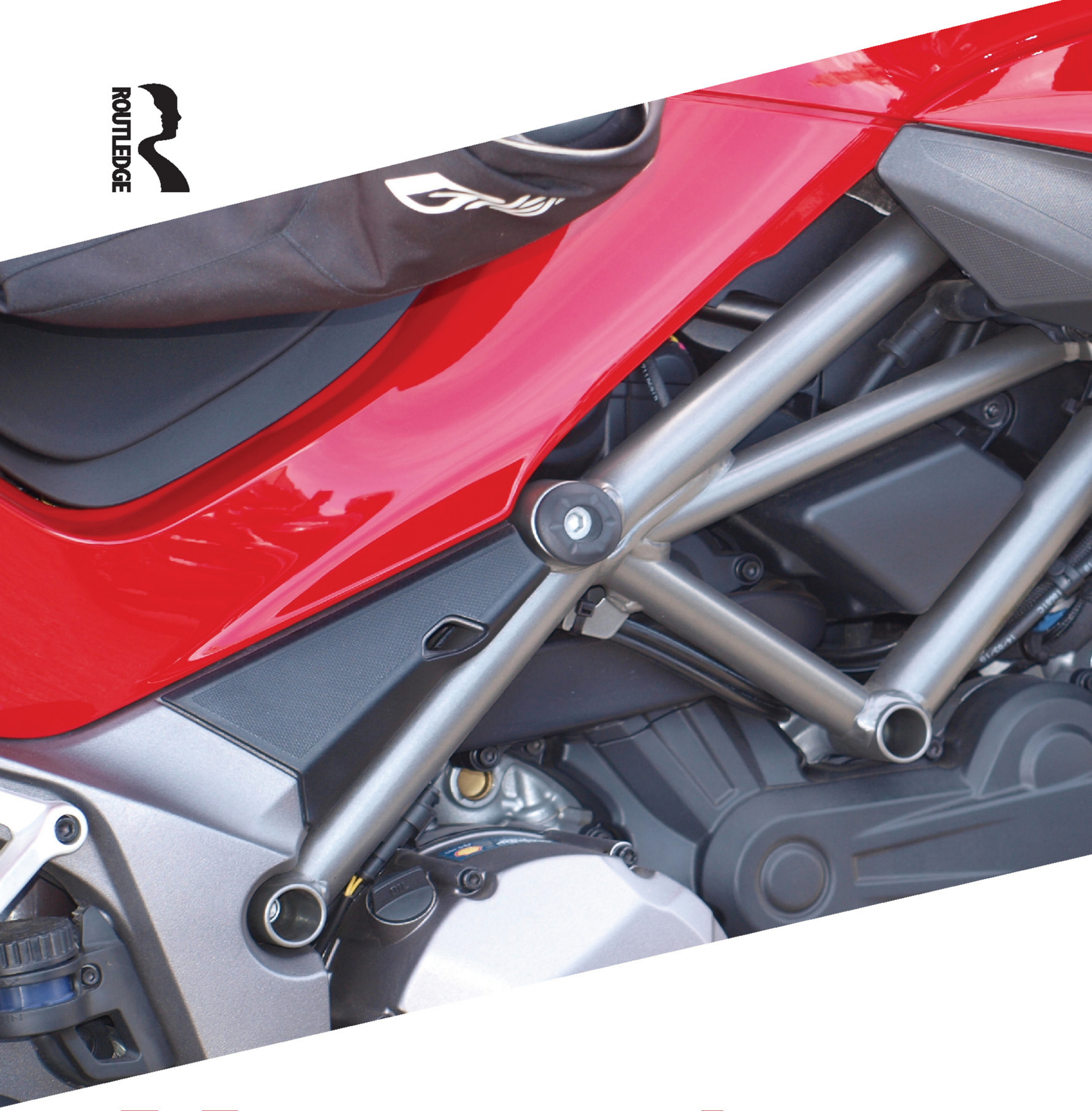

Motorcycle Engineering

Andrew Livesey

Motorcycle Engineering

Motorcycle Engineering is a primer and technical introduction for anyone interested in motorcycles, motorcycling, and the motorcycle industry. It provides insight into how motorcycles are made and operated.

Motorcycles, mopeds, and scooters are important factors in world transport, and they are playing an increasingly important role in transport policy as we move towards greater environmental awareness. Motorcycles and scooters give freedom of personal transport that enable large commuter distances to be covered quickly and easily. Their small footprint offers easy storage, as only minimal space is required. To celebrate the importance of motorcycles on the world stage, a brief history is included with a detailed timeline detailing the development of the motorcycle alongside major world events.

Written in an accessible fashion, no previous knowledge of engineering or technology is required, as all technical terms are readily explained and a glossary and abbreviation list is included. Whether you are an enthusiast, racer, student, or industry professional, you will surely find this an enjoyable read and a handy reference book on your shelf.

Andrew Livesey, MA, CEng, is a lecturer in engineering at Ashford College University Centre in Kent, England, when he is not riding his motorcycle, bicycle, or building something in his garage. He is a member of several motorcycle and bicycle groups, mixing social riding with competition events when possible. He also enjoys very fast high-performance cars. His Routledge publications include *Basic Motorsport Engineering* (2011), *Advanced Motorsport Engineering* (2012), *The Repair of Vehicle Bodies, 7th edition* (2018), *Practical Motorsport Engineering* (2018), and *Bicycle Engineering and Technology* (2021).

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Contents

Abbreviations and symbols

The abbreviations are generally defined by being written in full when the relevant technical term is first used in the book. In a very small number of cases, an abbreviation may be used for two separate purposes, usually because the general concept is the same but the use of a superscript or subscript would be unnecessarily cumbersome; in these cases, the definition should be clear from the context of the abbreviation. The units used are those of the internationally accepted *Systemé International* (SI). However, because of the large American participation in motorcycling and the desire to retain the well-known imperial system of units by many enthusiasts, where appropriate imperial equivalents of SI units are given. Therefore, the following is intended to be useful for reference only and is neither exhaustive nor definitive.

