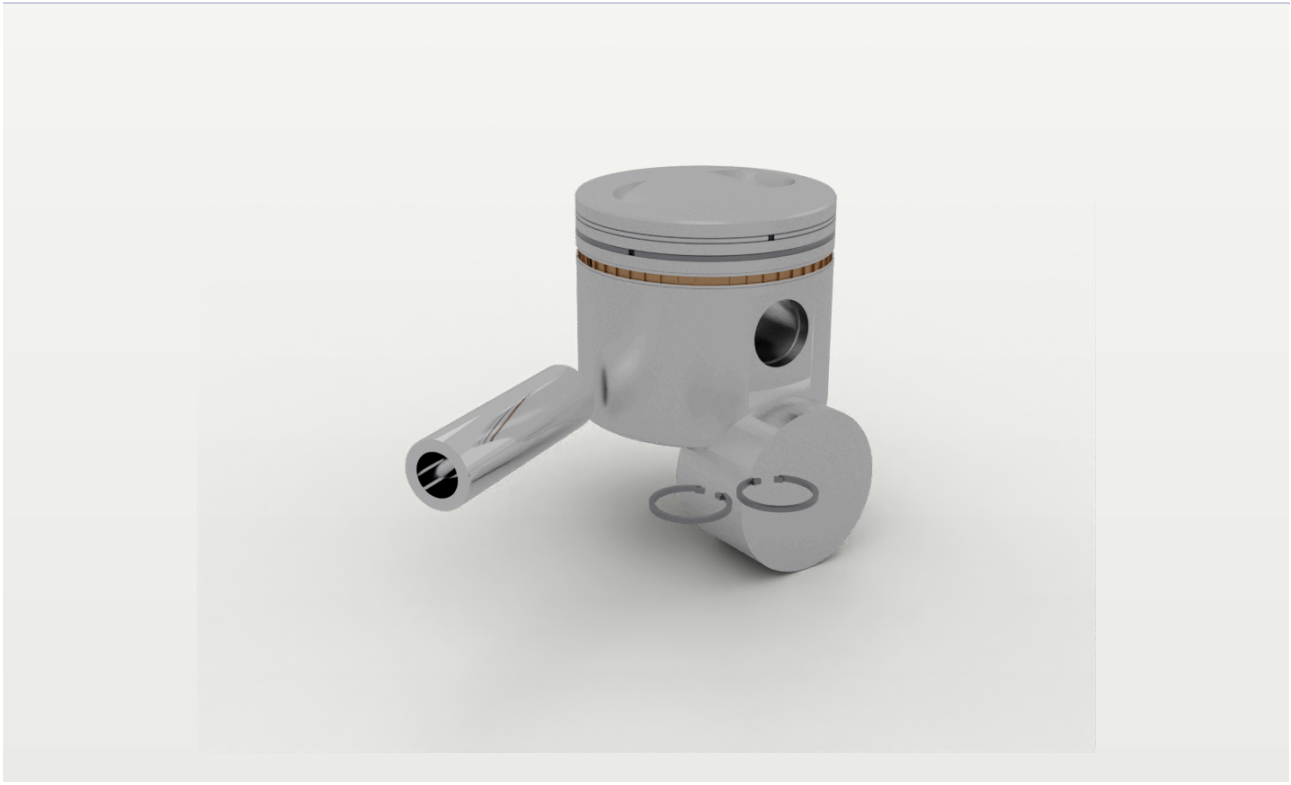


FIGURE 2.14 A piston with its ring pack, gudgeon pin and circlips laid out beside it.
Render: Transitions Lab, CC BY-SA 4.0

A four-stroke **ring pack** has three rings:

- **Top compression ring.** Seals combustion pressure, which also pushes the ring against the bottom of its groove and outward against the wall. It is usually chrome- or nitride-faced steel or ductile iron, marked to show which side faces up.
- **Second ring.** Completes the gas seal and scrapes oil downward. It is commonly a taper-faced or Napier (hooked) cast-iron ring, as the MAVCC course describes ("dark in colour, with a notch that points down").
- **Oil control ring.** Usually three pieces: two thin steel rails and a corrugated expander-spacer that presses them outward. Oil scraped from the wall drains through holes in the groove to the inside of the piston. The expander ends **must butt, not overlap**.

Two-stroke pistons usually have one or two rings, often of keystone section, located by pins in the grooves so their ends cannot spring into a port. **Ring end gaps** allow for thermal expansion; the K-Light 125 manual gives 0.15–0.30 mm for both compression rings with a 0.5 mm limit, and ring-to-groove side clearance of 0.015–0.05 mm (limit 0.09 mm).

Gudgeon pin and connecting rod

The **gudgeon pin** (piston pin) is a hollow case-hardened steel tube joining piston and small end, retained by circlips or wire clips. Four-stroke small ends usually run directly on the pin with a plain bushing or bare steel bore lubricated by splash; two-stroke small ends need a caged needle roller bearing because they receive no oil spray. K-Light 125 values: pin 12.994–13.000 mm (limit 12.96), piston pin bore 13.002–13.008 mm (limit 13.04), small end bore 13.010–13.018 mm (limit 13.06).

