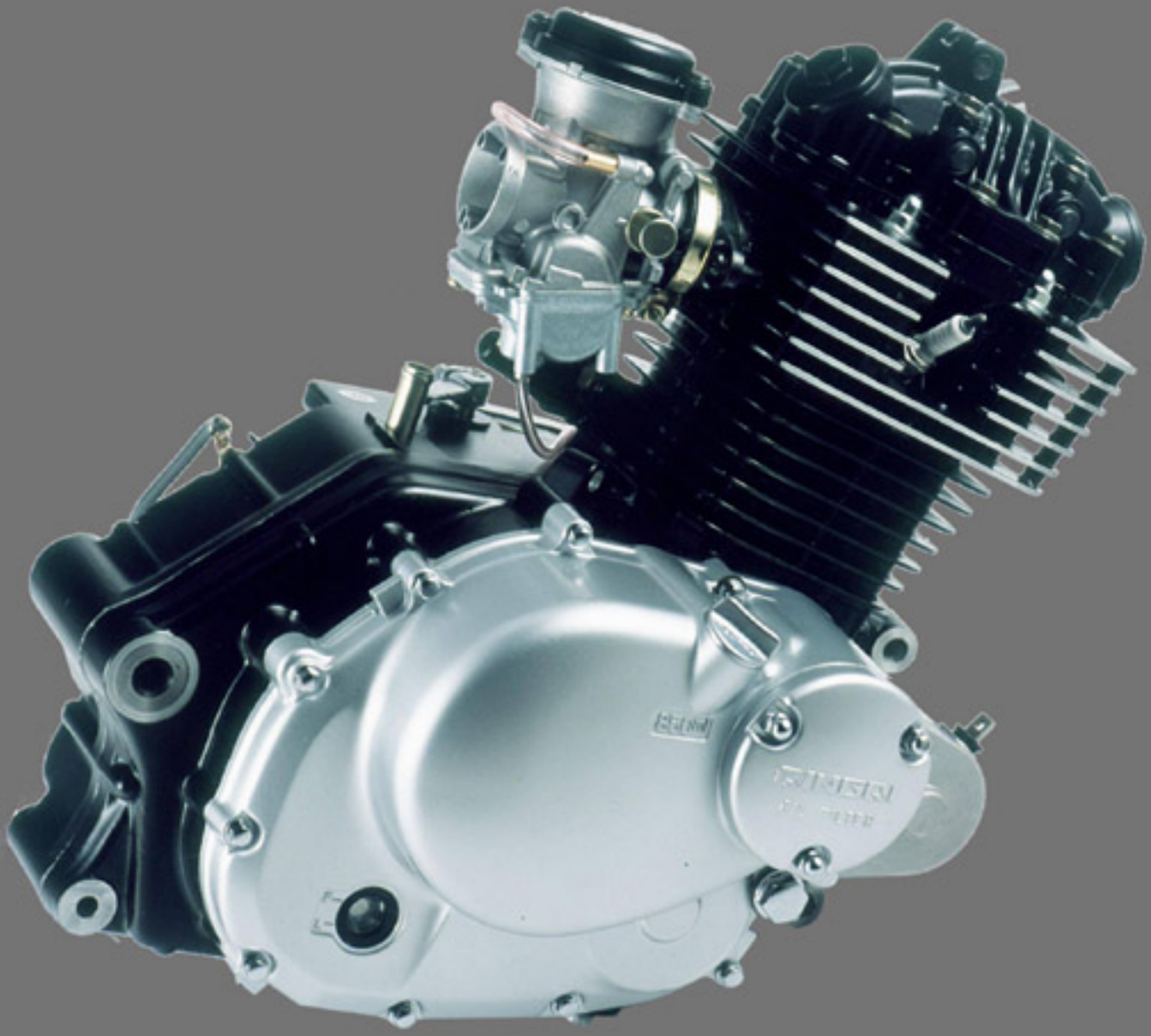

Motorcycle Technologies

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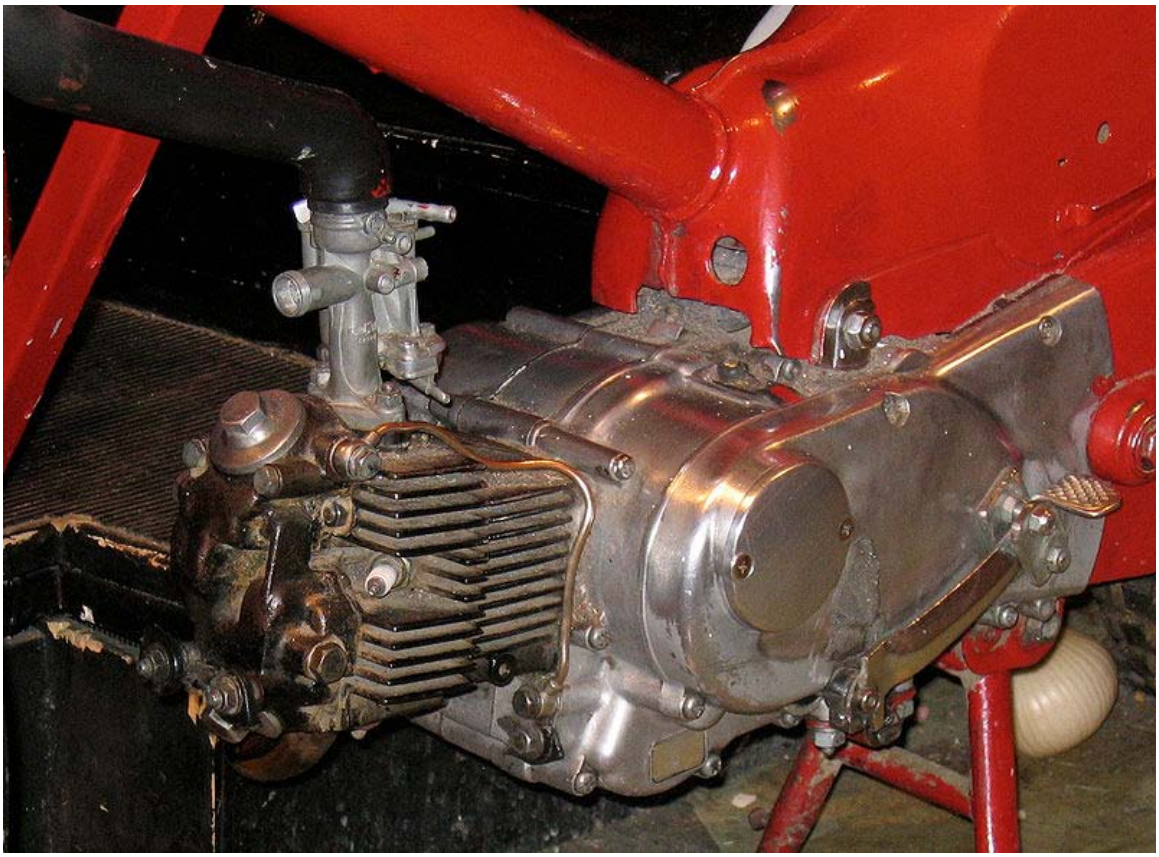
Motorcycle Engine



A Honda Super Cub engine. This 50 cc (3.1 cu in) horizontal single powers the most popular motorcycle in history, with over 60 million produced.

A **motorcycle engine** drives the rear wheel of a motorcycle and powers forward motion. Motorcycle engines vary in cylinder quantity, head design, displacement and layout.

Some motorcycle manufacturers have become strongly associated with one particular engine configuration. Modern Harley-Davidson motorcycles are exclusively transverse, narrow-angled V-twin engines, while Ducati and Moto Guzzi have specialised in 90° V-twins, the former transverse and the latter longitudinal with shaft drive. Longitudinal boxer twins are iconic of BMW motorcycles, although they now use a number of different engine layouts. British marques of the 1950s and 1960s were associated with parallel-twins even though they made other types as well. Japanese manufacturers vary greatly in layouts, and Honda in particular have produced almost every possible configuration and type.

History

Earliest motorcycle engine concept. This 1818 caricature was thought for many years to be entirely fanciful, until the Michaux-Perreaux, Roper and other steam cycles were rescued from obscurity, and the stories of the early steam cycle experiments were rediscovered. There were no steam motorcycles in 1818, but there soon would be.

The first motorcycles were powered by steam engines. The earliest example is the French Michaux-Perreaux steam velocipede of 1868. This was followed by the American Roper steam velocipede of 1869, and a number of other steam powered two and three wheelers, manufactured and sold to the public on through the early 20th century.

Using frames based both on the earlier boneshaker and the later—and in many ways completely modern—safety bicycle design, these early steam motorcycles experimented with a variety of engine placement strategies, as well as transmission and options. While

today nearly every motorcycle has its engine in the center of the frame, this became standard only around 1900-1910 after nearly every possible engine location was tried. The modern scooter engine arrangement was arrived at in the 1940s and remains the same today.

The Otto cycle gasoline internal combustion engine was first used on an experimental two wheeler created by Gottlieb Daimler to test the practicality of such an engine in a vehicle. This motorcycle, the Daimler Reitwagen, is credited as the *world's first motorcycle* by many authorities, partially on the assumption that a motorcycle is defined not as any two wheel motor vehicle, but a two wheel *internal combustion engine* motor vehicle. The Oxford English Dictionary, for example, defines the word motorcycle this way. The steam cycles were also simply neglected and forgotten by many historians, even as the Michaux-Perreaux waited forty years on display in the National Motor Museum, Beaulieu.

In recent years, a surge in interest in clean energy has put many new electric powered two wheelers on the market, and they are registered as motorcycles or scooters, without the type of powerplant being an issue. Diesel motorcycles were also been experimented with briefly throughout the 20th century, and are again the subject of interest due to fuel economy and the needs of military logistics. The USMC has ordered a new diesel motorcycle, the M1030 M1, that can use the same fuel, JP-8, as the rest of their armored vehicles, aircraft, cars and trucks.

The overwhelming majority of the motorcycles produced and used in the world today have small displacement air-cooled single-cylinder engines, both two- and four-strokes. In the wealthier parts of the world, Europe and Japan, larger displacements and multiple cylinders are common alongside small-displacement bikes required by various licensing and rider experience requirements, and so a very diverse range of sizes, cylinder numbers, configurations, and cooling systems are seen on the road. Many developed countries have graduated licensing, where a rider is licensed for a period of time to ride only smaller-displacement motorcycles before being allowed to ride larger ones. In the United States, there are no such mandates, and so the mix is skewed even further to the largest displacements, consumer demand drives manufacturers to offer their largest motorcycles to that country, and to export far fewer sub-600 cc (37 cu in) models to the American market.

Types

Almost all commercially available motorcycles are driven by conventional gasoline internal combustion engines, increasingly four-strokes in all size ranges. Some are still air-cooled (forced with a fan in some cases) but water-cooling is more common. The mid-range and large two-strokes seen in the 1970s and 1980s have almost disappeared, particularly as emission laws were introduced. There are a few small scooter-type models using batteries and an electric motor. Van Veen, Hercules, Norton, and Suzuki produced quite small numbers of motorcycles propelled by Wankel rotary engines. The 2009 TT races included a new category 'TTX' for electric bikes using either fuel-cells or batteries

Most motorcycle engines have the primary working member or crankshaft across the frame (transverse mounting). Others are arranged to turn a shaft-drive to the rear wheel and the crankshaft is longitudinal, along the frame.