Greek alphabet symbols

α (alpha) angle – tire slip angle
λ (lambda) angle of inclination
μ (mu) coefficient of friction
ω (omega) rotational velocity
ρ (rho) air density
η (eta) efficiency
θ (theta) angle

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General abbreviations

a	acceleration
A	area – frontal area of motorcycle and rider; or ampere
ABS	antilock braking system; or acrylonitrile butadiene styrene (a plastic)
AC	alternating current
AF	across flats – bolt head size
AFFF	aqueous film forming foam (firefighting)
bar	atmospheric pressure – 101.3 kPa or 14.7 psi as standard or normal
BATNEEC	best available technique not enabling excessive cost
BS	British Standard
BSI	British Standards Institute
C	Celsius or Centigrade
CAD	computer-aided design
CAE	computer-aided engineering
CAM	computer aided manufacturing
C_D	aerodynamic coefficient of drag
CG	center of gravity, also CoG
CIM	computer integrated manufacturing
C_L	aerodynamic coefficient of lift
cm	centimeter
cm^3	cubic centimeters – capacity; also called cc. 1000 cc is 1 liter
CO	carbon monoxide
CO_2	carbon dioxide
COSHH	Control of Substances Hazardous to Health (Regulations)
CP	center of pressure
CR	compression ratio
D	diameter
d	distance
dB	decibel (noise measurement)
DC	direct current
deg	degree (angle or temperature), also °

dia.	diameter
DTI	dial test indicator
EC	European Community
ECU	electronic control unit
EFI	Electronic Fuel Injection
EN	European Norm – European Standard
EPA	Environmental Protection Act; or Environmental Protection Agency
EU	European Union
f	frequency
F	Fahrenheit, force
ft	foot
ft/min	feet per minute
FWD	front-wheel drive
g	gravity; or gram
gal	gallon (U.S. gallon is 0.8 of UK gallon)
GRP	glass-reinforced plastic
HASAWA	Health and Safety at Work Act
HGV	heavy goods vehicle (used also to mean LGV – large goods vehicle)
HP	horsepower (CV in French, PS in German)
HSE	Health and Safety Executive; also, health, safety, and environment
HT	high tension
I	inertia
ID	internal diameter
IMechE	Institution of Mechanical Engineers
IMI	Institute of the Motor Industry
in^3	cubic inches – measure of capacity
IR	infrared
ISO	International Standards Organization
k	radius of gyration
kph	kilometers per hour
l	length
L	wheelbase
LH	left hand
LHD	left-hand drive
LHThd	left-hand thread
LPG	liquid petroleum gas
lumen	light energy radiated per second per unit solid angle by a uniform point source of 1 candela intensity
lux	unit of illumination equal to 1 $lumen/m^2$
M	mass
MAX	maximum
MIG	metal inert gas (welding)

MIN	minimum
N	Newton; or normal force
Nm	Newton meter (torque)
No	number
OD	outside diameter
OL	overall length
OW	overall width
P	power, pressure, or effort
Part no	part number
PPE	personal protective equipment
pt	pint (UK 20 fluid ounces, USA 16 fluid ounces)
PVA	polyvinyl acetate
PVC	polyvinyl chloride
Q	heat energy
r	radius
R	reaction
Ref	reference
RH	right hand
rpm	revolutions per minute; also RPM and rev/min
RTA	Road Traffic Act
RWD	rear-wheel drive
std	standard
STP	standard temperature and pressure
TE	tractive effort
TIG	tungsten inert gas (welding)
V	velocity; or volt
VOC	volatile organic compounds
W	weight
w	width
WB	wheel base
x	longitudinal axis of vehicle or forward direction
y	lateral direction (out of right side of vehicle)
z	vertical direction relative to vehicle

Superscripts and subscripts are used to differentiate specific concepts.

S I UNITS

cm	centimeter
K	Kelvin (absolute temperature)
kg	kilogram (approx. 2.25 lb)
km	kilometer (approx. 0.625 mile or 1 mile is approx. 1.6 km)
kPa	kilopascal (100 kPa is approx. 15 psi, that is atmospheric pressure of 1 bar)
kV	kilovolt

kW	kilowatt
l	liter (approx. 1.7 pint)
l/100 km	liters per 100 kilometers (fuel consumption)
m	meter (approx. 39 inches)
mg	milligram
ml	milliliter
mm	millimeter (1 inch is approx. 25 mm)
N	newton (unit of force)
Pa	pascal
ug	microgram

IMPERIAL UNITS

ft	foot (= 12 inches)
hp	horse power (33,000 ft lb/minute; approx. 746 watt)
in	inch (approx. 25 mm)
lb/in^2	pressure, sometimes written psi
lb ft	torque (10 lb ft is approx. 13.5 Nm)

Preface

Author at Whitstable Charity Motorcycle Event

Motorcycling gives you a freedom to travel. You are at one with the open road and can park in the smallest of spaces. Pressing the start button on my motorcycle and seeing the tachometer needle rise makes me feel ready to lap the world. Lots of riders are in fact doing just that on their adventure motorcycles, riding the silk routes across the Himalayas or the plains and jungles of Africa.

Motorcycles are very reliable now, so the need for maintenance is a minimum. This book is written as a primer to help you learn about the motorcycle, its operation, and the motorcycle business. It is hoped that it might encourage you to make motorcycles, or at least customize or modify your motorcycle. Or maybe it will tempt you into the motorcycle industry in some way. Motorcycle sales are increasing, and the range of available machines is amazing. Thank you to all the motorcyclists who have helped me on this motorcycle journey, especially 21st Moto Ltd of Swanley, Kent.

I hope that it will give you a pleasurable and informative read, to enable you to enjoy motorcycling as much as I do.

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Chapter 1

Power unit – engine

'There ain't no substitute for cubes.'

Whether it's cubic inches or cubic centimeters, the more of them that you have in your engine, the more power you can develop. That's how it is for petrol and diesel engines – with electric motors, you need volts and amps.

Motorcycle sport is often grouped into engine sizes, so the competitor is challenged to get the most power out of the engine. There are also usually regulations on what is, and is not, allowed to improve the power output.