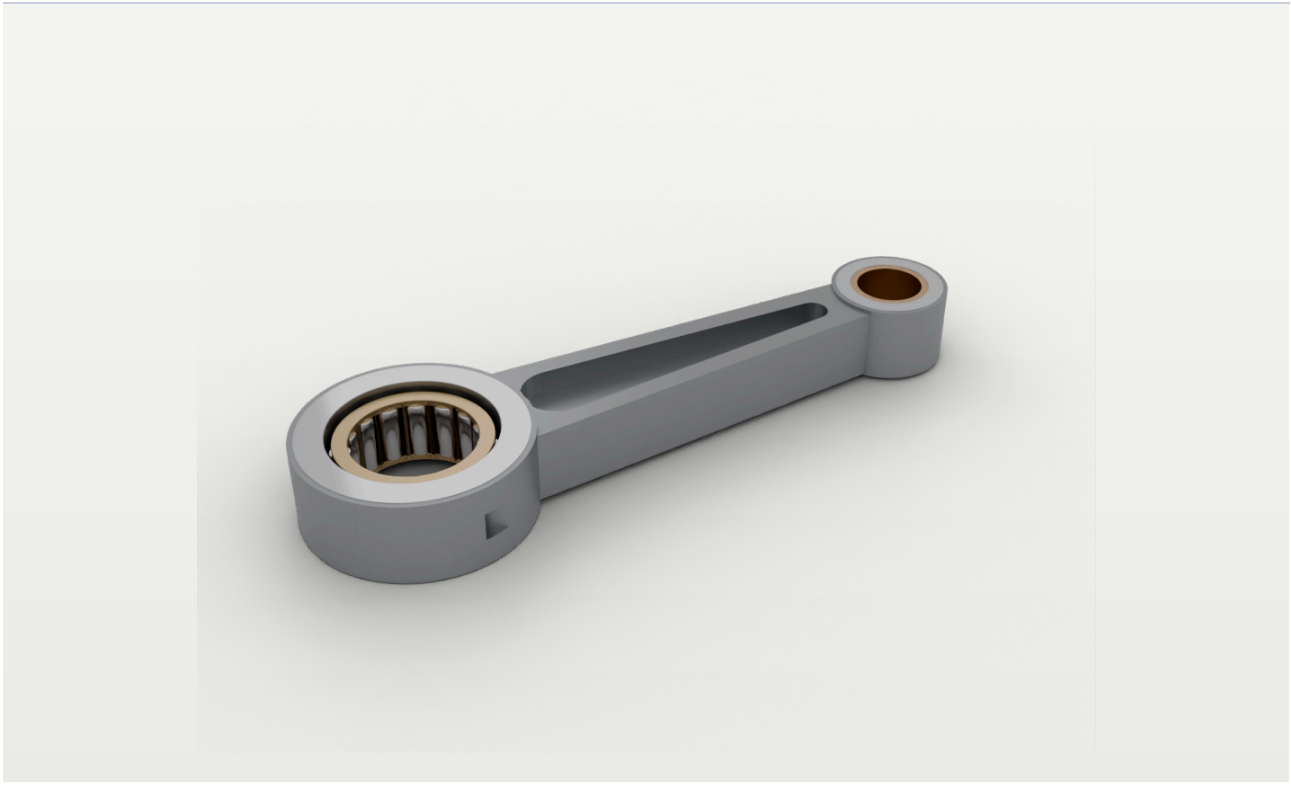


FIGURE 2.15 A forged I-section connecting rod with a caged needle-roller big end and a bronze-bushed small end.
Render: Transitions Lab, CC BY-SA 4.0

Connecting rods are forged steel (titanium in some racing engines) with an H- or I-section shank. Two arrangements dominate:

Feature	One-piece rod, roller big end	Split rod, plain bearing
Typical use	Singles, twins, all two-strokes, many commuter four-strokes (K-Light 125)	Multis and larger four-stroke singles
Crankshaft	Pressed-up (built-up) from webs and crankpin	One-piece forged
Bearing	Caged needle or crowded roller on hardened crankpin	Steel-backed bimetal or trimetal shell bearing
Lubrication	Splash or modest pressure; tolerant of low pressure	Full pressure feed at 3–6 bar; needs clean oil
Service	Replace crank assembly or press apart and rebuild	Shells replaced; crank reground in some cases

K-Light 125 crank values (K-Light 125 manual): big-end radial clearance 0.008–0.018 mm (limit 0.05 mm), side clearance 0.10–0.35 mm (limit 0.55 mm), crankshaft runout limit 0.10 mm in the specification table. The manual specifies replacing the crankshaft assembly if the main bearings are noisy or loose.

Crankshaft and balance

A **pressed-up crankshaft** consists of two flywheel webs with counterweights joined by a pressed-in crankpin, and must be trued after assembly to within about 0.02–0.05 mm runout, checked in V-blocks with a dial gauge. A **one-piece crankshaft** is forged alloy steel with hardened journals.



FIGURE 2.16 A one-piece four-cylinder crankshaft with counterweights, crankpins, main journals and the flywheel flange.
Render: Transitions Lab, CC BY-SA 4.0

The **reciprocating mass** (piston, rings, pin, clips and the upper part of the rod) stops and restarts twice per revolution. Its **primary inertia force** along the cylinder axis is approximately:

$$F_p = m \times r \times \omega^2 \times \cos\theta$$

$$F_s = m \times r \times \omega^2 \times (r/l) \times \cos 2\theta$$

where Fp is the primary force, Fs the secondary force, m the reciprocating mass, r the crank radius (half the stroke), ω the angular speed in rad/s, θ crank angle from TDC, and l the connecting rod centre-to-centre length.

Assuming a reciprocating mass of 0.20 kg for a 125 cm³ single (a typical value, not a K-Light specification), r = 0.02475 m and 9,000 rpm (ω = 942 rad/s), the peak primary force is 0.20 × 0.02475 × 942² = **4.4 kN**, reversing once per revolution. Counterweights can only balance a rotating force, so counterweighting a fraction of the reciprocating mass (the **balance factor**, typically 50–70 % in singles) trades vertical for horizontal shaking. A **balancer shaft**, geared to counter-rotate with an eccentric weight, cancels the remaining component, which is why many 150–650 cm³ singles and parallel twins carry one. Secondary forces at twice crank speed are about r/l (roughly 0.25–0.3) of primary and are cancelled only by a balancer at twice crank speed, as fitted to some large twins and fours.

Main bearings, crankcase and seals

Singles and two-strokes usually run the crank in ball or roller **main bearings** pressed into the crankcase halves; plain shell mains are used in most multis. Two-stroke cranks need lip seals on both mainshafts to keep the crankcase pressure-tight, and a **leaking crank seal** causes a lean high idle and hanging revs.