A sub-type of motorcycle, the scooter, has the engine as part of the rear suspension, so it is not fixed to the main frame. Such engines pivot to follow the road surface and are partly "unsprung weight". The final drive of scooters is much shorter than that of regular motorcycles and is contained within the engine casings in an oil-bath, a design that is only suitable for machines with small wheels, or is fully automatic using belts and expanding/contracting pulleys, ala DAF variomatic cars. The engines of the motorcycles known as underbones or "step-throughs" may be of either kind.

Two-stroke and four-stroke

Two-stroke engines have fewer moving parts than four-stroke engines, and produce twice the number of power strokes; consequently, two-stroke engines are more powerful for their mass. Two-strokes offer stronger acceleration, but similar top speed compared to a four-stroke engine. They are also easier to start. However, two-stroke engines have shorter life due to poorer piston lubrication, since lubrication comes from the fuel-oil mix.

Four-stroke engines are generally associated with a wider power band making for somewhat gentler power delivery, but technology such as reed valves and exhaust power-valve systems has improved ride-ability on two-strokes. Fuel economy is also better in four-strokes due to more complete combustion of the intake charge in four-stroke engines.

Nevertheless, two-strokes have been largely replaced on motorcycles in developed nations due to their environmental disadvantages. Cylinder lubrication is necessarily total-loss and this inevitably leads to a smokey exhaust, particularly on wide throttle openings. Two-stroke engined motorcycles continue to be made in large numbers, but mostly low power mopeds, small scooters and step-through underbones where they still compete strongly with four-strokes (including the highest selling motorcycle of all time, the 50 cc Honda Super Cub). The major markets of two-stroke motorcycles are in developing nations.

Heads

Motorcycle engine heads are the subject of a great deal of attention, due both to the critical role played by intake, exhaust and valve systems in the overall efficiency of an engine, but also because on a motorcycle the head is often the center of attention, aesthetically speaking. Harley-Davidsons, Moto Guzzis and BMWs are categorized by their heads, such as airhead, panhead, oilhead, and even knucklehead. The eras of Ducati production, and the camps or factions their enthusiasts gather in, are divided by head, whether they be pushrod, bevel heads, desmos, or chain- or belt-driven valves.

Valve control

Honda equipped the CBR400F with HYPER VTEC (or REV:Revolution-modulated valve control) in 1983. The system enabled to switch over the number of valve operations per cylinder between low and medium speed revolution range and high speed revolution range. In January 2002 HYPER VTEC evolved into Spec II and in December 2003 SPEC III was introduced.

Unit construction

Engines and gear-boxes were originally quite separate, with drive from one to the other by a chain (the 'primary'). Gradually these components were moved closer and closer together until they were eventually incorporated in the same case (actually, 2 compartments in one case).

Displacement

Engine displacement is defined as the total volume of air/fuel mixture an engine can draw in during one complete engine cycle. In a piston engine, this is the volume that is swept as the pistons are moved from top dead center to bottom dead center. This is the "size" of the engine. Motorcycle engines range from less than 50 cc, commonly found in many mopeds and small scooters, to a 6,000 cc engine used by Boss Hoss in its cruiser style motorcycle BHC-3 LS2. Many state laws in the U.S. define a motorcycle as having an engine larger than 50 cc, and a moped as a vehicle with an engine smaller than 60 cc.

Cylinders and configuration

Small motorcycles normally have a single cylinder, many smaller and mid-range motorcycles have twin cylinders and most medium to large motorcycles have four cylinders. However, no generalizations can be made, as there are a few large singles and twins. Three cylinders have been widely used and there have been some six-cylinder machines. Many different layouts have been used with vertical cylinders the most popular. There are some horizontally opposed and V layouts.

Single

1960 BSA Gold Star

Single cylinder engines (known as "singles" or occasionally "thumpers") may have the cylinder vertical or horizontal, the latter particularly common in step-through or underbone motorcycles. Single cylinder engines require a larger flywheel, hindering ultimate performance but are a lot easier to maintain in almost every respect. In road motorcycles, single-cylinders tend to be associated with cheaper, utility motorcycles for daily transport. These motorcycle engines are tuned to give more power at lower engine revolutions, improving control, safety and engine longevity.

The need for the flywheel effect is less pronounced in all forms of competition motorcycles since they spend almost no time at tick-over speeds, all through the 1950s many of the fastest road racing motorcycles such as the Manx Norton were single-

cylindered. The reduced weight and narrow width of single-cylinder motorcycles continue to make the layout well suited for the great majority of off road motorcycles, including those in top competition.

Split Single (a radical form of two-stroke) were used very successfully by DKW and Puch between and after the wars, losing out only to the loop-scavenging Japanese twin and triple machines of the 1970s.

Twin

1962 Honda CB77 Superhawk 305 cc (18.6 cu in) twin engine.

Two-cylinder engines are known as twins. The parallel twin as in most common British and many Japanese motorcycles. Engines of this design typically have the cylinders side by side vertically above the crankcase, with the exhaust ports pointing forward to

maximize airflow cooling. Longitudinal twins include the 500 cc Sunbeam S7 and S8. The two crankpins can be timed simultaneously, with each side firing alternately every 360° (most British bikes), or timed with 1 piston at TDC and the other at BDC to fire 180° apart, followed by a long "dead" interval (many Hondas). Some Hondas have been made with both crankshaft types. Some engines, such as the Matchless 650, have had a 3rd center main bearing between the crankpins, but this was not successful.

The parallel-twin engine configuration was made famous by Edward Turner's Triumph Speed Twin design as used on the Bonneville 20 years later.

V-twin

Harley-Davidson Sportster V-twin

The V-twin engine where the cylinders form a "V" around the crankshaft, which is oriented longitudinally with the cylinders protruding left and right on models such as on the Honda CX500 and most Moto Guzzi motorcycles, or more typically transversely . V-twins can also be separated into three types, one having a shared crankpin (a normal con-rod is inserted between a forked con-rod thus sharing the single crankpin and keeping the cylinders in line, a single crankpin with side-by-side connecting rods and offset cylinders, or two crankpins, with the cylinders offset, which nearly every one else uses.

The angle in the V-twins varies from around 42° (Indian), 45° (Harley-Davidson), 60°, and up to 90°. Typical of the former are the Harley-Davidson and Vincent engines which because of their firing order tend to vibrate more. Ducati and Moto Guzzi make V-twins with cylinders arranged at a 90 degree angle to quell primary vibrations.

Flat twin

BMW's opposed twin

The opposed twin engine's cylinders normally protrude sideways into the cooling air stream, although some early motorcycles had them transversely mounted.

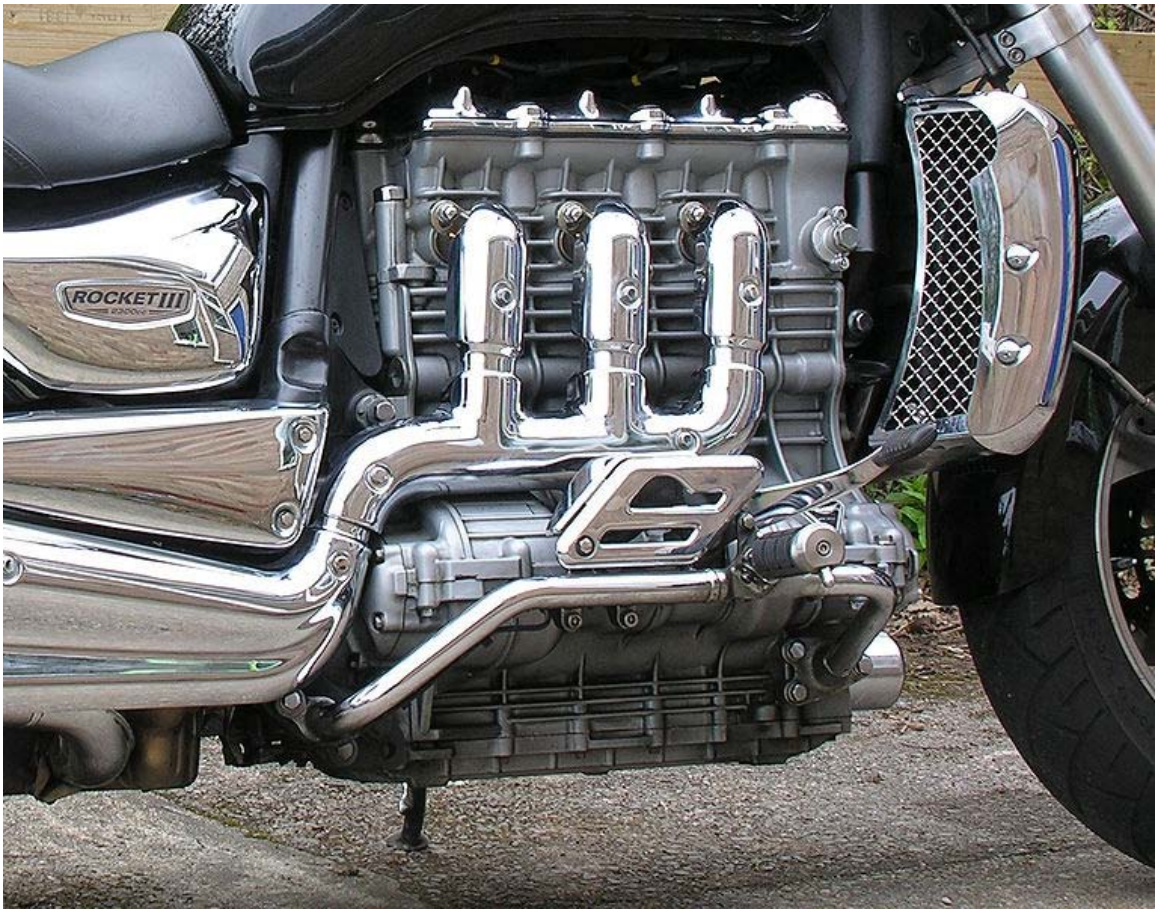
In the flat-twin (boxer) engine, which is used by BMW Motorrad, Ural, Harley-Davidson's WW2 "XA" model, Marusho, and historically by Douglas, the cylinders are horizontally opposed, protruding from either side of the frame. The boxer is the only twin-cylinder arrangement that has inherent primary balance without a rocking couple, producing very low vibration levels without the use of counterbalance shafts.

Tandem twin

The Tandem Twin where the cylinders are longitudinal, and have two cranks geared together such as Kawasaki's KR250 road bike and KR250 and KR350 GP Bikes.

Triple

Inline 3



Triumph Rocket III inline-3

Three-cylinder designs are referred to as "triples" and are normally inline triples in layout. The British Hinckley-built Triumph, mostly transverse but also the 2,300 cc longitudinal Rocket III, Italian Benelli and Japanese Yamaha XS750 are three motorcycle manufacturers who have used triples in their large displacement motorcycles. The Italian firm Laverda made a few 1,000 cc and 1,200 cc triples. BMW made the K75 longitudinal 750 cc triple with the cylinders parallel to the ground. BSA made the Rocket-3 transverse 750 cc and old Triumph the 750 cc Trident

Two-stroke triples were somewhat more common historically. The Kawasaki triples were produced with capacities of 250, 350, 400, 500, and 750 cc in the 1970s, while Suzuki produced 380, 550, and 750 triples (the last being water cooled). Motobecane made 350 cc and fuel injected 500 cc triples with 3 into 4 pipes in the early seventies. Honda produced the water cooled V-3 two-strokes MVX250 and NS400. There have been various race bike triples such as Kawasaki KR750, Suzuki TR750 transverse 3's, and Proton/Modenas KR3, Honda NS500 V-3s.