Tech Note

The term **horsepower** – **HP** – comes from steam engine sales agents of about 200 years ago saying how many horses their engines could replace. In French, this is **cheval vapour (CV)**; in German, this is **pferde starke (PS)**.

One HP, in any language, that is CV or PS, is equal to 33,000 foot-pounds per minute, that is 746 watts.

When we are talking about power output, we must be careful to compare like for like. When we say **BHP** (brake horsepower), we are talking about the engine power measured on an engine brake or dynamometer – **dyno**. But rolling road dynamometers measure power at the wheels – this is after the frictional losses in the transmission system – typically around 10% to 15%. Also, there are a number of different standards for measuring power outputs set by different organizations. The most popular are the American **SAE** standard and the German **DIN** standard. Both measure power but under different conditions, with variations like the use of air filters and the way that the cooling system is connected.

Power is about doing work in an amount of time – mathematically, it's work done per unit time.

Figure 1.1 Kick start to get the engine going on a lightweight motorcycle.

IDENTIFICATION

Identification of the engine before working on it is very important. The **VIN** number will help identify the type, or classification, of the engine. The detail of the engine will be given in a separate engine number, the pre-fix will identify the engine type, and the serial number will identify the exact engine.

ENGINE PERFORMANCE

The two common terms used are:

Power – this is **work done** in unit time.

Torque – turning moment about a point.

Let's discuss them for clarity and then look at the calculations. When we are using the term *power*, we are referring to how much energy that the engine has. A big heavy motorcycle needs a big powerful engine. Power is about doing work in a time period; it means burning fuel in the time period. We can make a small four-cylinder engine – say one from a motorcycle like a Kawasaki ZX6R – produce over 100 BHP from its 600 cc, but we need it to rev at about 12,000 rpm.

For a mathematical definition of these terms, we need to start with work done. Work done is the amount of load carried multiplied by the distance travelled. The load is converted into force: for instance, the force needed to move the motorcycle in newtons (N). The distance is measured in meters. That is:

$$\text{Work done(Nm)} = \text{Force}(N) * \text{Distance}(m)$$

As we also express torque in Nm, it is common to use the term joule (J) for work done.

Tech Note

Joule is a term for energy. 1 J = 1 Nm

If we use a force of 10,000 N to take a drag-bike down a 200-m drag strip, then we have exerted 2,000,000 Nm, or 2,000,000 J. We'd say 2 mega joules (2 MJ). We'd need to get this amount of energy out of the fuel that we were using

The force is generated by the pressure of the burning gas on top of the piston multiplied by the area of the top of the piston. So, the work done is the mean (average) force of pushing the piston down the cylinder bore multiplied by the distance traveled.

Example

The work done during the power stoke of an engine where the stoke is 60mm and the mean force is 5kN

$$\begin{aligned}\text{Work Done} &= \text{Force*Distance}\\ &= 5\ \text{kN*60 mm}\\ &= 5000N \times 0.06m\\ &= 300\ J\end{aligned}$$

Tech Note

The mathematical symbols used in this book are those found on your calculator or mobile phone:

* is multiply and / is divide

The same mean force is going to create the torque. This time we are going to use the crankshaft throw – this is half the length of the stoke.

Example

Using the same engine

$$\begin{aligned}\text{Torque} &= \text{Force*Radius}\\ &= 5\ \text{kN*30 mm}\\ &= 5000N * 0.03m\\ &= 150\ \text{Nm}\end{aligned}$$

The work done by a torque for one revolution is the mean force multiplied by the circumference. The circumference is 2Πr so:

$$\text{WorkDone} = F * 2\Pi r$$

$$\text{AsFr} = T$$

$$\text{So, Work Done} = 2\Pi T$$

That is for one revolution. For any number of revolutions, where n is any number, the formula is:

$$\text{Work Done in } n \text{ revolutions} = 2\Pi\text{nT}$$

Example

Using the same engine of the previous examples:
The work done in 1 minute at 6000 rpm will be:

$$\begin{aligned}\text{WD in } n \text{ revolutions} &= 2\Pi\text{nT}\\ &= 2 * \Pi * 6000 * 150\\ &= 5657\ \text{kJ}\end{aligned}$$

Power is, as we said, work done in unit time, which is:

$$\text{Power} = \text{Work Done / Time}$$

The motorcycle industry uses a number of different units and standards for power. From our calculations we can use watts (W) and kilowatts (kW) and then convert.

Tech Note

1 kW = 1000 W

1 watt = 1 J/second
1 kW = 1 kJ/s

Example

Following on from our engine in the previous calculations and examples:

Power = Work Done / Time
= 5657 kJ / 60
= 94.3 kW

The term **horsepower** (HP or hp) was derived by James Watt as the average power of a pit pony. These were small horses used to turn pulleys to draw water from Cornish tin mines (pits) before steam power became more popular. He equated the power of his steam engines to a number of these pit ponies. For our purposes 1 HP equals 33,000 ft-lb/minute.

In French horsepower is cheval vapour (CV); in German, it is pferde starke (PS).

For conversion purposes, 1 HP is equal to 746 W.

When talking about power and doing work, the weight of the bike comes into play. It's worth doing a comparison with performance motorcycles to get a good picture.

TERMINOLOGY

One metric ton is 1000 kg. As a kilogram is equivalent to 2.25 pounds, a metric ton is the equivalent of an imperial ton – 2250 lb.

Table 1.1 Typical BHP per ton figures

Bike/car	*Capacity*	*BHP*	*Weight (kg)*	*BHP per ton*
Kawasaki ZX6R	599 cc	130	185	702
Harley Davidson	883 cc	53	263	201
Triumph Bonneville T120	1198 cc	80	224	357
Suzuki Hayabusa	1299 cc	173	251	689
Kawasaki H2 motorcycle	1000 cc supercharged	310	215	1442
Typical BTCC car	2-liter turbo	350	1000	350
German Touring Motorcycle - DTM	4-liter supercharged	500	1122	445
Bugatti 16/4	8 liter with 4 turbos	1200	1990	603

The aim of any motorcycle designer is to get the maximum BHP per ton, not forgetting to have enough torque to get off the starting line – especially for hill climb events.