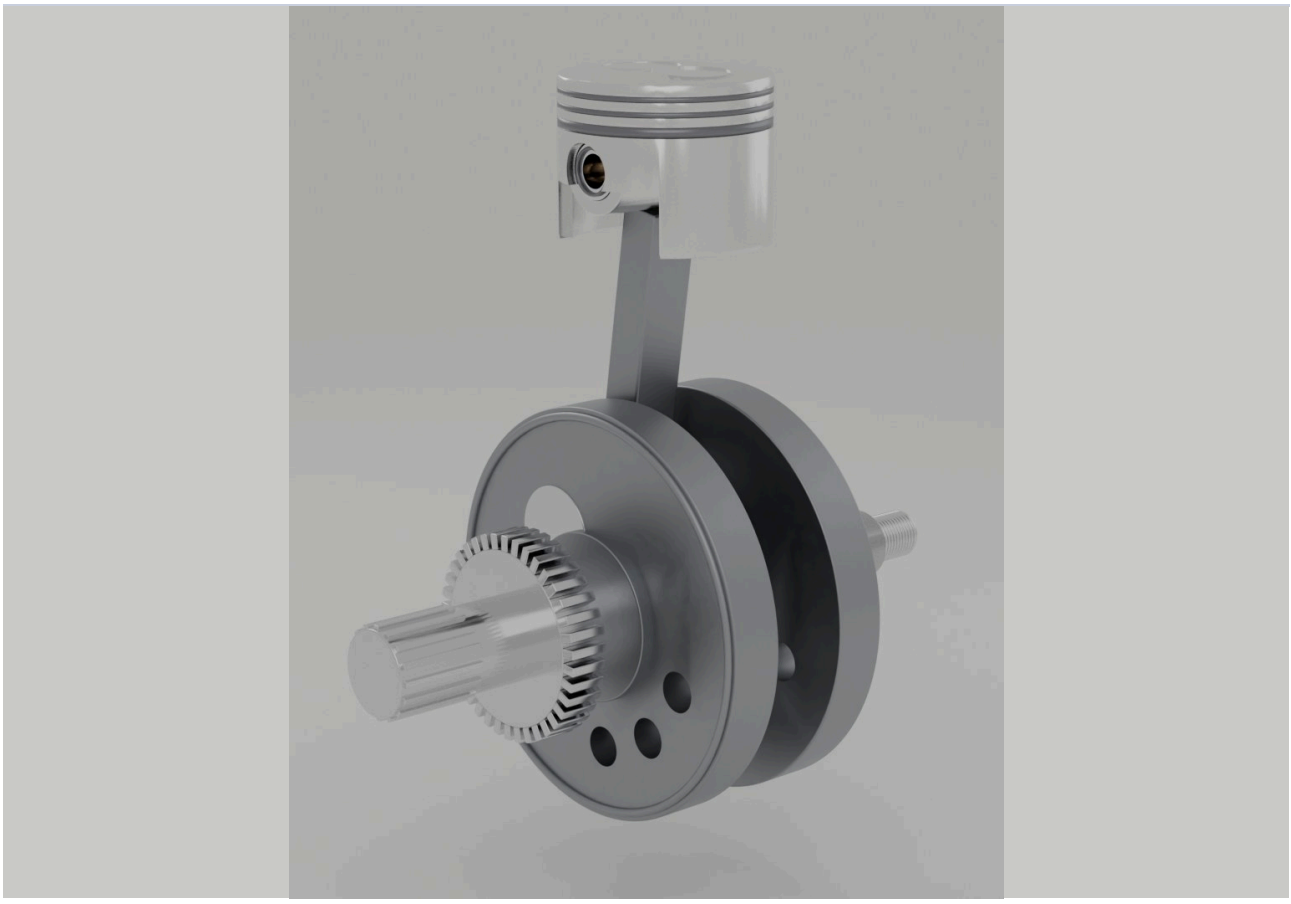


FIGURE 2.17 Pressed-up single-cylinder crank assembly: two full-circle flywheel webs with balance holes drilled opposite the crankpin, a roller-bearing big end on a forged I-section connecting rod, bronze-bushed small end, and a slipper-skirt piston with two compression rings and a three-piece oil ring. The splined left shaft carries the primary drive gear; the right shaft carries the cam-chain sprocket, the keyed taper for the alternator rotor and the rotor nut thread.

Render: Transitions Lab, CC BY-SA 4.0

Most motorcycle crankcases are split vertically (left and right halves, as on the K-Light 125, the CG125 and nearly all singles and two-strokes) or horizontally (upper and lower halves, as on most Japanese fours, which lets the crank and gearbox shafts drop into place). The K-Light 125 manual warns that the crankcase is a thin-walled casting that **must not be struck heavily**.

REVIEW QUESTIONS

1. Why is a piston cam-ground and tapered, and where is its diameter measured on the K-Light 125?
2. State the function of each of the three rings in a four-stroke ring pack.
3. Why does a two-stroke small end need a needle roller bearing when most four-stroke small ends do not?
4. A K-Light 125 big end shows 0.06 mm radial clearance. What action is required?
5. Calculate the peak primary inertia force of a single with 0.32 kg reciprocating mass, 60 mm stroke, at 7,000 rpm.
6. What is meant by balance factor, and what is the effect of choosing 100 %?
7. Why can a counterweight on the crank web never fully balance a single-cylinder engine?
8. A two-stroke idles high and revs hang when the throttle is closed. Which bottom-end component is a likely cause?

ANSWERS

1. The piston has more metal around the pin bosses and is hotter at the crown, so it expands more there; cam grinding and taper give a round, parallel shape at operating temperature. On the K-Light 125 it is measured at 90° to the pin, 11 mm above the bottom of the skirt.
2. Top ring: main gas seal. Second ring: secondary gas seal and oil scraping. Oil control ring: removes excess oil from the bore and returns it through the drain holes.
3. In a two-stroke the crankcase holds no oil bath; the small end receives only the oil mist carried by the charge and runs hot, so a rolling-element bearing with low friction and little oil demand is used. A four-stroke small end is splashed with oil from the crankcase.
4. 0.06 mm exceeds the 0.05 mm limit, so the crankshaft assembly (or rod, pin and rollers in a rebuildable design) must be replaced.
5. r = 0.030 m, ω = 7,000 × 2π / 60 = 733 rad/s. F = 0.32 × 0.030 × 733² = 0.32 × 0.030 × 537,300 = 5,158 N, about 5.2 kN.
6. Balance factor is the counterweight mass, at crank radius, expressed as a percentage of reciprocating mass. At 100 % the vertical primary force is cancelled, but an equal rotating force appears horizontally, so the engine shakes fore-and-aft instead.
7. The reciprocating force acts only along the cylinder axis and varies as cos θ, while a counterweight produces a constant-magnitude rotating force. Any counterweight that cancels the axial force adds an equal force at 90° to it.
8. A leaking crankshaft seal (or base gasket) admitting air into the crankcase, which weakens the mixture and lets the engine run on air not controlled by the throttle.

CHAPTER 2.6

Lubrication and cooling

LEARNING OBJECTIVES

- Trace oil flow through a wet-sump four-stroke and compare wet and dry sump systems.
- Interpret SAE J300 viscosity grades, API service categories and JASO MA, MA1, MA2 and MB classes, and choose an oil for a wet-clutch motorcycle and a scooter.
- Explain how air-cooled engines reject heat and what an oil cooler adds.
- Describe each part of a liquid-cooling system and how the pressure cap raises the boiling point.

Wet and dry sump systems

In a **wet sump** engine the oil is stored in the bottom of the crankcase, which on most motorcycles also houses the gearbox and the wet clutch, so one oil serves engine, transmission and clutch. A **dry sump** engine stores oil in a separate tank (in the frame, as on many enduro singles and Harley-Davidson twins); a scavenge pump returns oil from the crankcase to the tank and a pressure pump feeds the engine. Dry sumps allow a lower engine and avoid oil surge on steep slopes, at the cost of extra pumps and plumbing.