Four

Four-cylinder engines are most commonly found in a transverse-mounted inline four layout, although some are longitudinal (as in the earlier BMW K100). V-4 and boxer designs (as in the earlier Honda Gold Wing) have been produced. One of the more unusual designs was the Ariel Square Four, effectively two parallel-twin engines one in front of the other in a common crankcase – it had remarkably little vibration due to the contra-rotating crankshafts.

Inline 4

Honda CB750 transverse inline-4

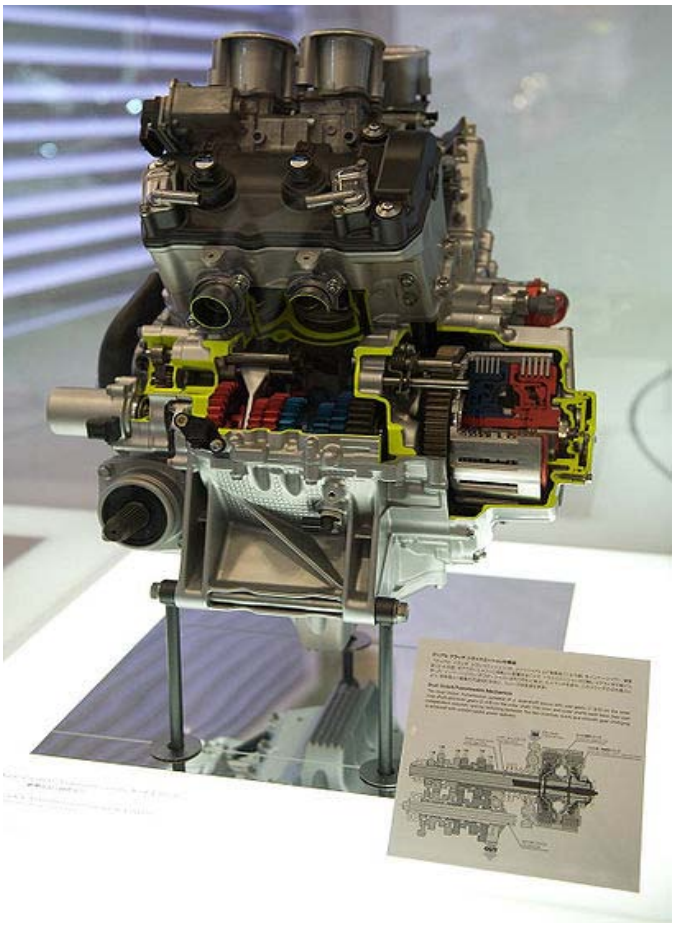
Since the advent of the Honda CB750 straight-four engine, straight-fours have dominated the non-cruiser street motorcycle segments. The German manufacturer Münch based their

motorcycles on four cylinder car engines (e.g. Mammut 2000 has a 2.0l with a turbo and cylinder heads by Cosworth).

Flat 4

The Honda GL1000 flat-four

V4



Honda VFR1200F engine with dual clutch transmission.

Honda uses V4 engines in the ST series and VFR series. As for two-stroke engines, there were four cylinders in the smaller classes such as Kawasaki's 125 cc KR3 square 4 and Yamaha's 250 cc RD500 V4 (RZ 500 in the US). Yamaha later raced transverse four TZ500/700/750's and virtually all the bikes in the last decade of the two-stroke GP500 era were fours (first squares then Vees) i.e. Honda, Kawasaki, Cagiva, Suzuki, Yamaha - Kawasaki also experimented with a trapezoidal four the 602S. Yamaha made the V4 RD500LC, and Suzuki the RG400 and RG500 square four road bikes.

Square 4

A square four is a U engine with two cylinders on each side. This configuration was used on the Ariel Square Four motorcycle from 1931 to 1959. This design was revived as a two-stroke version on some racing Suzuki models, and their subsequent road-going version the RG500. Although some racing success was achieved, the road bikes didn't sell in great numbers, and the design was phased out in favour of in-line, four-stroke designs, as at the time two stroke engines were quickly being superseded by more economical, reliable, and emissions-friendly four-strokes.

Five

V5

Honda V5 MotoGP engine

Honda has produced five-cylinder engines for racing, the RC211V 990 cc V5. No V5 engines are currently available in commercial production motorcycles.

Six

Inline 6

Benelli Sei inline-6

Six-cylinder engines are rare and found only on the biggest motorcycles. Two easily recognizable examples in recent times have been the Honda CBX and the Kawasaki KZ1300 and also Kawasakis Voyager XIII, Bennelli also made 750 cc and 900 cc Straight sixes known as the Sei. Honda made a 250 cc straight-six GP bike. Modern straight-six motorcycles include the BMW K1600GT and K1600GTL, which have a transverse-mounted 1,649 cc engine.

Flat 6

Honda Valkyrie flat-6

The six-cylinder engine is currently used by Honda in the boxer engine of the Rune, Valkyrie and Gold Wing.

V8

Moto Guzzi V8

Galbusera built a V8 in 1938, and Moto Guzzi experimented over a period of two years with its dual overhead cam 500 cc V8 (the Otto Cylindri) in the 1950s. Some custom and one-off motorcycles use more than six cylinders. For example, the Boss Hoss motorcycle uses (5,700 cc, 6,000 cc and 8,200 cc) Chevy V-8 crate motors. In the 1990s Daimler-Chrysler manufactured a limited number of Tomahawk concept bikes featuring a Dodge Viper's V-10 engine. Australian company Drysdale have built short runs of 750 cc V8 superbikes and 1L V8 roadgoing motorcycles, both with engines specifically developed for the purpose. No major motorcycle manufacturer has used eight or more cylinders although Honda made the 'almost' V8 oval piston NR750 road bike and NR500 GP bike (having eight connecting rods, for example) and Morbidelli has shown two V8 prototype road bikes, but has yet to get off the ground

Other types

Wankel rotary

Hercules (motorcycle), Norton Commando, ZF Sachs, Suzuki RE5

Oval pistons

Honda NR

Rotary engines

Megola, Killinger and Freund Motorcycle

Jet engines

MTT Turbine Superbike

Diesel

Only very small numbers of diesel engined motorcycles have ever been built. The improved fuel efficiency is offset by the increased weight, reduced acceleration and potential difficulty of starting, at least in colder climates. Enfield India built a few from 1965 onwards but is no longer doing so. In November 2006, the Dutch company E.V.A. Products BV Holland announced their first diesel-powered motorcycle, its Track T-800CDI, using an 800 cc three-cylinder Daimler Chrysler diesel engine.

Several armies are moving to an all-diesel engine fleet to reduce the fire risks of petrol and the need to provide two different fuels. This includes their despatch riders as well, encouraging the market for diesel motorcycles. Interest in biofuels is also likely to encourage future developments for small Diesels.

Diesels are also available in both two and four-stroke versions.

Engine cooling

Liquid

Liquid-cooled motorcycles have a radiator (similar to the radiator on a car) which is the primary way their heat is dispersed. Coolant is constantly circulated between this radiator and the cylinders when the engine is running. While most off-road motorcycles have no radiator fan and rely on air flowing over the radiators from the forward motion of the motorcycle, many road motorcycles have a small fan attached to the radiator which is controlled by a thermostat. Some off-road motorcycles are liquid cooled and anti-dirt protection is attached to the radiator. The cooling effect of this fan is enough to prevent the engine overheating in most conditions, so liquid-cooled bikes are safe to use in a city, where traffic may frequently be at a standstill.

Emissions regulations and the market demand for maximum power are driving the motorcycle industry to liquid-cooling for most motorcycles. Even Harley-Davidson, a strong advocate of air-cooled motors, has begun producing a Revolution liquid-cooled engine.

Air

Most air cooled motorcycles take advantage of air blowing past the cylinder and cylinder head while in motion to disperse heat. Frequent, sustained stationary periods may cause over-heating. Some models (mostly scooters) are equipped with fans that force the air to go past the cylinder block, which solves the problem of city driving. The cylinders on air cooled bikes are designed with fins (heat sinks) to aid in this process. Air cooled bikes are cheaper, simpler and lighter than their water-cooled counterparts.

Oil

The BMW R1150GS has an oil cooler below the headlights and fins for air cooling on the cylinders

Some manufacturers use a hybrid cooling method where engine oil is circulated between the engine case and a small radiator. Here the oil doubles as cooling liquid, prompting the name "oil-cooling." Suzuki has produced many "oil-cooled" motorcycles. Modern BMW R-series flat-twin motorcycles, such as the R1150GS, use air and oil cooling. Polaris's Victory motorcycles use oil/air cooling exclusively.

Other components

Fuel injection and computer engine management systems are now normal on middle range and larger motorcycles and are increasingly being incorporated onto the smaller machines, partly driven by better emission control and lower maintenance but mostly by manufacturing cost considerations. Ignition systems moved from magneto in the 1950s to battery-coil-contact breaker (points), and these were increasingly superseded by Capacitor Discharge Ignition (CDI) from the 1980s. Small, single cylinder motorcycles abandoned the flywheel magneto system with contact breakers to similar flywheel driven solid-state systems at about the same time.

Turbo and Superchargers. Superchargers (blowers) were common in the GP's, until they were banned (which didn't help the two-stokes, as pre Ernest Degners new technology, they needed the help against the four-strokes). The big four also made a turbo-ed bike, Honda made two....., mainly as an exercise in technical expertise and later discontinued for more conventional methods. Bolt on (well nearly) blowers are available to put on street bikes - and they are essential for drag bikes and land speed record streamliners etc. Most sports bikes now use some sort of 'ram-air' system where, as road speed increases, more and more air is forced through ducts in the fairing to pressurize the airbox — not to be confused with the original Ram-Air system where an air scoop/cowl was fitted to the top of the cylinder heads of Suzukis two-strokes to aid cooling.

Chapter 2

Two-Stroke Engine

Brons two-stroke V8 Diesel engine driving a Heemaf generator.

A **two-stroke** engine is an internal combustion engine that completes the process cycle in one revolution of the crank shaft (an up stroke and a down stroke of the piston, compared to twice that number for a four-stroke engine). This is accomplished by using the

beginning of the compression stroke and the end of the combustion stroke to perform simultaneously the intake and exhaust (or scavenging) functions. In this way two-stroke engines often provide strikingly high specific power, at least in a narrow range of rotations speeds. The functions of some or all of the valves required by a four-stroke engine are usually served in a two-stroke engine by ports that are opened and closed by the motion of the pistons, greatly reducing the number of moving parts. Gasoline (spark ignition) versions are particularly useful in lightweight (portable) applications such as chainsaws and the concept is also used in diesel compression ignition engines in large and non-weight sensitive applications such as ships and locomotives.