Fuel energy output measurement

The energy output of fuel varies. There are two ways of measuring the quantity of fuel: by the kilogram or by the liter. Energy companies tend to give outputs for kilograms. This is a more stable method of measurement and is traditionally used for ships and airplanes where mass is a more important factor. Typical values for consumer fuels are:

- Petrol 45.8 MJ/kg
- Diesel 45.5 MJ/kg

However, diesel is about 15% more dense than petrol. When measured at 15.55 °C this figure is used, as it is the equivalent of 60 °F – the temperature scale used in non-European countries. The specific gravity (also called relative density) of consumer fuels is:

- Petrol 0.739
- Diesel 0.82 to 0.95

The range of specific gravity (sg) values for diesel is because of the variety of products for commercial use and summer and winter products. Winter diesel is lighter than summer diesel to prevent waxing. When diesel turns solid – referred to as waxing – it takes place at between 14 °C and 18 °C, with the latter temperature for winter use.

So, taking typical consumer fuels – pump fuels – we get the following values per liter:

- Petrol 33.7 MJ/liter
- Diesel 36.9 MJ/liter

Tech Note

There have been a variety of diesel motorcycles over the years, mainly for military use. As we are in a period of change, the author has included it for interest and to highlight its good qualities.

Alternative fuels – Certain classes of racing allow, sometimes insist on, the use of other fuels. **Methanol** is a clean-burning fuel; it is used in the United States. **Biodiesel** like methanol is made from renewables and is therefore environmentally friendly. **Liquified natural gas** (LNG) is a product of

Table 1.2 Typical energy outputs of alternative fuels

Fuel	*MJ/kg*	*MJ/liter*
Methanol	19.9	15.9
Biodiesel	37.8	33.3
LNG	38	25.5

shale – bored or fracked from the ground – and is not environmentally friendly. There are various forms of gas products – they all burn dry, and because of their dry burning characteristics limit engine life, even with special operating procedures. LNG/ Liquid Petroleum Gas (LPG) is used by cost-conscious operators, as it attracts a lower level of duty or tax.

Bomb calorimeter – This is used to measure the energy output of fuel. It is shaped like you would imagine a bomb to look and works by burning – exploding – a spoon full of fuel to see how much energy it will generate. You do this by measuring the temperature change brought about by burning the fuel under controlled conditions. Bomb calorimeters are readily available and allow you to check the fuel that you are using. Remember that for maximum power you want the fuel which produces the highest energy output for a given volume, so it must be high-density, high-calorific output.

A typical calculation using a bomb calorimeter

The formula:

$$\begin{aligned}\text{Calorific value} &= \text{Total water mass} \times \text{Temperature rise} \\ &\quad \times \text{Specific heat of water} \\ &= 2.652 * 4.58 * 4.19 \\ &= 50{,}900 \text{ kJ / kg}\end{aligned}$$

Table 1.3 Data for bomb calorimeter

No.	*Name*	*Reading*
1	Density of fuel – density	0.845
2	Water equivalent of calorimeter – mfg figures	652 g
3	Mass of water	200 g
4	Mass of fuel	1 g
5	Temp. of water before combustion	19.26 °C
6	Temp. of water after combustion	23.84 °C
7	Temperature increase, that is No. 6–No. 5	4.58 °C
8	Specific heat of water	4.19 kJ/kg deg K

ENGINE CONSTRUCTION

Key points

- The engine burns fuel at a very high temperature to force the piston down the cylinder bore.
- The connecting rod and crankshaft convert the reciprocating motion of the piston into rotary motion.
- Engine size is calculated as a product of the cylinder bore and the piston stroke.
- Engines may be petrol (SI) or diesel (CI).
- Two-stroke petrol engines can be found in some small motorcycles and garden machinery.

Almost all motorcycle engines are petrol engines. Royal Enfield and one or two other manufacturers have made diesel motorcycle engines; but these were mainly for military use.

Tech Note

Race engines are developed to produce the maximum power with a specific capacity to conform to the regulations of the racing classification – this usually means high engine speed with a narrow power band.

Cylinder block and crankcase

There are quite a lot of different designs of motorcycle engines, as most of the manufacturers have what they consider to be their ideal design. In the car industry many manufacturers share an engine; for instance, you will find Ford engines in Peugeot, Renault, and Fiat. In low-volume-production motorcycles, you will find the use of other manufacturers' engines. You will also find the same engine used across a range of motorcycles from the same manufacturer but at different levels of tune.

To reduce weight and improve reliability, motorcycle engines and gearboxes are usually made in what is referred to as unit construction: this uses one main casting for the engine crankcase and gearbox housing. This term is often misused and confused with other concepts. Most front-wheel-drive motorcycles use a variation on this concept. Early engines were made from cast iron; almost universally motorcycle engines are mainly aluminum alloy. The crankcase and gearbox housing are one main casting; on top of this is bolted the cylinder block, and on top of the cylinder block is bolted the cylinder head.

If you consider this you can see that you can use one crankcase casting to serve a whole range of engine options:

- The block can be changed within the same fitting to the crankcase to give different sizes of bore and stroke, that is, different engine capacity options.
- The cylinder heads and valve arrangements can be changed to give different levels of tune – that is, different performance levels.

Pistons – These move up and down in the cylinder bores. This up-and-down movement is called **reciprocating motion**. The piston forms a gastight seal between the combustion chamber and the crankcase. The burning of the fuel and air mixture in the combustion chamber forces the piston down the cylinder to do useful work. The pistons are usually made from aluminum alloy for its lightweight and excellent heat-conducting ability. The top of the piston is called the crown; the lower part is called the skirt. The pistons must be perfectly round to give a good seal in the bore when the engine is at its normal running temperature. However, aluminum expands a lot when it is heated up. The pistons have slits in their skirts to allow for their expansion in diameter from cold to their normal operating temperature. When cold, pistons may be a slightly oval shape, so that when at running temperature they are a perfect fit in the cylinder bore.