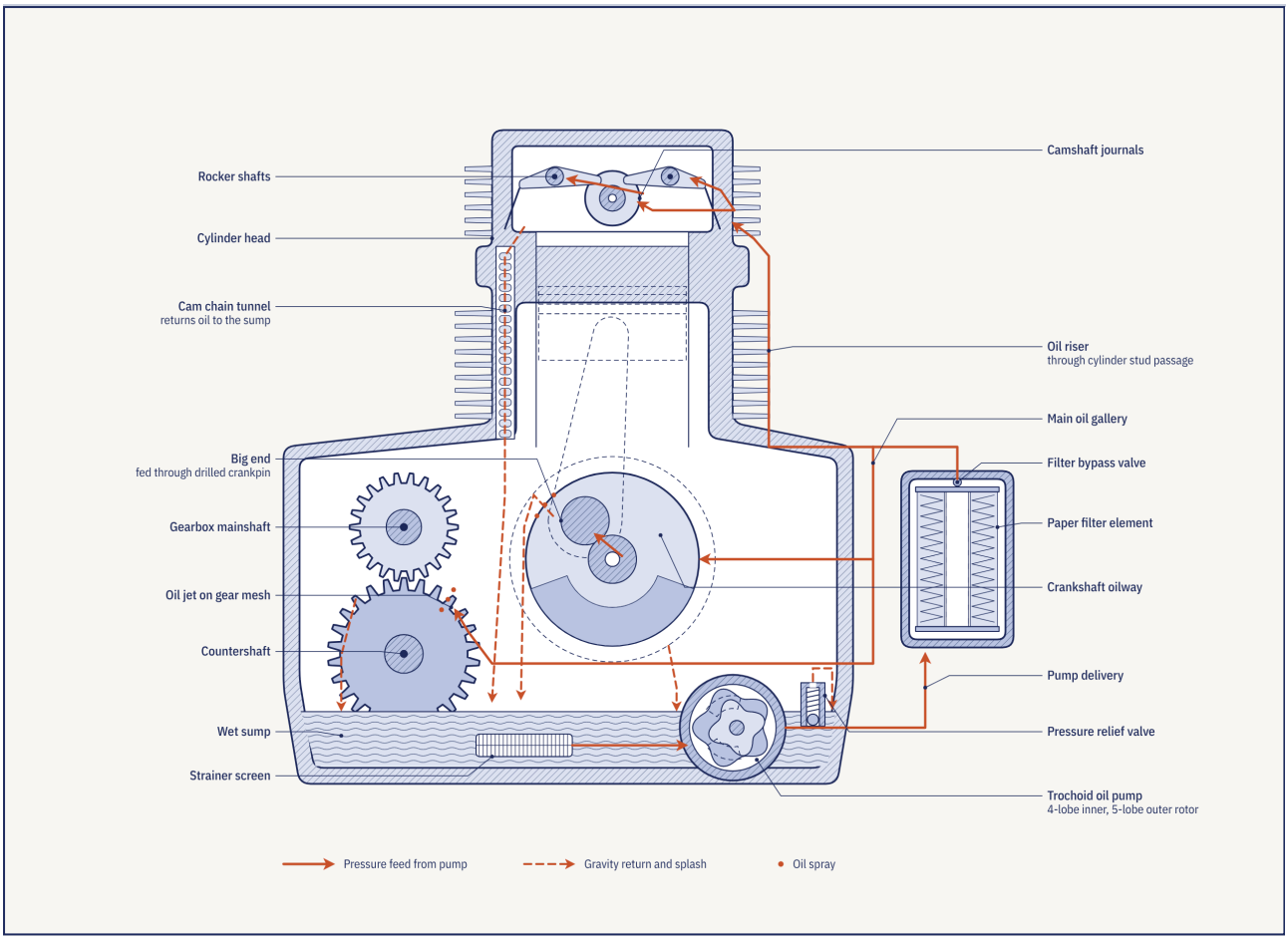


FIGURE 2.18 Wet-sump lubrication circuit of a single-cylinder four-stroke: strainer, trochoid pump, filter, crankshaft and big end, cylinder head and camshaft, gearbox and return to the sump, with oil flow shown in accent colour.

The pump is usually a **trochoid** (rotor) type, an inner rotor with one lobe fewer turning inside an outer rotor so that the chambers between them grow on the suction side and shrink on the delivery side; a **relief valve** limits pressure, typically to 3–6 bar on multis. The K-Light 125 manual gives rotor tip clearance **0.10–0.15 mm** (limit **0.25 mm**), outer rotor to body **0.10–0.15 mm** (limit **0.25 mm**) and rotor end clearance **0.07–0.12 mm** (limit **0.15 mm**). Oil passes a mesh **strainer** before the pump and then a filter. The K-Light, like the CG125, uses a centrifugal **oil filter rotor** on the crankshaft, which spins sludge to its outer wall and must be cleaned at service, in addition to the strainer screen behind the drain plug; most larger engines use a spin-on or cartridge paper filter with a bypass valve. Pressure-fed oil reaches the big end through crank drillings and the cam and rockers through a passage up a stud or pipe; the gearbox, cylinder wall and gudgeon pin are lubricated by spray and splash.

▤ REFERENCE DATA **K-Light 125 lubrication data (K-Light 125 manual)**

Pressure and splash lubrication, wet sump, oil capacity **1.1 ± 0.1 L** at a change and **1.2 ± 0.1 L** after overhaul, oil change every **3,000 km**, strainer and filter cleaned at the specified intervals. Check the level with the machine upright on level ground, with the dipstick resting in the hole, not screwed in.

Engine oil specifications

SAE J300 defines **viscosity grades**. The number after the W is the high-temperature grade, defined by kinematic viscosity at 100 °C: SAE 30 is 9.3 to under 12.5 mm²/s, SAE 40 is 12.5 to under 16.3, SAE 50 is 16.3 to under 21.9, and SAE 60 is 21.9 to under 26.1, with minimum high-temperature high-shear (HTHS) values at 150 °C. The W (winter) number is defined by cold-cranking and pumping viscosity limits at low temperature, so a 10W-40 behaves like a 10W oil when cold and a 40 grade when hot. Typical motorcycle choices are 10W-30, 10W-40 and 15W-50.

API service categories (SL, SM, SN, SP for petrol engines) define wear protection, deposit control and oxidation resistance. Car oils marked "Resource Conserving" contain friction modifiers that can make a wet clutch slip, which is why motorcycle oils are also classified by **JASO T903**:

Class	Friction level	Use
JASO MA	High friction, no slip-promoting modifiers	Four-strokes with wet clutch sharing engine oil
JASO MA1	High friction, lower band of MA	Wet clutch, less demanding
JASO MA2	Highest friction band	Wet clutch, often required by manufacturers with catalysts
JASO MB	Low friction	Scooters and engines with dry or centrifugal clutches

The 2023 revision of JASO T903 aligned its crankcase performance requirements with current API categories, updated the SAE No. 2 clutch friction test to current friction materials and reference oils, and revised physical-chemical limits to protect three-way catalysts. **Never** use a JASO MB or energy-conserving car oil in a motorcycle with a wet clutch. Change intervals range from **3,000 km** on small air-cooled singles such as the K-Light 125 to 6,000–12,000 km on liquid-cooled multis with paper filters; dust, heat and short trips justify shorter intervals.