Invention of the two-stroke cycle is attributed to Scottish engineer Dugald Clerk who in 1881 patented his design, his engine having a separate charging cylinder. The crankcase-scavenged engine, employing the area below the piston as a charging pump, is generally credited to Englishman Joseph Day (and Frederick Cock for the piston-controlled inlet port).

Applications

A two-stroke minibike.

Lateral view of a two-stroke Forty series British Seagull outboard engine. The serial number dates it to 1954/1955

The two-stroke engine was very popular throughout the 20th century in motorcycles, small engined devices such as chainsaws and outboard motors and was also used in some cars, a few tractors and many ships. Part of their appeal was due to their simple design (and resulting low cost) and often high power-to-weight ratio. Many designs use total-loss lubrication, with the oil being burnt in the combustion chamber, causing "blue smoke" and other types of exhaust pollution. This is a major reason for two-stroke engines losing out to and being replaced by four-stroke engines in many applications.

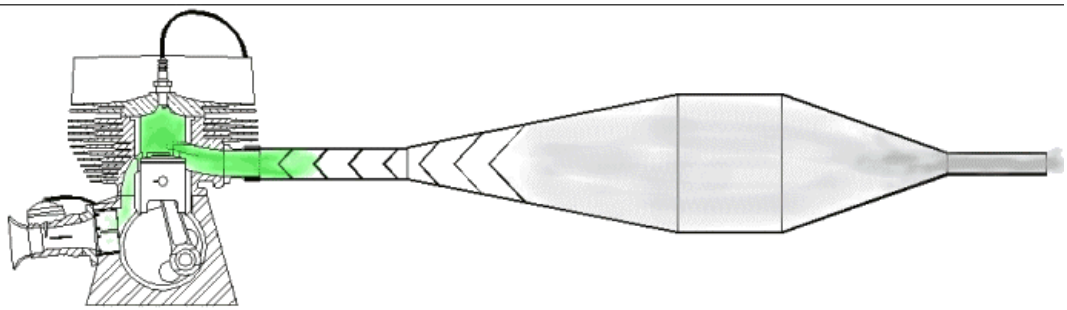
Two-stroke engines continue to be commonly used in high-power, handheld applications such as string trimmers and chainsaws. The light overall weight, and light-weight

spinning parts give important operational and even safety advantages. Only a two-stroke running on a gasoline-oil mixture can power a chainsaw running in any position.

These engines are still used for small, portable, or specialized machine applications such as outboard motors, high-performance, small-capacity motorcycles, mopeds, underbones, scooters, tuk-tuks, snowmobiles, karts, ultralights, model airplanes (and other model vehicles) and lawnmowers. The two-stroke cycle is used in many diesel engines, most notably large industrial and marine engines, as well as some trucks and heavy machinery.

A number of mainstream automobile manufacturers have used two-stroke engines in the past, including the Swedish Saab and German manufacturers DKW and Auto-Union. The Japanese manufacturer Suzuki did the same in the 1970s. Production of two-stroke cars ended in the 1980s in the West, but Eastern Bloc countries continued until around 1991, with the Trabant and Wartburg in East Germany. Lotus of Norfolk, UK, has a prototype direct-injection two-stroke engine intended for alcohol fuels called the Omnivore which it is demonstrating in a version of the Exige.

Different two-stroke design types



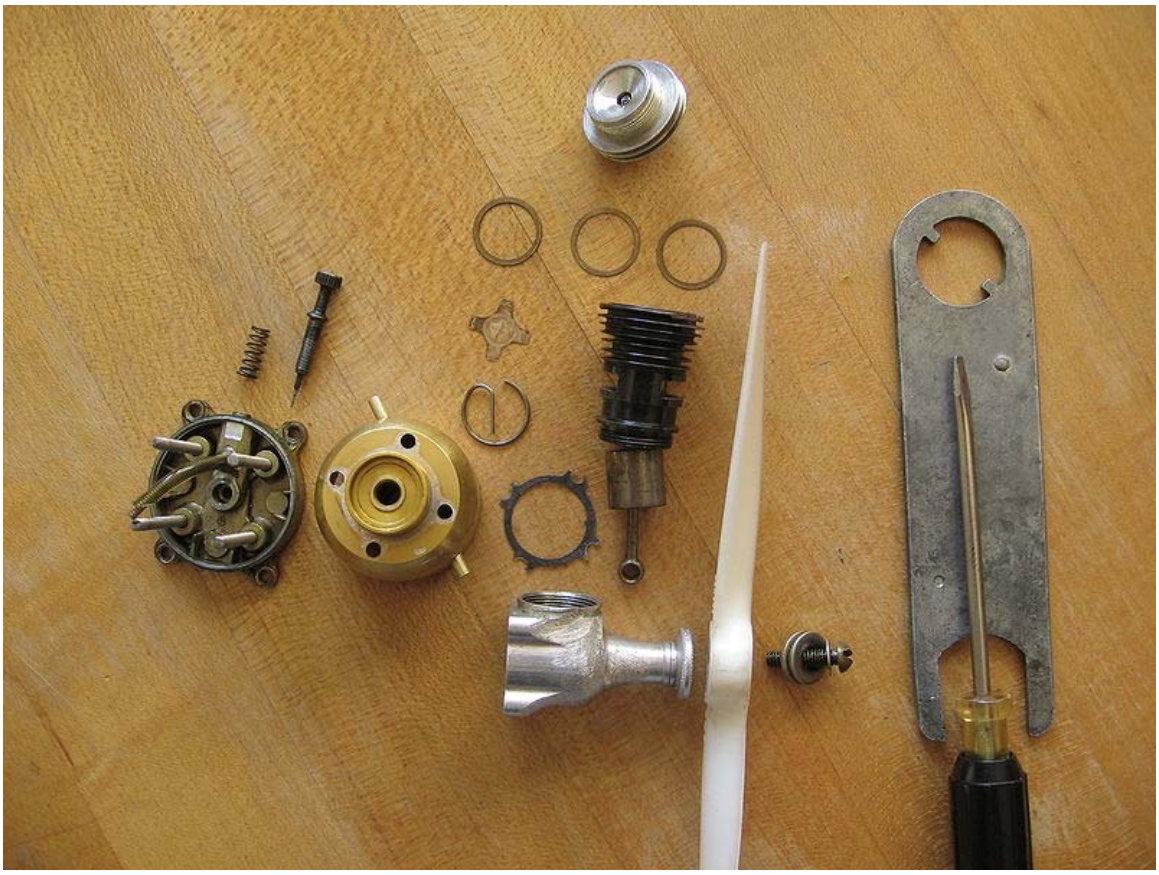
A two-stroke engine, in this case with a tuned expansion pipe illustrating the effect of a reflected pressure wave on the fuel charge. This feature is essential for maximum charge pressure (volumetric efficiency) and fuel efficiency. It is used on most high-performance engine designs.

Although the principles remain the same, the mechanical details of various two-stroke engines differ depending on the type. The design types of the two-stroke engine vary according to the method of introducing the charge to the cylinder, the method of scavenging the cylinder (exchanging burnt exhaust for fresh mixture) and the method of exhausting the cylinder.

Piston controlled inlet port

Piston port is the simplest of the designs. All functions are controlled solely by the piston covering and uncovering the ports as it moves up and down in the cylinder. A fundamental difference from typical four-stroke engines is that the crankcase is sealed and forms part of the induction process in gasoline and hot bulb engines. Diesel engines have mostly a roots blower or piston pump for scavenging.

Reed inlet valve



A Cox Babe Bee 0.049 cubic inch (0.8 cubic cm.) reed valve engine disassembled. It uses glow plug ignition. The mass is 64 grams.

The reed valve is a simple but highly effective form of check valve commonly fitted in the intake tract of the piston-controlled port. They allow asymmetric intake of the fuel-charge, improving power and economy, while widening the power band. They are widely used in ATVs, and marine outboard engines.

Rotary inlet valve

The intake pathway is opened and closed by a rotating member. A familiar type sometimes seen on small motorcycles is a slotted disk attached to the crankshaft which covers and uncovers an opening in the end of the crankcase, allowing charge to enter during one portion of the cycle.

Another form of rotary inlet valve used on two-stroke engines employs two cylindrical members with suitable cutouts arranged to rotate one within the other - the inlet pipe having passage to the crankcase only when the two cutouts coincide. The crankshaft itself may form one of the members, as in most Glowplug model engines. In another embodiment, the crank disc is arranged to be a close-clearance fit in the crankcase and is

provided with a cutout which lines up with an inlet passage in the crankcase wall at the appropriate time, as in the Vespa motor scooter.

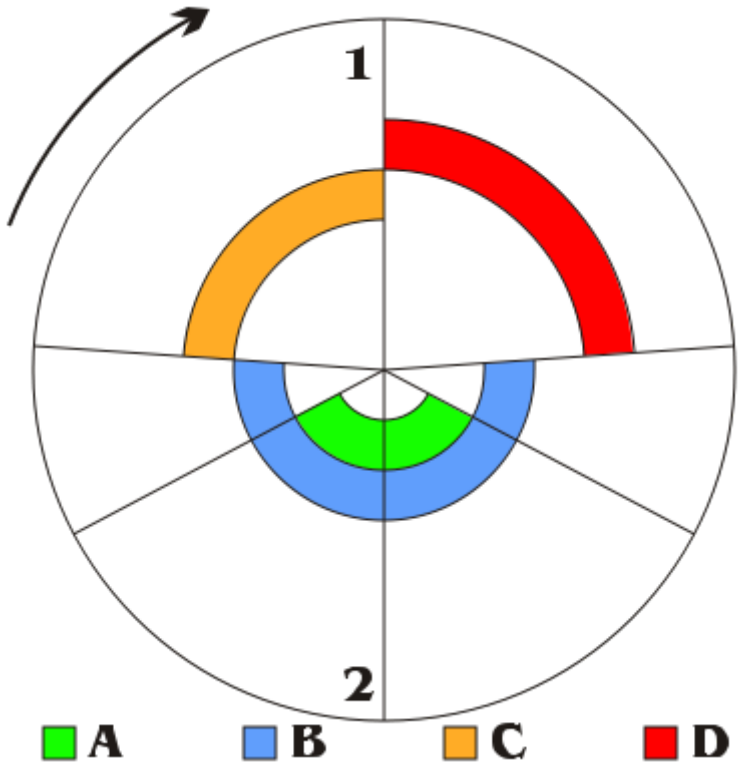
The advantage of a rotary valve is that it enables the two-stroke engine's intake timing to be asymmetrical which is not possible with two-stroke piston port type engines. The two-stroke piston port type engine's intake timing opens and closes before and after top dead center at the same crank angle making it symmetrical whereas the rotary valve allows the opening to begin earlier and close earlier.

Rotary valve engines can be tailored to deliver power over a wider speed range or higher power over a narrower speed range than either piston port or reed valve engine. Where a portion of the rotary-valve is a portion of the crankcase itself it is particularly important that no wear is allowed to take place.

Crossflow-scavenged

In a crossflow engine the transfer ports and exhaust ports are on opposite sides of the cylinder and a deflector on the top of the piston directs the fresh intake charge into the upper part of the cylinder pushing the residual exhaust gas down the other side of the deflector and out of the exhaust port. The deflector increases piston's weight and its exposed surface area, and also makes it difficult to achieve an efficient combustion chamber shape. This design has been largely superseded by loop scavenging method (below), although for smaller or slower engines the crossflow-scavenged design can be an acceptable approach.