The pistons are fitted with piston rings to ensure a gastight seal between the piston and the cylinder walls. This is needed to keep the burning gases in the combustion chamber. The piston rings are made from close grain cast iron, a metal that is very brittle. But the piston rings are slightly springy because of their shape. Usually there are three piston rings. The top two are compression rings to keep the gases in the combustion chamber. The bottom one is an oil ring; its job is to scrape the oil off the cylinder walls. The oil is returned to the sump by passing through the slots in the piston rings and running down inside the pistons. The piston rings are made from cast iron – this is very brittle, so when piston rings are being fitted great care must be taken not to break them.

Tech Note

Pistons on race engines are as light as possible to give very high-speed running. To reduce their weight, the skirts are made very short and cut away to a *slipper* shape – referred to as slipper pistons.

Tech Note

What do the terms bore and stroke mean?

The bore is the cylindrical hole, or cylinder, in which the piston runs. The bore must be perfectly smooth, round, and parallel. It is also the term used to describe the diameter of the cylinder; this is usually expressed in millimeters (mm) or inches (in). The stroke is the distance the piston travels from the bottom of the cylinder – called bottom dead center (BDC) – to the top of the cylinder – called top dead center (TDC). The stroke also may be measured in millimeters or inches. The surface inside the cylinder is called the cylinder wall.

Connecting rod (con rod) – This connects the piston to the crankshaft. The con rod has two bearings: the **little end** connects to the piston and the **big end** to the crankshaft. The con rod is made from either cast iron or forged steel. The big end bearing is a shell bearing; this allows for easy replacement and cheap manufacture.

Crankshaft – This, in conjunction with the con rod, converts the reciprocating motion of the pistons into the rotary motions, which turn the flywheel. The crankshaft is located in the cylinder block by the main bearings. The big end bearings are attached to the crank pins; the crank pins are at the ends of the crank webs. The distance between the center of the **crank pin** and the center of the **main bearing** is called the **throw**. The throw is half of the **stroke**.

Key points

From TDC to BDC is the stroke. For the piston to travel from TDC to BDC, the crankshaft rotates 180 degrees – half a revolution. The crank pin is moved from above the main bearing – the length of one throw – to below the main bearing – the length of another throw. That is, two throws are equal to the length of the stroke.

Cylinder head (head) – The head sits on top of the cylinder block. The head contains the combustion chambers and valves. Between the head and the block is a cylinder head gasket. The cylinder head gasket allows for the irregularities between the block and the head and keeps a **gastight seal** for the combustion chamber. The engine cylinder head locates the spark plugs.

Valve cover and sump – The cylinder head is fitted with a valve cover (also called a **rocker box** or **cam box**). The valve cover encloses the valves and their operating mechanism, forming an oil-tight seal for the engine oil. The bottom of the crankcase on some engines is fitted with a sump.

The sump has two jobs; it is a store for the engine lubricating oil and forms an oil-tight seal to the bottom of the engine. Both the valve cover and the sump are usually made from thin pressed steel. The sump is removed to gain access to the oil pump and bearings.

Timing mechanism – At the front or side of the engine is the timing mechanism. This is a belt, a chain, or a shaft that connects the crankshaft to the camshaft. A casing covers the timing mechanism. The timing end of the engine is often called the free end. **Cylinder numbers** always start from the free end. On some engines, the chain is in the middle of the engine between the cylinders.

Flywheel – The flywheel is attached to the crankshaft. The flywheel end of the engine is the drive end. That is, the flywheel turns the clutch and the gearbox to move the vehicle.

Tech Note

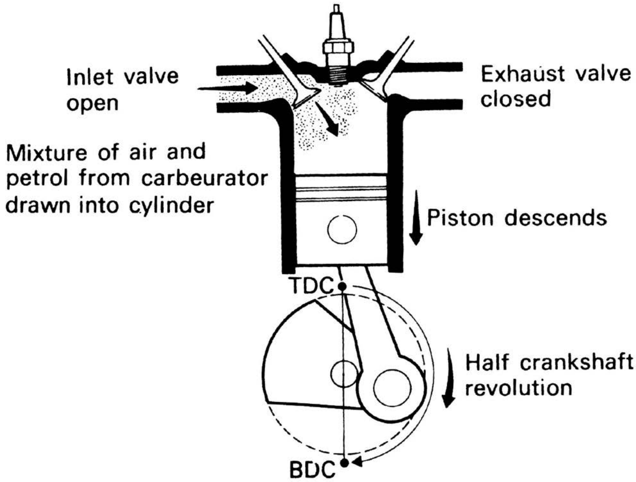
As a mechanic, it is good to understand the different metals that are used in engines. The different metals must be considered when you are handling the part, and particularly when tightening up nuts and bolts.

- Cast iron is used for cylinders and cylinder heads on older engines; it is very heavy and brittle, so it will break if dropped.
- Aluminum is lightweight and expands a great amount when heated up. It is also soft, so it is easily scratched. You must be careful not to overtighten spark plugs in aluminum cylinder heads or you will damage the threads.
- Pressed steel is used for sumps and valve covers; this is easily bent. A bent sump may leak around the joints.
- Hardened steel is used for the crankshaft; this is both heavy and expensive.

Four-stroke petrol engine

The four-stroke petrol engine works on a cycle of four up-and-down movements of the piston. These up-and-down movements are called strokes. The piston moves down from TDC to BDC, then up to TDC again. Each stroke corresponds to half of a turn of the crankshaft; therefore, the complete cycle of four strokes takes two revolutions of the crankshaft.

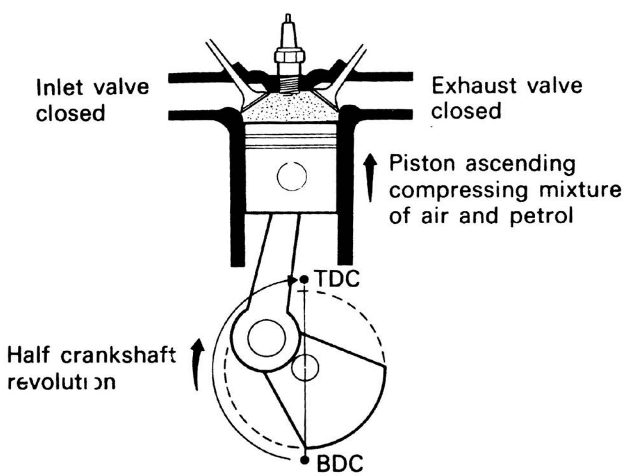
The petrol and air mixture is burned in the combustion chamber during one of the strokes. The heat from the burning fuel causes a pressure increase in the combustion chamber. This pressure forces the piston down the bore to do the useful work. The mixture is ignited by the spark plug – hence the term spark ignition (SI).



a *Induction stroke*

Figure 1.2 Induction stroke.