Air cooling

An air-cooled cylinder and head shed heat through **fins**, which multiply the surface area exposed to the airflow. Fins are deepest around the exhaust port and combustion chamber, where heat flux is highest. Air cooling is light and cheap, but temperatures vary with speed and ambient conditions, so clearances must be larger and compression ratios lower. Oil may carry 20–30 % of the rejected heat, and many larger engines add an **oil cooler** or, like Suzuki's SACS engines, route oil through the head. Mud-packed or broken fins cause overheating, detonation and seizure.

Liquid cooling

A liquid-cooled engine has water jackets cast around the cylinder and combustion chamber. A centrifugal **water pump**, usually driven by the crankshaft or camshaft, circulates **coolant** through the jackets to a **radiator** at the front of the machine. A wax-element **thermostat** keeps coolant in the engine until it reaches about 80–85 °C, then opens progressively, so the engine warms quickly and runs at a stable temperature. A thermo-switch or the ECU starts an electric **fan** at about 95–105 °C when airflow is low, for example in traffic.



FIGURE 2.19 An air-cooled single with deep horizontal fins on the cylinder and head, a radiator mounted ahead of it for the oil or coolant circuit, and the round generator and clutch covers on the crankcase below.

Photograph: Transitions Lab collection

The **pressure cap** holds the system at typically **0.9–1.4 bar** above atmospheric. Since boiling point rises with pressure, a 50 % ethylene-glycol mixture that boils at about 107 °C at atmospheric pressure will not boil until about 125–130 °C under the cap. A cap with a weak seal or spring lets coolant boil, foam and escape to the overflow tank, and a failed head gasket pressurises the system with combustion gas. Coolants are glycol with aluminium-safe inhibitors mixed 50:50 with deionised water (frost protection to about −35 °C), replaced every two to three years as inhibitors deplete.

> SAFETY **Hot cooling systems**
>
> **Never** open a radiator cap on a hot engine. The coolant is above its atmospheric boiling point and flashes to steam when the pressure is released, causing severe scalds. Wait until the engine is cold and release the cap slowly to its first stop.

REVIEW QUESTIONS

1. Give two advantages of a dry sump system over a wet sump on an enduro motorcycle.
2. A K-Light 125 oil pump shows 0.28 mm tip clearance. What is the limit, and what will the rider notice if the pump is left in service?
3. What do the two numbers of a 10W-40 oil describe?
4. Why must a wet-clutch motorcycle use JASO MA/MA2 oil rather than an energy-conserving car oil?

5. Which JASO class is appropriate for a CVT scooter with a dry centrifugal clutch, and why?
6. What is the function of the thermostat, and what happens if it sticks open? If it sticks closed?
7. Why does a pressure cap raise the operating temperature margin of a cooling system?
8. Bubbles appear continuously in the radiator header tank of a liquid-cooled engine at idle. What is the likely cause and how would you confirm it?

ANSWERS

1. Oil supply is maintained when the machine is inclined or decelerating hard, and the engine can be made lower and narrower because no deep sump is needed; churning losses are also lower.
2. The limit is 0.25 mm, so the pump must be replaced. Oil delivery and pressure at the head will be reduced, especially when hot, causing rocker and cam wear, noisy valve train and possible big-end distress.
3. 10W is the cold-temperature grade (cranking and pumping viscosity limits); 40 is the viscosity grade at 100 °C (12.5 to under 16.3 mm²/s).
4. Energy-conserving car oils contain friction modifiers that reduce the coefficient of friction between clutch plates, so the clutch slips, overheats and wears. JASO MA classes guarantee friction within a band suitable for wet clutches.
5. JASO MB, because there is no oil-bathed clutch to slip, and its lower friction reduces engine friction and fuel consumption.
6. It keeps coolant out of the radiator until operating temperature is reached, giving quick warm-up and stable temperature. Stuck open: the engine runs cold, with poor economy and high wear. Stuck closed: coolant cannot reach the radiator and the engine overheats quickly.
7. Raising pressure raises the boiling point of the coolant, by about 2.5–3 °C per 0.1 bar, so the engine can run hotter at the metal surfaces without local boiling that would reduce heat transfer.
8. Combustion gas leaking into the coolant through a failed head gasket or cracked head. Confirm with a combustion leak (block) tester that detects CO_2 in the header tank, or with a leak-down test showing bubbles in the coolant.

CHAPTER 2.7

Engine diagnosis and service

LEARNING OBJECTIVES

- → Use a symptom-cause-check-remedy table to narrow down common engine faults.
- → Perform and interpret dry and wet compression tests and a leak-down test.
- → Check and adjust rocker-arm valve clearance to the K-Light 125 specification.
- → Measure cylinder and piston wear and compare the results with service limits.
- → Rebuild a two-stroke top end and read a spark plug to assess combustion.

Diagnostic approach

An engine needs **compression, a correctly timed spark and the right mixture** (MAVCC), and diagnosis proceeds from the least to the most invasive check. The MAVCC tune-up order (plugs, valve clearance, cam chain, ignition timing, air filter, crankcase ventilation, fuel adjustment, oil change) follows because each adjustment depends on the earlier ones. Confirm fuel, battery voltage, air filter and oil level before dismantling anything.

Symptom	Likely cause	Check	Remedy
Hard starting, cranks normally	No or weak spark; fuel not delivered; low compression; valve clearance too small	Spark test; fuel pressure or injector pulse; compression test; valve clearance	Repair ignition or fuel fault; adjust valves; overhaul top end
Hard hot starting only	Valve clearance closing up; decompressor stuck; rich mixture from leaking injector	Clearance check; compression hot and cold	Adjust; repair decompressor; replace injector
Low power, runs smoothly	Blocked air filter or exhaust (catalyst); retarded timing; worn rings; slipping clutch	Filter; back-pressure; timing light; compression; clutch test in top gear	Clean or replace; repair
Blue smoke	Oil burning: worn rings or bore, worn valve stem seals or guides, overfilled sump	Wet compression test; smoke on overrun (guides) or under load (rings)	Rings, rebore, seals or guides; correct level
Black smoke	Rich mixture: blocked filter, faulty sensor, leaking injector, choke on	Plug reading; ECU fault codes; injector test	Replace or repair
White smoke that persists when warm	Coolant burning: head gasket or cracked head	Coolant level; combustion leak test	Gasket or head
Knocking or pinking under load	Detonation: low octane, carbon, lean mixture, overheating, over-advanced timing	Fuel; timing; plug colour; carbon	Correct fuel; decarbonise; repair cause
Deep knock that rises with load	Big-end or main bearing wear	Crank play with top end removed	Crank assembly
Overheating	Low oil (air-cooled); low coolant, failed fan, stuck thermostat, blocked radiator; lean mixture	Levels; fan switch; thermostat test; plug colour	Repair cause
High oil consumption	Rings, bores, guides, seals; external leaks; breather carrying oil	Compression and leak-down; inspect for leaks and oily air box	Overhaul; renew seals or breather