Loop-scavenged

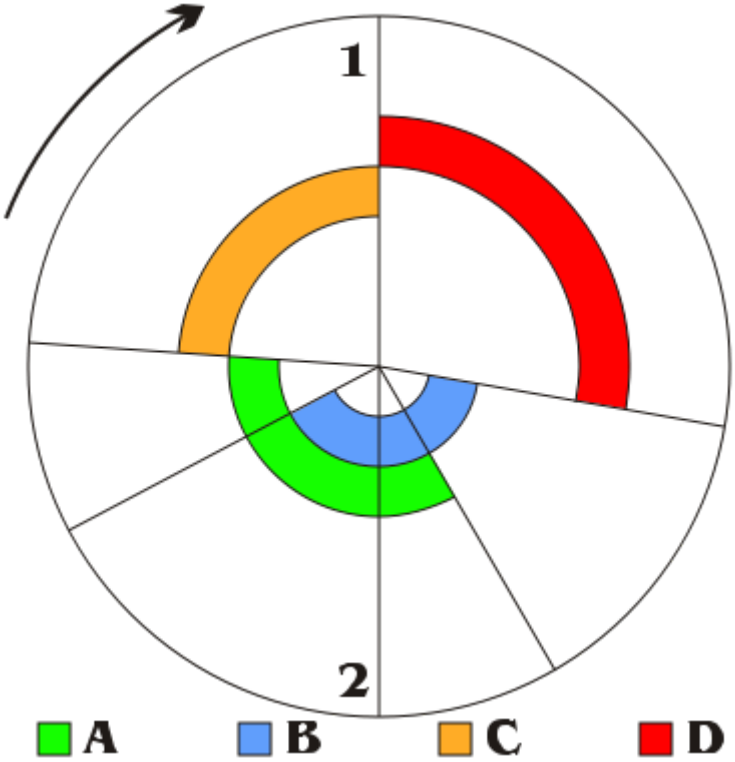


The Two-stroke cycle
1=TDC
2=BDC
A: intake/scavenging
B: Exhaust
C: Compression
D: Expansion(power)

This method of scavenging uses carefully shaped and positioned transfer ports to direct the flow of fresh mixture toward the combustion chamber as it enters the cylinder. The fuel/air mixture strikes the cylinder head then follows the curvature of the combustion chamber then is deflected downward. This not only prevents the fuel/air mixture from traveling directly out the exhaust port but creates a swirling turbulence which improves combustion efficiency, power and economy. Usually a piston deflector is not required, so this approach has a distinct advantage over the cross flow scheme (above). Often referred to as "Schnuerle" (or "Schnürl") loop scavenging after the German inventor of an early form in the mid 1920s, it became widely adopted in that country during the 1930s and spread further afield after World War II. Loop scavenging is the most common type of fuel/air mixture transfer used on modern two stroke engines. Suzuki was one of the first manufacturers outside of Europe to adopt loop scavenged two stroke engines. This operational feature was used in conjunction with the expansion chamber exhaust developed by German motorcycle manufacturer, MZ and Walter Kaaden. Loop

scavenging, disc valves and expansion chambers worked in a highly coordinated way that saw a significant increase in the power output of two-stroke engines, particularly from the Japanese manufacturers Suzuki, Yamaha and Kawasaki. Suzuki and Yamaha enjoyed success in grand Prix motorcycle racing in the 1960s due in no small way to the increased power afforded by loop scavenging. An additional benefit of loop scavenging was that the piston could be made nearly flat or slightly dome shaped. This enabled the piston to be appreciably lighter and stronger and consequently tolerated higher engine speeds. The "flat top" piston also has better thermal properties and is less prone to uneven heating, expansion, piston seizures, dimensional changes and compression losses.

Uniflow-scavenged



The Uniflow Two-stroke cycle
1=TDCdg
2=Bbb
A: Intake(effective scavenging ≈140°-250°)
B: Exhaust
C: Compression
D: Expansion(power)

In a uniflow engine the mixture, or air in the case of a diesel, enters at one end of the cylinder controlled by the piston and the exhaust exits at the other end controlled by an exhaust valve or piston. The scavenging gas-flow is therefore in one direction only, hence the name uniflow. The valved arrangement is common in diesel locomotives (Electro-

Motive Diesel) and large marine two-stroke engines (Wärtsilä). Ported types are represented by the opposed piston design in which there are two pistons in each cylinder, working in opposite directions such as the Junkers Jumo and Napier Deltic. The once-popular split-single design falls into this class being effectively a folded uniflow. With advanced angle exhaust timing uniflow engines can be supercharged with a crankshaft driven (piston or Roots) blower.

In Japan. Nissan Diesel Motor was manufacturing **Uniflow Two-stroke Diesel Engine**(ja:ユニフロー掃気ディーゼルエンジン) from General Motors from under a license of Detroit Diesel Series 71.

The latest invention, called the Reversed Uniflow two-stroke engine, has a large intake valve for compressed intake air without fuel-oil mixture. Direct fuel injection is to be used for gasoline or diesel fuel, pending intake air pressure. This engine will work on the Miller cycle. US Patent #6889636.

Stepped piston engine

The piston of this engine is "top-hat" shaped, the upper section forming the regular cylinder. and the lower section performing a scavenging function. The units run in pairs, the lower half of one piston charging an adjacent combustion chamber.

This system is still partially dependent on total loss lubrication (for the upper part of the piston), the other parts being sump lubricated with cleanliness and reliability benefits. The piston weight is only about 20% heavier than a loop-scavenged piston because skirt thicknesses can be less. The patents on this design are held by Bernard Hooper Engineering Ltd (BHE).

Power valve systems

Many modern two-stroke engines employ a power valve system. The valves are normally in or around the exhaust ports. They work in one of two ways: either they alter the exhaust port by closing off the top part of the port which alters port timing such as Ski-doo R.A.V.E, Yamaha YPVS, Honda RC-Valve, Cagiva C.T.S., Suzuki AETC system or by altering the volume of the exhaust which changes the resonant frequency of the expansion chamber, such as Honda V-TACS system. The result is an engine with better low-speed power without sacrificing high-speed power.

Direct injection

Direct injection has considerable advantages in two-stroke engines, eliminating some of the waste and pollution caused by carbureted two-strokes where a proportion of the fuel/air mixture entering the cylinder goes directly out, unburned, through the exhaust port. Two systems are in use, low-pressure air-assisted injection, and high pressure injection.

Since the fuel does not pass through the crank case, a separate source of lubrication is needed.

Two-stroke diesel engines

Diesel engines rely solely on the heat of compression for ignition. In the case of Schnuerle ported and loop-scavenged engines, intake and exhaust happens via piston-controlled ports. A uniflow diesel engine takes in air via scavenge ports, and exhaust gases exit through an overhead poppet valve. Two-stroke diesels are all scavenged by forced induction. Some designs utilize a mechanically driven Roots blower, whilst marine diesel engines normally use exhaust-driven turbochargers, with electrically-driven auxiliary blowers for low-speed operation when exhaust turbochargers are unable to deliver enough air.

Marine two-stroke diesel engines directly coupled to the propeller are able to start and run in either direction as required. The fuel injection and valve timing is mechanically readjusted by using a different set of cams on the camshaft. Thus the engine can be run in reverse to move the vessel backwards.

Lubrication

Most small petrol two-stroke engines cannot be lubricated by oil contained in their crankcase and sump, since the crankcase is already being used to pump fuel-air mixture into the cylinder. Traditionally the moving parts (both rotating crankshaft and sliding piston) were lubricated by a pre-mixed fuel-oil mixture (at a ratio between 16:1 and 50:1). As late as the 1960s petrol stations would often have a separate pump that would deliver such a pre-mix fuel to motorcycles. Even then, in many cases the rider would carry a bottle of his own two-stroke oil. Taking care to close the fuel-tap first, he or she would meter in a little oil (using the cap of the bottle) and then put in the petrol, this action mixing the two liquids.

Modern two-stroke engines pump lubrication from a separate tank of oil. This is still a total-loss system with the oil being burnt the same as in the older system, but at a lower and more economical rate. It is also cleaner, reducing the problem of oil-fouling of the spark-plugs and coke formation in the cylinder and the exhaust. Almost the only motors still using pre-mix are hand-held two-stroke devices such as chainsaws (which must operate in any attitude) and some of the smallest model engines.

All two-stroke engines running on a petroil mix will suffer oil-starvation if forced to rotate at speed with the throttle closed, e.g. motorcycles descending long hills and perhaps when decelerating gradually from high-speed by changing down through the gears. Two-stroke cars (such as those that were popular in Eastern Europe in mid-20th century) were in particular danger and were usually fitted with freewheel mechanisms in the powertrain, allowing the engine to idle when the throttle was closed, requiring the use of the brakes in all slowing down situations.

Large two-stroke engines, including diesels, normally use a sump lubrication system similar to four-stroke engines. The cylinder must still be pressurized but this is not done from the crankcase but by a pump or supercharger. A turbo-charger is not suitable for this purpose as it does not provide any starting pressure.

Two-stroke reversibility

For the purpose of this discussion, it is convenient to think in motorcycle terms, where the exhaust pipe faces into the cooling air stream, and the crankshaft commonly spins in the same axis and direction as do the wheels i.e. "forwards". Some of the considerations discussed here apply to four-stroke engines (which cannot reverse their direction of rotation without considerable modification) almost all of which spin forwards too.

Regular gasoline two-stroke engines will run backwards for short periods and under light load with little problem, and this has been used to provide a reversing facility in microcars such as the Messerschmitt KR200 that lacked reverse gearing. Where the vehicle has electric starting, the motor will be turned off and re-started backwards by turning the key in the opposite direction. Two-stroke golf carts have used a similar kind of system. Traditional flywheel magnetos (using contact-breaker "points" but no external coil) worked equally well in reverse because the cam controlling the points is symmetrical, breaking contact before TDC equally well whether running forwards or backwards. Reed-valve engines will run backwards just as well as piston-controlled porting, though rotary valve engine have asymmetrical inlet timing and will not run very well.

There are serious disadvantages to running any engine backwards under load for any length of time, and some of these reasons are general, applying equally to both two-stroke and four-stroke engines. Some of this disadvantage is intrinsic, unavoidable even in the case of a complete re-design. The problem comes about because in "forwards" running the major thrust face of the piston is on the back face of the cylinder which, in a two-stroke particularly, is the coolest and best lubricated part. The forward face of the piston is less well-suited to be the major thrust face since it covers and uncovers the exhaust port in the cylinder, the hottest part of the engine, where piston lubrication is at its most marginal. The front face of the piston is also more vulnerable since the exhaust port, the largest in the engine, is in the front wall of the cylinder. Piston skirts and rings risk being extruded into this port, so it is always better to have them pressing hardest on the back wall (where there are only the transfer ports) and there is good support. In some engines, the small end is offset to reduce thrust in the intended rotational direction and the forward face of the piston has been made thinner and lighter to compensate - but when running backwards, this weaker forward face suffers increased mechanical stress it was not designed to resist.

Large two-stroke ship diesels are sometimes made to be reversible. Like four-stroke ship engines (some of which are also reversible) they use mechanically operated valves and so require additional camshaft mechanisms.