The cylinder head is fitted with inlet valves; these open and close to control the flow of the petrol and air mixture from the inlet manifold into the combustion chamber. The cylinder head is also fitted with exhaust valves to control the flow of the spent exhaust from the combustion chamber into the exhaust manifold and exhaust system. The passage in the cylinder head, which connects the manifold to the combustion chamber, is called the port. There are inlet ports and exhaust ports. The valves are situated where the



b *Compression stroke*

Figure 1.3 Compression stroke.

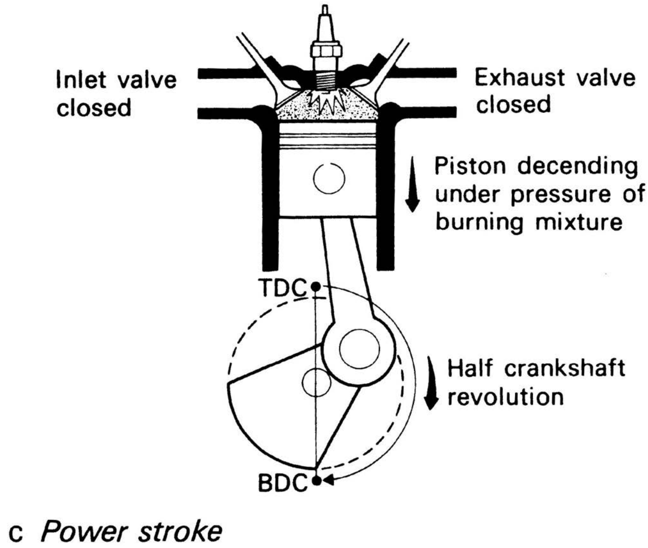


Figure 1.4 Power stroke.

ports connect into the combustion chamber. The valves are operated by the camshaft; this is discussed later in this chapter.

Induction stroke

The piston travels down the cylinder bore from the TDC, drawing in the mixture of petrol and air from the inlet manifold. This is like a syringe

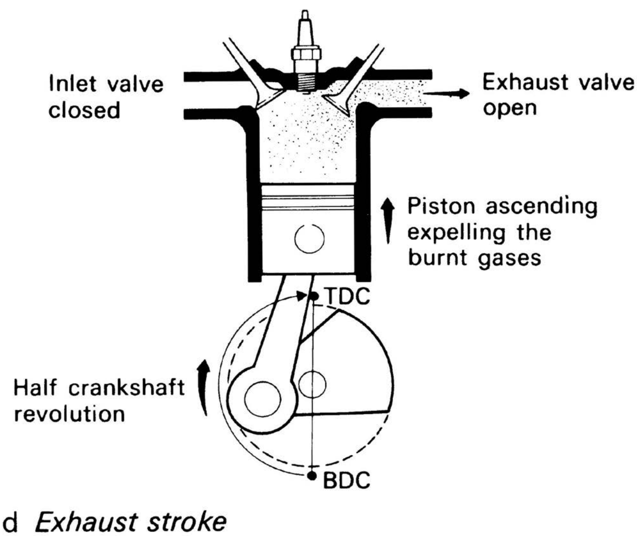


Figure 1.5 Exhaust stroke.

drawing up a liquid. The downward movement of the piston has caused a depression above the piston. This depression, or partial vacuum, is satisfied by the air coming into the inlet manifold through the air filter. The air mixes with the petrol that is supplied from either from the injectors or a carburetor.

Compression stroke

When the piston reaches BDC, it starts to return up the bore. At about BDC the inlet valve is closed by the camshaft; the exhaust valve was already closed. The mixture of petrol and air, which was drawn in on the induction stroke, is now compressed into the combustion chamber. This increases the pressure of the mixture to about 1250 kPa (180 psi). The actual pressure depends on the compression ratio of the engine – on race engines, it is typically between 10:1 and 16:1. On WSB and BSB machines, this figure may exceed 20:1. Increasing the compression ratio within limits will increase the power output.

Nomenclature

The mathematical sign : means to and signifies a ratio.

Power stroke

As the piston reaches TDC on the compression stroke, the spark occurs at the spark plug. This spark, which is more than 40 kV (40,000 volts), ignites the petrol–air mixture. The mixture burns at a temperature of over 2000 degrees Celsius and raises the pressure in the combustion chamber to over 5000 kPa (750 psi). The pressure of the burning petrol–air mixture now starts to force the piston back down the cylinder bore to do useful work. The piston rings seal the pressure of the burning mixture into the combustion chamber, so that the pressure exerts a force on the piston, the gudgeon pin, and then the con rod, which converts this downward motion into rotary motion at the crankshaft. It's good to remember that a modest-speed engine will fire on each cylinder over 50 times every second.

Tech Note

How much force does the burning mixture actually exert on the con rod or crankshaft, and why do they not bend?

The amount of force depends on the size of the engine; but as a rough guide, imagine an elephant sat on the top of the piston every time it goes down. The components will not bend as long as the engine is rotating and the force is being passed on to the transmission to move the vehicle.

Exhaust stroke

At the end of the power stroke the exhaust valve opens. When the piston starts to ascend on the exhaust stroke, this is the last stroke in the cycle; the burnt mixture is forced out into the exhaust. The mixture of petrol and air has been burnt to change its composition. Its energy has been spent. The temperature of the exhaust gas is about 800 to 1200 degrees Celsius. The petrol–air mixture has been burnt to become carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O), nitrogen (N), and free carbon (C). The exhaust gas is passed through the exhaust system to the catalytic converter to be cleaned and made nontoxic. The exhaust gas exits the engine in waves – it is not a continuous stream, nor in parcels like a sausage machine. The speed of sound at 20 °C is 343 m/s – the different exhausts give different pitches; compare the exhaust noise of a Ferrari V12 with a Ducati twin.