Job sheet 2.7.1: Compression test

Tools and materials	Reference values
Screw-in compression gauge with adapter, spark plug socket, oil can with engine oil, safety glasses	K-Light 125 cylinder pressure **1.0–1.2 MPa** (145–174 psi) (K-Light 125 manual)

1. Warm the engine to operating temperature, then stop it.
2. Remove the spark plug cap and clean around the plug before removing it so dirt cannot fall in. On EFI engines **disconnect the injector** so fuel is not sprayed during cranking, and earth the plug lead or disconnect the coil.

3. Screw the gauge adapter in by hand until it seals; a leaking adapter gives a false low reading.
4. Open the throttle **fully** and crank with a fully charged battery (or kick firmly) until the needle stops rising, normally 4–8 compression strokes.
5. Record the reading and release the gauge.
6. For a wet test, add about **5 mL** (a teaspoon) of engine oil through the plug hole, crank a few turns to spread it, and repeat the test.
7. Interpret: a dry reading within specification means compression is sound. A low dry reading that rises substantially (more than about **10–15 %**) on the wet test points to rings, piston or bore, because the oil temporarily seals the ring gap. A low reading that hardly changes points to valves (clearance too small, burnt or bent valve, poor seat) or the head gasket. A reading above specification indicates heavy carbon build-up. On a multi, compare cylinders: a difference greater than about **10 %** between cylinders is significant even if each is within limits.
8. Refit the plug to **15 N·m** (K-Light 125 manual) and reconnect the injector.

Pass criteria: dry reading within the manufacturer's range (K-Light 125: 1.0–1.2 MPa), cause of any low reading correctly attributed using the wet test.

Job sheet 2.7.2: Leak-down test

Tools: cylinder leakage tester (two gauges with a calibrated restrictor), regulated compressed air supply of at least 4–7 bar, spark plug adapter, means of holding the crankshaft (gear engaged with rear brake applied, or crank holding tool), safety glasses.

1. Warm the engine, remove the plug and set the piston at **TDC on the compression stroke**, with both valves closed. Confirm by watching the inlet valve open and close, then aligning the T mark (see job sheet 2.7.3).
2. **Lock the crank.** Air at several bar on the piston will turn the engine violently if it is even a few degrees off TDC.
3. Fit the adapter, connect the tester with its regulator wound fully out, then connect the air line and set the input gauge to the tester's calibration pressure (typically 100 psi or 7 bar; the MAVCC sheet uses 60 psi).
4. Read percentage leakage directly, or calculate it as (input − cylinder) / input × 100. With 60 psi in and 40 psi in the cylinder, leakage = 20/60 × 100 = 33 %.
5. Listen to locate leakage: hissing at the exhaust means an **exhaust valve**; at the throttle body or air box, an **inlet valve**; at the oil filler or breather, the **rings**; bubbles in the radiator or air at the head joint, the **head gasket**.
6. Interpret: as a general guide (consult the manual), under **10 %** is good, 10–20 % indicates wear, and over **20–30 %** indicates a fault needing repair. Readings are comparable only on the same tester, because restrictor sizes differ.

Pass criteria: test carried out at TDC compression with the crank secured, percentage leakage recorded, and source of leakage identified.

Job sheet 2.7.3: Checking and adjusting valve clearance on a rocker-arm single

This procedure applies to SOHC rocker engines and to OHV push-rod engines such as the K-Light 125, since both use a screw-and-locknut adjuster at the rocker tip.

Tools and materials	Reference values (K-Light 125 manual)
Feeler gauges (0.05, 0.06, 0.07 mm), ring spanner for locknut, adjuster tool or screwdriver, 14 mm socket for turning the crank, new cover gaskets	Inlet **0.05–0.07 mm**, exhaust **0.05–0.07 mm**, engine **cold** (below 35 °C); adjuster locknut **10–15 N·m**

1. Work on a cold engine. Remove the valve inspection caps or rocker cover and the timing hole cap on the left crankcase cover.
2. Turn the crankshaft in its normal direction (anticlockwise on the K-Light flywheel nut, as the manual states) with a socket on the rotor nut. Watch the inlet rocker: when the inlet valve has opened and closed, continue turning slowly until the **T mark** on the rotor aligns with the index mark. The piston is now at TDC on the compression stroke.
3. Confirm both rockers have free play. If either is tight, turn the crank one more turn and realign the T mark.
4. Slide a feeler gauge of the specified thickness between the adjuster screw tip and the valve stem. The correct gauge should slide with a light drag; the gauge 0.01 mm thicker should not enter.
5. To adjust, hold the adjuster, slacken the locknut, turn the adjuster until the gauge has a light drag, then hold the adjuster still and tighten the locknut to **10–15 N·m**. The manual instructs adjusting the exhaust valve first, then the inlet.
6. Recheck the clearance after tightening, because tightening the locknut can turn the adjuster slightly and close the gap.
7. Rotate the crank two full turns, realign T, and recheck both valves.
8. Refit caps with new O-rings. A clearance found too small at the previous service, especially on the exhaust, indicates valve recession and suggests a compression test.

Pass criteria: both valves within 0.05–0.07 mm cold at TDC compression after locknut tightening, locknuts at specified torque, no oil leaks.

Job sheet 2.7.4: Cylinder and piston measurement

Tools and materials	Reference values (K-Light 125 manual, mm)
Dial bore gauge or telescopic gauge with 50–75 mm outside micrometer, 50–75 mm outside micrometer for the piston, feeler gauges, straightedge, clean lint-free cloth	Bore standard 56.500–56.505 (the table prints "56-56.505"), limit **56.6**; out-of-round and taper limit **0.05**; piston OD 56.470–56.485 at 11 mm above skirt bottom, limit **56.43**; piston-to-cylinder clearance limit **0.17**; ring end gap 0.15–0.30, limit **0.5**; ring side clearance limit **0.09**; cylinder top flatness limit **0.05**

1. Clean the cylinder and piston, remove carbon from the piston crown and ring grooves (a broken old ring makes a good groove scraper), and inspect for scoring, seizure marks and cracks before measuring. A cylinder that is visibly scored needs reboring regardless of dimensions.