On top of other considerations, the oil-pump of a modern two-stroke may not work in reverse, in which case the engine will suffer oil starvation within a short time. Running a motorcycle engine backwards is relatively easy to initiate and in rare cases can be triggered by a back-fire. It is not advisable.

Model airplane engines with reed-valves can be mounted in either tractor or pusher configuration without needing to change the propeller. These motors are compression ignition, so there are no ignition timing issues and little difference between running forwards and running backwards.

Chapter 3

Semi-Automatic Transmission

A semi-automatic transmission is one that cannot change gears automatically but only half-automatically. ("Semi" meaning half in Latin.) This requires the driver to intervene in order to execute a gear change by moving a gear lever or pressing a clutch pedal or actuating a switch lever or other action. An **automated transmission** (also known as **self-changing transmission**, **clutchless manual transmission**, automated manual transmission, flappy-paddle gearbox, or paddle shift gearbox) is a system which uses electronic sensors, pneumatics, processors and actuators to execute gear shifts on the command of the driver or by a computer. This removes the need for a clutch pedal which the driver otherwise needs to depress before making a gear change, since the clutch itself is actuated by electronic equipment which can synchronise the timing and torque required to make gear shifts quick and smooth. The system was designed by automobile manufacturers to provide a better driving experience, especially in cities where congestion frequently causes stop-and-go traffic patterns.

Many modern automated transmissions can also operate in the same manner as a conventional type of automatic transmission by allowing the transmission's computer to automatically change gear if, for example, the driver were redlining the engine. The ability to shift gears manually, often via paddle shifters, can also be found on certain automatic transmissions (manumatics such as Tiptronic) and continuous variable transmissions (CVTs) (such as Lineartronic). Despite superficial similarity to other automated transmissions, automated transmissions differ significantly in internal operation and driver's "feel" from manumatics and CVTs. A manumatic, like a standard automatic transmission, uses a torque converter instead of clutch to manage the link between the transmission and the engine, while a CVT uses a belt instead of a fixed number of gears.

The automated transmission may be derived from a conventional automatic; for instance Mercedes-Benz's AMG SPEEDSHIFT MCT automated transmission is based on the 7G-Tronic manumatic, however the latter's torque converter has been replaced with a wet, multi-plate launch clutch.. Other automateds have their roots in a conventional manual; the SMG II drivelogic (found in the BMW M3 (E46) is a Getrag 6-speed manual

transmission, but with an electrohydraulically actuated clutch pedal, similar to an Formula One style transmission.

Operation

Steering wheel of Ferrari F430 with paddle-shifters

In standard mass-production automobiles, the gear lever appears similar to manual shifts, except that the gear stick only moves forward and backward to shift into higher and lower gears, instead of the traditional H-pattern. The Bugatti Veyron uses this approach for its seven-speed transmission. In Formula One, the system is adapted to fit onto the steering wheel in the form of two paddles; depressing the right paddle shifts into a higher gear, while depressing the left paddle shifts into a lower one. Numerous road cars have inherited the same mechanism.

Hall effect sensors sense the direction of requested shift, and this input, together with a sensor in the gear box which senses the current speed and gear selected, feeds into a central processing unit. This unit then determines the optimal timing and torque required for a smooth clutch engagement, based on input from these two sensors as well as other factors, such as engine rotation, the Electronic Stability Control, air conditioner and dashboard instruments.

The central processing unit powers a hydro-mechanical unit to either engage or disengage the clutch, which is kept in close synchronization with the gear-shifting action the driver has started. In some cases, the hydro-mechanical unit contains a servomotor coupled to a gear arrangement for a linear actuator, which uses brake fluid from the braking system to impel a hydraulic cylinder to move the main clutch actuator. In other cases, the clutch actuator may be completelly electric.

The power of the system lies in the fact that electronic equipment can react much faster and more precisely than a human, and takes advantage of the precision of electronic signals to allow a complete clutch operation without the intervention of the driver.

For the needs of parking, reversing and neutralizing the transmission, the driver must engage both paddles at once, after this has been accomplished the car will prompt for one of the three options.

The clutch is really only needed to start the car. For a quicker upshift, the engine power can be cut, and the collar disengaged until the engine drops to the correct speed for the next gear. For the teeth of the collar to slide into the teeth of the rings, both the speed and position must match. This needs sensors to measure not only the speed, but the positions of the teeth, and the throttle may need to be opened softer or harder. The even-faster shifting techniques like powershifting require a heavier gearbox or clutch or even a dual clutch transmission.

History

Racing

According to the Car Crazy episode "Le Mans Museum of the Automobile", the paddle shifter interface could be found as early as 1912. The system used an inner steering wheel to select a gear level and can be seen on the "Bollée Type F Torpédo" of 1912, on show at the "Musée Automobile de la Sarthe" at the Le Mans race circuit.

In Formula One, the first attempt at clutch-less gear changing was in the early 1970s, with the system being tested by the Lotus team. However, it would be much later that attention was turned back to the concept. In 1989, John Barnard and Harvey Postlethwaite, then-Ferrari engineers and designers, created a automated gearbox for use in the Ferrari 640 single-seater. Despite serious problems in testing, the car won its first race at the hands of Nigel Mansell. By 1994, the automated transmission was dominant in terms of gearbox technology, and the last F1 car fitted with a manual gearbox raced in 1995.

After concerns that the technology allowed software engineers to pre-program the cars to automatically change to the optimum gear according to the position on the track, without any driver intervention, a standardized software system was mandated, ensuring the gears would only change up or down when instructed to by the driver. Buttons on the steering wheel, which go directly to a certain gear—rather than sequentially—are still permitted.

Chrysler

Historically, the first automated transmission which was marketed by a major manufacturer was the 1941 M4/Vacamatic Transmission by Chrysler. It was an attempt to compete against rivals' automatic transmissions, though it still had a clutch, it was primarily used to change range. The main difference was the addition of a fluid coupling between engine and clutch, and the shifting mechanism.

In normal driving, the clutch was not used. The transmission itself was a fully synchronised manual type, with four forward gears, one reverse, where the shifting was done 'automatically' by either vacuum cylinders (early, M4, Vacamatic), or hydraulic cylinders (late, M6, Presto-Matic).

Packard

Nearly simultaneously, Packard introduced the Electro-Matic clutch, which was a vacuum operated clutch pedal, signaled by the position of the accelerator. Significantly, it came with an 'off' switch, probably due to the fact that the system was somewhat unstable during engine warm-up. Packard's system was used in conjunction with their regular transmission so the H-pattern shifting remained.

Earlier, and by many manufacturers, an arrangement to disengage the clutch during coasting was tried to ease shifting. Called "freewheeling", it was bedeviled by the absence of adequate brakes.

Volkswagen

In later production years, the Volkswagen Beetle offered an optional "Autostick", which was essentially a clutchless manual with three forward gears, using the Saxomat auto-clutch.

Renault

For the Renault 8, a automated transmission was offered in 1965. It was produced by Jaeger, and consisted of a three speed electrically operated gearbox and a powder ferromagnetic coupler.

Mercedes-Benz

Mercedes used a system similar to the VW Autostick, called Hydrak. Hydrak had one major flaw- the oil supply for the torque converter was sealed within the converter itself and did not circulate via a pump, and also had no oil cooler. Idling in gear for even short periods would overheat the oil and burn up the seals in the converter, which would then need to be replaced.

Citroën

Citroën produced a number of variants on automated transmission. The Citroën DS, introduced in 1955, used a hydraulic system to select gears and operate the conventional clutch using hydraulic servos. There was also a speed controller and idle speed step-up device, all hydraulically operated. This allowed clutchless shifting with a single selector mounted behind the steering wheel. This system was nicknamed 'Citro-Matic' in the U.S.

The Citroën 2CV gained an optional centrifugal clutch, marketed in English-speaking countries as "Trafficlutch". It did not help with gear changing, but it disengaged automatically when the engine slowed to an idle. A device was fitted to the carburettor to prevent the throttle closing abruptly, and the resultant clutch disengagement and lack of engine braking.

Later, the manufacturer introduced optional automated transmissions on their medium and large saloon and estate models in the 1970s; the Citroën GS and CX models had the option of three-speed, automated transmission marketed as 'C matic'. This was simpler than the DS implementation: instead of hydraulics it used a floor mounted quadrant lever operating conventional gear selector rods and an electrically controlled wet plate clutch in conjunction with a torque converter. The torque converter gave more of the feel of a conventional automatic transmission, which was completely lacking in the DS. Citroën automated transmission of this era made no use of electronics: the entire gear selecting operation was carried out by simply moving the gear lever from one ratio to the next.

NSU

The German automobile manufacturer NSU produced a automated system for the rotary-engined Ro80 saloon car in the 1960s, similar in concept to Citroën's system except that it used an electric switch on the gear shifter which disengaged the clutch.

Honda

Honda marketed both cars and motorcycles with the Hondamatic transmission in the 1970s and early 1980s. This transmission is frequently referred to as the 'Bang-O-Matic' by mechanics. The design is noteworthy because it preserves engine braking by eliminating a sprag between first and second gears.

Daihatsu

The 993 cc Daihatsu Charade in 1985 at least had the option of a two-speed automated transmission, which was similar to a conventional auto with torque converter and planetary gearset but lacked a full valve body for making decisions regarding shifting. This was left entirely to the driver and as a result could be accelerated from rest in top gear if desired, depending entirely on the torque converter action. The standing ¼mile time with two 60 kg (130 lb) occupants and using low gear appropriately was 21.0 sec while using top gear only was 21.5 sec.

Ferrari

Ferrari's first automated gearbox in a road car (They had used them previously in their Formula One cars since 1989) went on sale in 1997 in the Ferrari F355. The most recent iteration of its robotised manual came forward in the Ferrari 599 GTO which was capable of changing gear in 60 ms. In the new Ferrari California & Ferrari 458 Italia, Ferrari has opted to use a double-clutch transmission.

Vauxhall

Vauxhall Motors in Great Britain (Opel in continental Europe) produced a automated transmission gearbox, the Easytronic gearbox. As with all standard automateds, the Easytronic car has only two pedals (accelerator pedal and brake pedal) but it does have a clutch, though this is inbuilt into the car and is electrohydraulic. The Easytronic can be driven in "manual mode" simply by using the paddle shifter selector to change gears if the driver wishes to do so, or alternatively it can be driven in exactly the same way as a fully conventional automatic—however, many Easytronic owners have complained that gear shifts in "automatic mode" are jerky; a common complaint with semi-autos based on a conventional manual gearbox. As with conventional, full automatic transmission cars, the Easytronic will "creep" forwards when the driver's foot is released from the brake pedal when the car is stationary.

Other applications

Trucks, buses, and trains

Automated transmissions have also made its way into the truck and bus market in the early 2000s. Volvo offers its I-shift on its heavier trucks and buses, while ZF markets its ASTronic system for trucks, buses and coaches. In North America, Eaton offers the "AutoShift" system which is an add-on to traditional non-synchromesh manual transmissions for heavy trucks. These gearboxes have a place in public transport as they have been shown to reduce fuel consumption in some specific cases.