Flywheel inertia

There is only one firing stroke for each cycle. The flywheel keeps the engine turning between firing strokes. Single-cylinder engines need a bigger flywheel in proportion to their size than those with more cylinders do. The flywheel on a large V8 engine is smaller than one on a four-cylinder engine. The flywheel's desire to keep rotating is called inertia; it is inertia of motion.

Valve operation

The inlet and the exhaust valves each open once every two revolutions of the crankshaft. The mechanism for opening the valves is a camshaft, which is either direct acting on the valves or operates them through a push rod and a rocker shaft assembly.

If the camshaft is situated above the valves, the engine is referred to as overhead cam (OHC). Other types are overhead valve (OHV) and side valve. A rubber-toothed belt, a chain, or a bevel gear shaft may drive the camshaft. As the camshaft must rotate at half the speed of the crankshaft to open the valves once for every two revolutions of the crankshaft, the drive is through a 2:1 gear ratio. The cam gear wheel has twice as many teeth as the crankshaft gear wheel.

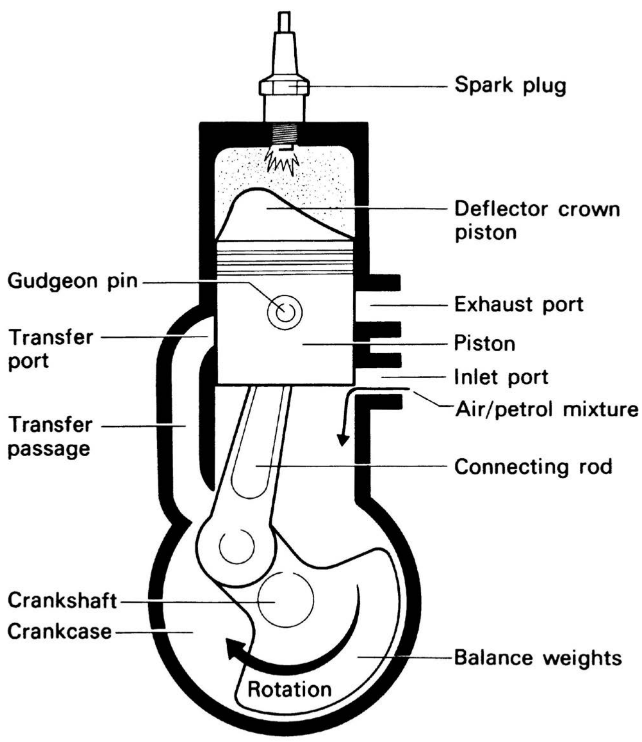
The actual point at which the valves open and close depends on the engine design. The motorcycle's workshop manual will give the valve timing figures; these are usually expressed in degrees of the crankshaft relative to TDC and BDC.

It is essential that the valves close firmly against their seats to give a good gastight seal and allow heat to conduct from them to the cylinder head so that they may cool down. The valves are held closed by springs. To ensure that the valves close firmly, even when the components have expanded because of the heat, the valve mechanism is given a small amount of clearance. The valve clearance is measured with a feeler gauge; a typical figure is 0.15 mm (0.006 in). If the valve clearance is too great, then a light metallic rattling noise will be heard.

Two-stroke petrol engine

The two-stroke petrol engine is used mainly in small motorcycles, although they have been used in some larger racing machines. It operates on one up-stroke and one down-stroke of the piston; that is, one revolution of the crankshaft. The most common type is the Clerk Cycle engine; this has no valves, just three ports. The three ports are the inlet port, the transfer port, and the exhaust port. The flow of the gas through these ports is controlled by the position of the piston. When the piston is at TDC, both the transfer and the exhaust ports are closed. When the piston is at BDC, the piston skirt closes the inlet port.

The piston travels up the bore. As it reaches TDC, it closes both the transfer and the exhaust ports. At the same time, the piston is compressing the



a *Two-stroke petrol engine: piston approaching TDC*

Figure 1.6 Two-stroke approaching TDC.

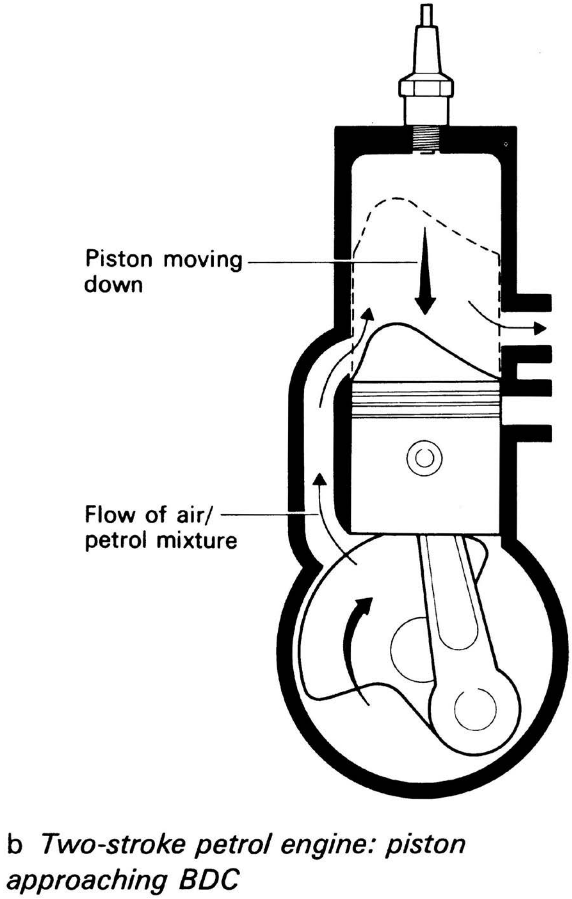


Figure 1.7 Two-stroke approaching BDC.

charge of petrol and air above it into the combustion chamber. At about TDC the spark plug ignites the petrol–air mixture. The burning of the petrol–air mixture increases the temperature and the pressure so that the burning gas pushes the piston down the bore. The downward force of the piston passes through the gudgeon pin to the con rod and crankshaft to drive the vehicle.