2. Measure the bore at three heights (top, about 10 mm below the deck; middle; bottom, just above the area swept by the skirt) and in two directions at each height: in line with the crankshaft (X) and at 90° to it (Y, the direction of piston thrust), giving six readings, as the MAVCC course and the K-Light 125 manual describe.
3. **Out-of-round** at each height is the difference between X and Y. **Taper** (cylindricity) is the difference between the largest and smallest readings in one direction from top to bottom. Wear is greatest at the top of the ring travel in the Y direction.
4. Measure the piston at 90° to the pin, 11 mm above the bottom of the skirt.
5. Piston-to-cylinder clearance = largest bore reading − piston diameter. New K-Light parts give 56.500 − 56.485 = 0.015 mm to 56.505 − 56.470 = 0.035 mm; replace or rebore at **0.17 mm**.
6. Push each compression ring squarely into the bore with the piston crown to about 10–20 mm below the top (and at the least-worn bottom of the bore when checking for rebore), then measure the end gap with feeler gauges. A gap over **0.5 mm** means new rings; a large gap at the top and a small one at the bottom indicates taper.
7. Fit the rings to the piston and measure side clearance with a feeler gauge between ring and groove land; over **0.09 mm** means a worn groove and a new piston.
8. Check the cylinder top face for flatness with a straightedge and feeler gauges, and the gudgeon pin, pin bore and small end against their limits (section 2.5).

Example: readings top Y 56.592, top X 56.560, bottom Y 56.538, bottom X 56.534, piston 56.46. Out-of-round at top = 0.032 mm (within 0.05); taper in Y = 56.592 − 56.538 = 0.054 mm (over 0.05 limit); clearance = 56.592 − 56.46 = 0.132 mm (within 0.17). The taper exceeds the limit, so the cylinder should be rebored to the next oversize and fitted with a matching piston and rings.

Pass criteria: six bore readings and piston, ring and pin measurements recorded and correctly compared with every limit, with a justified decision (reuse, hone and re-ring, or rebore).

Job sheet 2.7.5: Two-stroke top-end rebuild

Tools: service manual, basic hand tools, torque wrench, piston pin extractor, circlip pliers or pick, micrometers and bore gauge, feeler gauges, gasket scraper, fine abrasive pad, clean rags, new piston, rings, small-end needle bearing, pin clips and gaskets, two-stroke oil.

1. Clean the machine, then remove the fuel tank, carburettor or throttle body, exhaust and coolant (if liquid-cooled).
2. Disconnect any power valve linkage, remove the head nuts in a cross pattern, smallest first (MAVCC), and lift the head; **never prise on fins**.
3. Lift the cylinder with the piston at TDC, tilting it so ring fragments fall outside the crankcase. Stuff the crankcase mouth with clean rag immediately.
4. Remove one pin clip, push the pin out (use an extractor if tight; **never hammer**, which bends the rod), and remove the piston and small-end bearing.
5. Check the rod: up-and-down play at the big end indicates a worn big-end bearing and requires crank overhaul; some side play is normal. Check the small-end bore against limits.
6. Clean carbon from the piston crown, head and exhaust port (not the transfer ports, which may carry coatings), and remove all gasket material without gouging the faces. Clean the power valve.

7. Measure the bore (six readings, middle readings close to the ports) and replace the piston, rings or cylinder as needed. Many modern two-strokes have nickel-silicon carbide plated bores that cannot be rebored; replating or cylinder replacement is required.
8. Check the end gap of the new rings in the bore and fit them with markings upward and their ends at the locating pins.
9. Fit a new oiled small-end bearing, the piston (arrow toward the exhaust) and pin, and new clips with their gaps away from the removal notch. **Check that clips are fully seated**: a clip that comes out destroys the cylinder.
10. Fit a new base gasket over the dowels, oil the bore and rings, compress the rings by hand and slide the cylinder on. Fit the head with new gasket or O-rings and torque nuts in a cross pattern to specification.
11. Check squish clearance if specified (solder wire squeezed between piston and head), reassemble the remaining parts, and run in by avoiding sustained full throttle and varying speed for the period specified, often 1–2 hours.

Pass criteria: all measurements recorded and within limits, clips seated, torque values applied, engine starts and idles, and no air leaks at the base or head joint.

Job sheet 2.7.6: Spark plug reading

Tools: plug socket, magnifier or plug viewer, wire-type gap gauge, torque wrench. Reference: K-Light 125 plug D7RTC, gap **0.7 ± 0.1 mm**, torque **15 N·m** (K-Light 125 manual).

1. Read the plug after a run at steady load, not after idling, which leaves soot on any plug; for a precise reading, stop the engine under load (a "plug chop").
2. Examine the insulator nose, electrodes and shell:

Appearance	Meaning	Action
Light grey or tan insulator, little deposit	Normal combustion, correct heat range (the K-Light manual: "light gray, combustion good")	None
Dry black soot	Rich mixture, blocked filter, excessive idling, plug too cold	Check filter, EFI sensors, injector
Wet black oily deposit	Oil entering: rings, guides, seals (four-stroke); excessive premix or failed oil pump control (two-stroke)	Compression and leak-down test
Chalk-white blistered insulator, eroded electrodes	Overheating: lean mixture, air leak, over-advanced timing, plug too hot	Find cause before running further
Small metal specks on insulator	Detonation or piston damage beginning	Stop and inspect
Glazed yellow-brown deposits	High-speed operation after deposits built up, fuel additives	Replace plug

3. Check and set the gap with a wire gauge, bending only the earth electrode; never lever against the centre electrode. Fit by hand to avoid cross-threading, then torque.

Pass criteria: condition correctly identified with a plausible cause, gap and torque set to specification.

REVIEW QUESTIONS

1. Why should a compression test be done with the throttle fully open and a charged battery?
2. A K-Light 125 reads 0.75 MPa dry and 0.95 MPa wet. Interpret the result.
3. A leak-down tester shows 100 psi in and 78 psi cylinder. Calculate the leakage and say whether it is acceptable.
4. Why must valve clearance be checked at TDC on the compression stroke with the engine cold?
5. After tightening a K-Light locknut, the 0.05 mm gauge no longer enters. What happened and what should you do?
6. A bore measures 56.585 mm top Y and the piston 56.44 mm. Is the clearance within the K-Light limit?
7. A ring end gap measured at the top of the bore is 0.42 mm, and at the bottom 0.25 mm. What does this tell you?
8. A plug from a two-stroke is wet and black after a ride. List three possible causes.