Bristol/Leyland Buses

The British employed Pneumatic valve bodies to regulate gear shifting by charging pistons with compressed air within the gearbox. These pneumatic pistons or gear-levers are activated by a series of valve bodies and controlled by electronic actuators linked to the gear shifter. As each gear cycle is energized, air valves open and close to engage the corresponding gear-lever. Compressed air is drawn from the braking system and in the event of loss of pressure, the transmission will remain in the last gear selected or if in neutral, will not shift into gear.

In the UK though, automated transmission has been very popular on buses for some time, from the 1950s right through to the 1980s, an example being the well known London Routemaster, although the latter could also be driven as a fully automatic in the three

highest gears. Most heavy-duty bus manufacturers offered this option, using a gearbox from Self-Changing Gears Ltd of Coventry, and on urban single- and double-deck buses it was the norm by the 1970s. This coincided with the development of city buses with engines and transmissions at the rear rather than the front, which was beyond the capability of a manual gearchange/clutch linkage from the driver's position. Leyland manufactured many buses with automated transmission, including its Leopard and Tiger coaches. Fully automatic transmission became popular with increasing numbers of continental buses being bought in the UK, and more and more British manufacturers began offering automatic options, mostly using imported gearboxes, and automated transmission lost favour. These days, very few buses with automated transmission remain in service, although many are still on the roads with private owners. Modern types of automated transmission though is becoming more common, mostly replacing manual gearboxes in coaches and small buses.

The Self-Changing Gears automated gearbox was also fitted to the several thousand diesel railcars built for the British railway system in the late 1950s-early 1960s, which lasted in service until the 1990s-2000s. Their whole engine-transmission system was based on that from the main bus manufacturers of the period such as Leyland and AEC. Gear selection was by the train driver with a hand-held lever as the train accelerated. Such trains were formed of a number of such railcars coupled together and each power car had two engine/automated gearbox units mounted under the floor. Synchronising controls by control cables connected through the train ensured all the gearboxes under all coaches of the train changed gear together.

Motorcycles

In addition to the Hondamatic system noted above, Yamaha Motor Company introduced a automated transmission on its 2007 model year FJR1300 sport-touring motorcycle in 2006. Notably, this system can be shifted either with the lever in the traditional position near the left foot, or with a switch accessible to the left hand where the clutch lever would go on traditional motorcycles.

Honda has begun production of the VFR1200F, which includes an optional dual clutch transmission, the first to be fitted to a motorcycle.

ATVs

Honda released automated electric shift ATVs starting in model year 1998 with the TRX450FE aka Foreman 450ES ESP (Electric Shift Program). Shifting is accomplished by pressing either one of the gear selector arrows on the left handlebar control. The current selected gear is indicated by a digital display. The primary components of the shifting mechanisms were the same on both the manual and electric shift models, but the major difference was the deletion of the shift pedal and the addition of an internal electric shift servo which actuated the components (clutch assy, shift drum, etc.)in one motion instead of the traditional foot lever. In the event of a malfunction, a supplied override lever can be placed on a shaft protruding from the crankcase in the traditional spot where

the pedal would have been. This electric shift technology was later applied to their complete line of ATVs.

Marketing names

- 2-tronic, EGC (Electric Gearbox Control) or Piloted Manual – Peugeot
- Twin Clutch SST – Mitsubishi
- Dual clutch transmission (DCT), a generic term – Volkswagen Group, Bugatti, Koenigsegg
- Direct-Shift Gearbox (DSG) – Volkswagen Group: SEAT, Skoda Auto, Volkswagen
    - S tronic – Audi
- Dualogic – Fiat
- Duo Select – Maserati
- Durashift EST – Ford
- E-Gear – Lamborghini
- Easytronic – Opel / Vauxhall
- Multimode manual transmission – Toyota
- PDK (Porsche Doppelkupplungen)/Sportomatic (Clutchless manual pre-1969) – Porsche
- Pleasure Shift – Saleen
- Quickshift – Renault
- Retrotek, MasterShift, Twist Machine, etc. – Detroit's Big 3
- Sensonic or ACS – Saab
- Selespeed – Alfa Romeo, Fiat
- SensoDrive or EGS (Electronic Gearbox System) or BMP – Citroen
- Steptronic, SMG/SSG (Electrohydraulic manual transmission) – BMW
- Speedgear – Fiat
- Sportshift – Aston Martin
- MasterShift – Aftermarket

Types

- Dual clutch transmission
- Electrohydraulic manual transmission (e.g., BMW sequential manual gearbox, SMG)
- Saxomat
- Multimode manual transmission

Chapter 4

Suspension (Motorcycle)

A motorcycle's suspension serves a dual purpose: contributing to the vehicle's handling and braking, and providing safety and comfort by keeping the vehicle's passengers comfortably isolated from road noise, bumps and vibrations.

The typical motorcycle has a pair of fork tubes for the front suspension, and a swingarm with one or two shock absorbers for the rear suspension.

Front suspension

The most common form of front suspension for a motorcycle is the telescopic fork. Early front suspension designs used frames with springs.

Vincent Black Lightning with Girdraulic front suspension

Some British manufacturers (e.g. Greeves) used a version of the swinging arm for front suspension on their motocross designs. A single-sided version of the idea is also used in motor scooters such as the Vespa.

The Hub-center steering as developed by Ascanio Rodorigo, on a concept associated to Massimo Tamburini is a complex front swingarm alternative system that entails suspension and steering, as seen in projects such as Bimota Tesi and Vyrus motorcycles.

Telescopic forks

In 1934 Nimbus was the first manufacturer to produce a motorcycle with hydraulically damped telescopic forks. Most motorcycles today use telescopic forks for the front suspension. The forks can be most easily understood as simply large hydraulic shock absorbers with internal coil springs. They allow the front wheel to react to imperfections in the road while isolating the rest of the motorcycle from that motion.

Telescopic forks on a 1969 BMW

The top of the forks are connected to the motorcycle's frame in a triple tree clamp (otherwise known to British riders as the top yoke and bottom yoke), which allows the forks to be turned in order to steer the motorcycle.

The bottom of the forks are connected to the front axle around which the front wheel spins.

On typical forks, the upper portion, known as the *fork tubes*, slide inside the *fork bodies*, which are the lower part of the forks. As the tubes slide in and out of the body they are

telescoping, thus the term *telescopic forks*. The fork tubes must be smooth to seal the *fork oil* inside the fork, and typically have a mirrored finish, though some fork tubes, especially those on off-road motorcycles, are enclosed in plastic protective sleeves, known as *gaiters*.

"Upside-down" (USD) forks, also known as inverted forks, are installed inverted compared to typical forks, with the tubes at the bottom and the bodies at the top. This decreases the unsprung weight of the motorcycle and improves its handling. USD forks are usually found on sportbikes, though Honda's large power-cruiser, the Valkyrie, sported USD forks.

Pre-load adjustment

Motorcycle suspensions are designed so that the springs are always under compression, even when fully extended. Pre-load is used to adjust the initial position of the suspension with the weight of the motorcycle and rider acting on it. Both the front forks and the rear shock or shocks can be adjusted for pre-load on most modern motorcycles.

The difference between the fully extended length of the suspension and the length compressed by the weight of the motorcycle and rider is called "total sag". Total sag is set to optimize the initial position of the suspension to avoid "bottoming out" or "topping out" under normal riding conditions. "Bottoming out" occurs when the suspension is compressed to the point where it mechanically cannot compress any more. "Topping out" occurs when the suspension extends fully and cannot mechanically extend any more. Increasing pre-load increases the initial force on the spring thereby reducing total sag. Decreasing pre-load decreases the initial force in the spring thereby increasing total sag.

Since the weight of the motorcycle and rider are the only forces compressing the suspension from the fully extended position. Two simple examples using the motorcycle's forks shows why:

1. Suppose that the bike and rider put a total weight on the front suspension of 300 lb. Suppose the spring rate of each fork spring is 50 lb per inch. That would put total sag at 3 inch. Installing a 1 inch long spacer in each fork leg gives a pre-load of 50 lb per spring, a total of 100 lb. When the weight of the rider and motorcycle are loaded onto the suspension it will compress 2 inch from full extension (2 inches total sag). Now the force exerted on (and by) each fork spring is 150 lb (1 inch pre-load + 2 inch total sag = 3 inch total spring compression) for a total of 300 lb. This is not going to be exact the same numbers for different spring rates. Because with a spring rate of 25 lb per inch in each fork, Would double the total sag and a spring rate of 100 lb per inch would cut it in half. This is just an example.
2. Suppose we now install a 2 inch long spacer in each fork leg. The pre-load is now 100 lb per spring, a total of 200 lb. The total sag will change since we still have the same 300 lb loading the forks. The total sag will now be 1 inch. The total force on each spring is still 150 lb on each fork spring for a total of 300 lb force.

The front suspension's initial position is 1 inch longer than in the preceding example (1 inch less total sag).

The difference is that there is less chance of topping out in example 1, less chance of bottoming out in example 2. Motorcycle manufacturers generally provide optimal total sag settings.

This is also why too-soft springs cannot be "fixed" by adding pre-load, too-stiff springs cannot be "fixed" by reducing pre-load. It will help but changing to springs of the correct spring rate for the total weight of the bike and rider is the only solution.

Some motorcycles have externally accessible pre-load adjustments. Typically, this is a screw-type adjustment that moves a backing plate inside the fork against the top of the fork spring. The farther down the adjuster is screwed, the higher the preload.

A few motorcycles allow adjustment of pre-load by changing the air pressure inside the forks. Valves at the top of the forks allow air to be added or released from the fork. More air pressure gives more preload, and vice versa.

Pre-load on bikes without adjusters can be changed by disassembling the fork and changing the length of the spacer between the top of the fork spring and the *fork cap*. Spacers can be installed under the rear shock springs similarly. A longer spacer gives higher preload, and vice-versa.

The pre-load on both forks should always be the same. Dangerous handling behavior and possible mechanical damage can result otherwise.

Damping adjustment

Some stock telescopic forks have external adjustments for damping. The adjuster is either a dial or a knob slotted for a screwdriver. Turning the adjuster turns a rod inside the fork which brings different sized orifices into alignment with the damping fluid flow path inside the fork. Smaller orifices restrict the flow of the fork oil more and give greater damping, and vice versa.

This adjustment is either for compression damping, rebound damping, or for both.

Fork oil

Since forks act as hydraulic shocks, changing the weight of the fork oil will change the damping. Higher weight fork oil will give more damping, and vice versa.

Fork oil collects impurities over time and should be changed periodically. A motorcycle's manual will give guidelines on how often the oil should be changed. Decades ago, it was often recommended to use ATF (automatic transmission fluid) as fork oil. Currently most sources recommend using an oil specifically designed to be used as fork oil.

Cartridge forks

Cartridge forks use internal cartridges with various leaf springs covering orifices to control the damping of the fork.

Some of the leaf springs lift with little force allow fluid to flow through the orifice. Other springs require greater force to lift and allow flow. This gives the fork *digressive* damping, allowing it to be stiff over small bumps, but get (relatively) softer over larger bumps.

Also, the springs only allow flow in one direction, so one set of springs controls compression damping, and another rebound damping. This allows the dampings to be set separately.

Cartridge emulators are aftermarket parts that make non-cartrdige forks behave like cartridge forks.