While the piston is ascending, its skirt uncovers the inlet port. The upward motion of the piston causes a vacuum in the crankcase, which is satisfied by the petrol–air mixture from the carburetor entering through the now open inlet port.

Tech Note

Two-stroke engines have a separate crankcase that is not combined with the gearbox.

When the piston is traveling downwards – being forced down by the burning mixture – the piston crown first uncovers the exhaust port. This allows the spent gas to escape into the exhaust system. The skirt of the piston covers the inlet port at the same time as the piston crown uncovers the transfer port at the top of the cylinder. The underside of the piston therefore acts like a pump plunger, forcing the fresh charge of petrol and air that is in the crankcase up and through the transfer port into the cylinder so that another cycle is started.

The two-stroke petrol engine is much lighter and simpler than the four-stroke petrol engine and has fewer moving parts. It has neither valves nor a valve operating mechanism. Two-stroke petrol engines usually run at high speeds. The problem is that oil must be mixed with the petrol for lubrication – this causes the exhaust to smoke.

Tech Note

Two-stroke engines were used in the early motorcycles, and there are racing classes for these; however, because of emission regulations, no new ones are being made. Old racing two-stroke motorcycles were loved by many for the smell of the burnt oil – even though it could be a health hazard. The oil was vegetable based and called *Castrol R* – it is currently available for historic applications.

Four-stroke diesel engine

The operation of the four-stroke diesel engine is similar to the four-stroke petrol engine. The diesel engine draws in air only and then compresses this at a very high pressure and temperature to cause the fuel to combust and burn. The fuel is injected directly into the engine at a very high pressure. Vehicles with diesel engines are economical, and they produce lots of pulling power at low engine speeds. Some military motorcycles have used diesel engines, as their advantage is that other than for starting, an electrical supply is not needed. This is an advantage in that it can be operated without any electrical power supply and is therefore unstoppable by military equipment that can cut out ignition systems.

Flywheel inertia

Because of their high compression ratios and heavy moving parts, diesel engines usually have large flywheels.

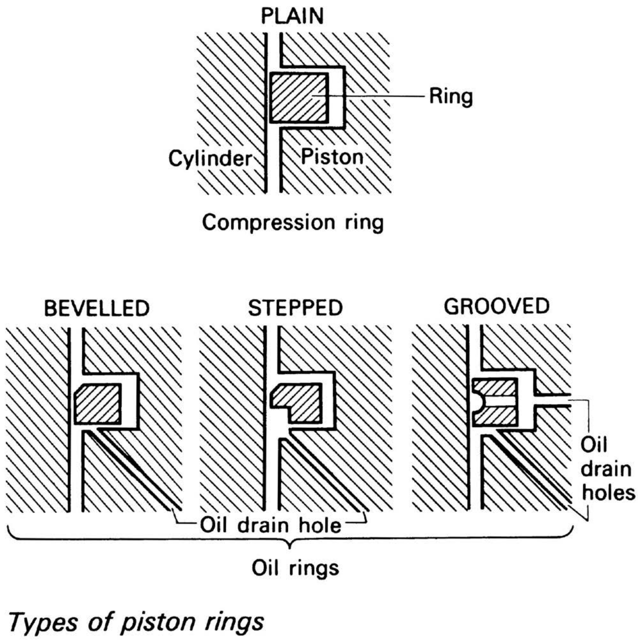


Figure 1.8 Types of piston rings.

Firing order

By increasing the number of cylinders, the engine becomes more compact in terms of size and smoother running. Smoothness of running is further improved by setting the sequence in which the cylinders fire; this is called the firing order. The normal firing orders for four-cylinder engines are 1-3-4-2 and 1-2-4-3.

Engine capacity

To find the capacity of an engine, first you need to find the size of each cylinder; this is called the swept volume. This is the volume that is displaced when the piston goes from BDC to TDC. The swept volume of each cylinder is the product multiplying the cross-sectional area and the stroke.

$$\text{Swept Volume} = \Pi D^2 L / 4$$

Π = 3.142
D = Diameter of bore
L = Length of stroke
All divided by 4

The engine capacity is the product of the swept volume and the number of cylinders.

$$\text{Capacity} = \text{Swept Volume} * \text{Number of Cylinders}$$

You will find the following abbreviations:
V_s = Swept Volume
N = Number of Cylinders
The engine capacity is usually measured in cubic centimeters (cc).

NOMENCLATURE

There are 1000 cc in 1 liter. A 1000-cc motorcycle is therefore referred to as 1 liter. American motorcycles are sized in cubic inches (cu in). One liter is equal to 62.5 cu in.

Compression ratio

The compression ratio is the relationship between the volume of gas above the piston at BDC compared to that at TDC. You need to know the swept volume (V_s) and the volume of the combustion chamber, which is referred to in this case as the clearance volume (V_c).

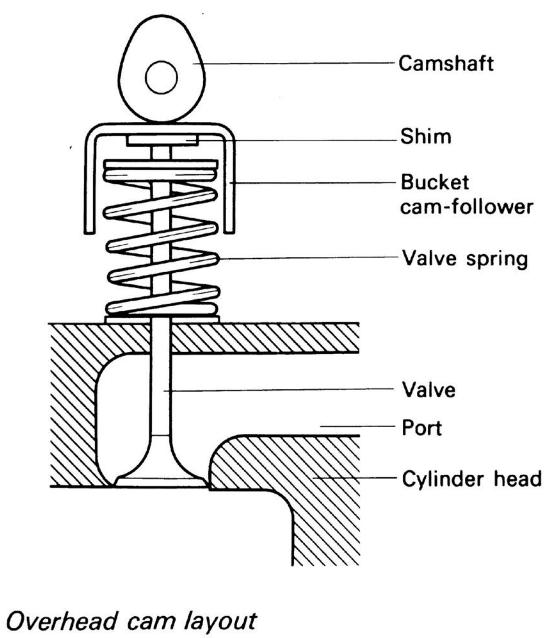


Figure 1.9 OHC valve layout.