ANSWERS

1. A fully open throttle lets the cylinder fill completely, and a strong battery maintains cranking speed; a closed throttle or slow cranking gives a low and misleading reading.
2. The dry reading is below the 1.0–1.2 MPa range and rises by 27 % with oil, so the rings, piston or bore are worn: the oil temporarily sealed the ring gap.
3. Leakage = (100 − 78) / 100 × 100 = 22 %. This exceeds the 20 % guide and indicates a fault needing diagnosis.
4. At TDC compression both valves are fully closed with the followers on the cam base circle, so the true clearance is present. The specification is a cold value because parts expand when hot.
5. The adjuster turned with the locknut and reduced the clearance. Slacken the locknut, readjust while holding the adjuster firmly, retighten and recheck.
6. Clearance = 56.585 − 56.44 = 0.145 mm, within the 0.17 mm limit; however the bore (56.585 mm) is close to its 56.6 mm limit and the piston (56.44 mm) close to its 56.43 mm limit, so their remaining life is short.
7. The bore is worn larger at the top than the bottom (taper); the 0.17 mm difference in gap corresponds to a diameter difference of about 0.17/π = 0.054 mm, exceeding the 0.05 mm limit.
8. Too much oil in the premix (for example 25:1 instead of 50:1) or oil pump over-delivery; rich jetting or blocked air filter; worn crank seal on the gearbox side drawing in gearbox oil; plug heat range too cold.

Glossary

Balance factor: crank counterweight expressed as a percentage of reciprocating mass. **Balancer shaft**: a geared shaft with eccentric weight that cancels primary or secondary inertia forces. **Blowdown**: the rush of exhaust gas when the exhaust valve or port first opens, before the transfers or the piston's upward stroke clear the remainder. **BMEP (brake mean effective pressure)**: the constant pressure on the piston that would produce the measured brake torque; $4\pi \times T / Vd$ for a four-stroke. **Cam-ground piston**: piston made slightly oval so it becomes round at operating temperature. **Clearance volume**: volume above the piston at TDC. **Compression ratio**: (swept volume + clearance volume) / clearance volume. **Decompressor**: device that holds an exhaust valve slightly open during cranking. **Detonation (knock)**: spontaneous ignition of unburnt end gas after the spark, producing a sharp pressure spike. **Displacement (swept volume)**: $\pi/4 \times \text{bore}^2 \times \text{stroke} \times \text{number of cylinders}$. **DOHC**: double overhead camshafts, one for inlet and one for exhaust valves. **Dry sump**: lubrication system with oil stored in a separate tank and returned by a scavenge pump. **Expansion chamber**: tuned two-stroke exhaust with diverging and converging cones that use pressure waves to improve scavenging and trapping. **Firing interval**: crank angle between successive power strokes. **Gudgeon pin**: pin joining piston and connecting rod small end. **JASO MA/MB**: Japanese classifications of four-stroke motorcycle oil for wet-clutch (MA) and non-wet-clutch (MB) use. **Leak-down test**: measurement of the percentage of compressed air that escapes from a cylinder at TDC compression. **Loop (Schnürle) scavenging**: two-stroke scavenging in which transfer streams loop up the far cylinder wall and down to the exhaust. **Mean piston speed**: $2 \times \text{stroke} \times \text{rpm} / 60$. **OHV**: overhead valves operated by a camshaft in the crankcase through push rods and rockers. **Otto cycle**: idealised constant-volume heat-addition cycle for spark-ignition engines. **Out-of-round**: difference between bore diameters measured in two perpendicular directions at the same height. **Overlap**: crank angle during which both inlet and exhaust valves are open around TDC. **Power valve**: device that varies two-stroke exhaust port height or exhaust volume with rpm. **Premix**: two-stroke lubrication by oil mixed into the fuel in a fixed ratio. **Primary inertia force**: reciprocating force varying at crank frequency, $m \times r \times \omega^2 \times \cos\theta$. **Reed valve**: non-return valve of flexible petals controlling two-stroke inlet flow. **SOHC**: single overhead camshaft operating both inlet and exhaust valves, usually through rockers. **Squish**: narrow zone between piston and head at TDC that drives charge toward the centre. **Taper**: change in bore diameter from top to bottom of the cylinder. **TDC/BDC**: top and bottom dead centre, the extreme piston positions. **TPI**: KTM transfer port injection, fuel injected into the transfer ports of a two-stroke. **Transfer port**: passage carrying charge from crankcase to cylinder in a two-stroke. **Valve clearance (lash)**: gap in the valve train when the valve is closed. **Valve float**: loss of contact between follower and cam at high rpm due to insufficient spring force. **Valve recession**: sinking of a valve into its seat through wear, reducing clearance. **Volumetric efficiency**: actual air mass inducted per cycle divided by the mass that would fill the swept volume at reference density. **Wet sump**: lubrication system with the oil stored in the bottom of the crankcase.

Further reading

- Heywood, J. B. (2018). *Internal Combustion Engine Fundamentals*, 2nd edition. McGraw-Hill. The standard reference on cycles, gas exchange, combustion and friction.
- Jennings, G. (1973). *Two-Stroke Tuner's Handbook*. H. P. Books. Port timing, expansion chambers and two-stroke development practice.
- Blair, G. P. (1996). *Design and Simulation of Two-Stroke Engines*. SAE International. Detailed scavenging and exhaust tuning theory.
- Bell, A. G. (1998). *Four-Stroke Performance Tuning*, 2nd edition. Haynes. Practical cylinder head, cam and valve train work.
- Robert Bosch GmbH. *Bosch Automotive Handbook*, 11th edition (2022). Wiley/Bosch. Reference data on engines, lubricants and coolants.
- SAE International. *SAE J300: Engine Oil Viscosity Classification*.
- Japanese Automotive Standards Organization. *JASO T903:2023 Motorcycle four-stroke cycle gasoline engine oil*; *JASO M345 Two-stroke cycle gasoline engine oils*.
- UNECE. *UN Regulation No. 85: Measurement of the net power of internal combustion engines*.
- Haynes workshop manuals for the Honda CG125 and Yamaha YZ125, for worked procedures and service limits on similar engines.
- KS Motorcycles / Qianjiang. *K-Light 125 maintenance manual* (source PDF of this course): specification table, inspection and adjustment, cylinder head and valves, cylinder and piston, lubrication and crankcase chapters.
- Mid-America Vocational Curriculum Consortium (1988). *Motorcycle Mechanic*, teacher edition, Units VII (Motorcycle engines), XVI (Basic engine tune-up) and XIX (One-cylinder top-end service).
- Hero Honda technician starter kit. *Unit 2: The Motorcycle*.
- Krens, T. (ed.) (1998). *The Art of the Motorcycle*. Solomon R. Guggenheim Foundation, with essays on technical evolution.

Moto Zero is an open course of Transitions Lab. Text and illustrations are released under the Creative Commons Attribution-ShareAlike 4.0 International licence (CC BY-SA 4.0): you may copy, translate, adapt and redistribute them, including commercially, provided you credit Transitions Lab and share adaptations under the same licence.

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.