Gas-charged cartridge forks

In 2007 Traxxion Dynamics offered the first gas-charged bolt-in cartridge set for modern sportbike forks to the public. This kit is legal for "supersport" styled classes of racing, which regulations don't allow a complete fork replacement, and force competitors to use the stock fork casings. This was the first significant change in fork damping technology for road bikes since the introduction of the standard pumping style cartridge decades prior.

Brake dive

Applying the brakes of a moving motorcycle increases the load borne by the front wheel and decrease the load borne by the rear wheel due to a phenomenon called load transfer.

BMW's 1955-1969 Earles fork eliminated and reversed brake dive

If the motorcycle is equipped with telescopic forks, the added load on the front wheel is transmitted through the forks, which compress. This shortening of the forks causes the front end of the bike to move lower, and this is called **brake dive**.

Brake dive can be disconcerting to the rider, who may feel like he or she is about to be thrown over the front of the motorcycle. If the bike dives so far as to bottom out the front forks, it can also cause handling and braking problems. One of the purposes of a suspension is to help maintain contact between the tire and road. If the suspension has bottomed out, it is no longer moving as it should, and is no longer helping to maintain contact.

Brake dive with telescopic forks can be reduced by either increasing the spring rate of the fork springs, or increasing the compression damping of the forks. However, all of these changes make the motorcycle less pleasant to ride on rough roads, since the front end will feel stiffer, in the 1980s various manufacturers attempted to get round this by methods of anti-dive such as:

- ACT: Developed by Marzocchi and fitted to Buell motorcycles such as the Buell RR 1200 (1988).
- ANDF (Anti Nose Dive Forks): This was fitted to a number of Suzuki GSX models and the RG250.
- AVDS (Automatic Variable Damping System): This was fitted to a number of Kawasaki motorcycles.
- NEAS (New Electrically Activated Suspension): As fitted to the Suzuki GSX-R 1100 and GSX-R 750 Limited Edition.
- PDF (Posi Damp Fork): This was fitted to the Suzuki RG500 and GSX-R 750 and worked by brake fluid pressure closing a valve in the mechanism when the brakes are applied, restricting the flow of damping oil and slowing fork compression. The valves are spring loaded so if the wheel hits a bump when the brakes are on, they bounce off their seats and restore the flow of oil for a moment to allow the suspension to absorb the shock.
- TCS (Travel Control System): Anti-dive system with variable damping. TCS was introduced on the FZ 400 R (1984, only for the Japanese market).
- TRAC (Torque Reactive Anti-dive Control): This was fitted to a number of Honda motorcycles such as the CB1100F, CB1000C, and VFR750F and worked by utilizing a pivoting caliper that activated a valve in the fork leg.

Another method to reduce or eliminate brake dive in telescopic forks is to use a reactive link or torque arm to connect the braking components to the motorcycle frame via the triple clamp.

Some fork designs mitigate dive, eliminate it, or even reverse it without affecting the front suspension adversely. The Earles fork is among the latter; when braking the front brake hard, the front end of the motorcycle actually rises. BMW's Telelever fork is designed to nearly eliminate dive, but could have been designed to eliminate it completely if the manufacturer chose to do so. Leading link front forks, such as used on some Ural motorcycles, can also be designed either to reduce or eliminate dive.

Saxon-Motodd (Telelever) fork

BMW's Telelever

The Saxon-Motodd (marketed as **Telelever** by BMW) has an additional swingarm that mounts to the frame and supports the spring. This causes the rake and trail to increase during braking instead of decreasing as with traditional telescopic forks.

Hossack/Fior (Duolever) fork

The Hossack/Fior (marketed as Duolever by BMW) separates completely the suspension from steering forces. It was developed by Norman Hossack though used by Claude Fior and John Britten on racebikes. Hossack himself described the system as a 'steered upright'. In 2004 BMW announced the K1200S with a new front suspension that is based upon this design.

Single-sided

The only production motorcycle to use a single-sided front *swingarm* suspension was Yamaha's GTS1000, introduced in 1993. The GTS used the RADD front suspension designed by James Parker. However, a single sided girder fork was use by the German firm Imme between 1949 and 1951, and the Vespa scooter has a single-sided trailing-link fork. More recently, the ItalJet "Dragster" scooter also uses a single-sided swingarm suspension, though unlike the GTS1000 there is no upper control arm; the upper part of the suspension on the Dragster serves only to transmit steering input.

Rear suspension

Plunger rear suspension on a BMW R51/3

Early rear suspensions

While front suspensions were almost universally adopted before World War I, several manufacturers did not use rear suspension on their bikes until after World War II. However, motorcycles with rear suspension were offered to the public before World War I. Notable among these are the 1913 Indian Single with a swingarm suspended from a leaf spring and the 1913 Pope with wheels supported on a pair of plungers which were each suspended by a coil spring.

Plunger suspension

Several motorcycles before and immediately after World War II used **plunger suspension** in which the vertical movement of the rear axle was controlled by plungers suspended by springs.

Notable manufacturers of bikes with plunger suspension include Adler, Ariel, BMW, BSA, Indian, MZ, Norton, and Zündapp

Swingarms

The basic motorcycle swingarm is a rectangle, with one short side connected to the motorcycle's frame with bearings so that it can pivot. The other short side is the rear axle around which the rear wheel turns. The long sides are connected to the motorcycle's frame or rear sub-frame with one or two shocks with coil-over springs.

In production motorcycles, swingarms are not exactly rectangular, but their function can be more easily understood by thinking of them as such.

Moto Guzzi's *CA.R.C.*

When a swingarm is present on only one side of the motorcycle, this is known as a *single-sided* swingarm. Notable examples include the Honda VFR800 and the BMW R- and K-series. Single-sided swingarms make rear-wheel removal easier, though they generally increase the unsprung weight of the rear suspension. This is due to the additional material required to give identical rigidity to a conventional (two-sided) swingarm setup. For this reason sports bikes are rarely seen using the setup. Notable exclusions are the Ducati 916 which was intended to be taken endurance racing, the MV Agusta f4 which has a hollow interior for reducing weight (a magnesium version is also available), and the Ducati 1098, which was given a single sided swingarm purely for styling reasons.

BMW's Paralever rear suspension on a R1200GS

On many shaft-drive motorcycles the drive shaft is contained in one of the long sides of the swingarm. Notable examples include all post-1955 BMW models prior to BMW's use of the single-sided swingarms, Urals, many Moto Guzzi twins, the Honda Goldwing, the Yamaha XS Eleven, and the Yamaha FJR1300.

The BMW R- and K-series combine a shaft-drive contained in the swing arm with a single-sided swingarm, and the combination is marketed as the *Paralever*. Newer Moto Guzzi motorcycles use a similar arrangement marketed as the *CA.R.C.* ("CArdano Reattivo Compatto" - Compact Reactive Shaft Drive).

For motorcycles with chain drives, the rear axle can be adjusted forward and back in relation to the swingarm, to adjust chain tension.

Shock absorbers

The hydraulic shock absorbers used on the rear suspensions of motorcycles are essentially the same as those used in other vehicle applications.

Motorcycle shocks do differ slightly in that they nearly always use a coil-over spring. In other words, the spring for the rear suspension is a coil spring that is installed over, or around, the shock.

In terms of adjustment, rear shocks span the range from pre-load adjustments only to racing shocks with adjustments for pre-load, and four different kinds of damping. Most

shocks have internal oil reservoirs, but some have external ones, and some offer air-assisted damping.

A number of companies offer custom-built rear shocks for motorcycles. These shocks are assembled for a specific motorcycle and rider combination, taking in to account the characteristics of the motorcycle, the weight of the rider, and the rider's preferred riding style/aggressiveness.

Twin shock absorbers

Twinshock refers to motorcycles that have two shock absorbers. Generally, this term is used to denote a particular era of motorcycles, and is most frequently used when describing off-road motorcycles.

During the late 1970s and 1980s, motorcycle rear suspension design and performance underwent tremendous advances. The primary goal and result of these advances were increased rear wheel travel, as measured in the how far the rear wheel could move up and down. Before this period of intense focus on rear suspension performance, most off-road motorcycles had rear wheel travel of about 3.5–4 inch (9–10 cm). At the end of this period, most of these motorcycles had rear wheel travel of approximately 12 inch (30 cm). At the beginning of this period, various rear suspension designs were used to reach this degree of performance. However, by the end of this period, a design consisting of using only one shock absorber (instead of two) was universally accepted and used. Motorcycles with only one shock absorber are called monoshock motorcycles. The performance of monoshock motorcycles was vastly superior to twin shock motorcycles. Accordingly, this design distinction is readily used to categorize motorcycles. Since monoshock motorcycles have been the norm since the 1980s, the term "twinshock" is now used to categorize vintage motorcycles. This distinction is important in that it provides classes used for vintage motorcycle competition. For example, vintage motocross races are held for older motocross motorcycles. To prevent the better performing monoshock motorcycles from dominating the competition, there are separate competition classes for monoshock and twinshock motorcycles, which prevents them from competing directly against each other.

Mono-shock

On a motorcycle with a mono-shock rear suspension, there is only one shock that connects the rear swingarm to the motorcycle's frame. Typically this lone shock absorber is in front of the rear wheel, and uses a linkage to connect to the swingarm.

Mono-shocks eliminate torque to the swingarm and provide more consistent handling and braking. They are also easier to adjust, since there's only one shock absorber to adjust, and there is no worry about matching two shocks. Also, the linkages used to connect the shock to the swing-arm are frequently designed to give a rising rate of damping for the rear.

Honda refers to its mono-shock designs as *Pro-link* suspensions.

Pre-load adjustment

The pre-load on a rear shock absorber is typically adjusted via a threaded or notched collar on the shock. As the collar is rotated, the coil-over spring is compressed more or less. The more the spring is compressed, the higher the pre-load, and vice versa.

Some shock absorbers, known as *air-assist* shock absorbers, allow adjustment of preload by changing the air pressure inside the shock. A valve on the shock absorber allows air to be introduced or released from the shock. More air pressure gives more preload, and vice versa.

Damping adjustment

Stock rear shocks typically offer no damping adjustment, or a single adjustment for both compression and rebound damping. This adjustment is usually made by a dial at the very top or very bottom of the shock. The dial selects one of a few different orifice sizes for the damping fluid flow path. The larger the orifice, the less the damping, and vice versa.

Chapter 5

Motorcycle Components

Motorcycle components and systems for a motorcycle are engineered, manufactured, and assembled in order to produce motorcycle models with the desired performance, aesthetics, and cost. The key components of modern motorcycles are presented below.

Chassis

The chassis of a motorcycle includes the frame and suspension, along with the front forks, of the vehicle.

Frame

The frame is typically made from welded aluminium or steel (or alloy) struts, with the rear suspension being an integral component in the design. Carbon fibre and titanium are used in a few very expensive custom frames.

The frame includes the head tube that holds the front fork and allows it to pivot. Some motorcycles include the engine as a load-bearing (or *stressed*) member; this has been used all through motorcycle history but is now becoming more common.

Oil-in-Frame (OIF) chassis, where the lubricating oil is stored in the frame of the motorcycle, was used for Vincent motorcycles of the 1950s, and for a while during the 1970s on some NVT British motorcycles. It was widely unpopular and generally regarded as a bad idea at the time. Today it is a used on some "thumpers" (single-cylinder four-strokes) that usually have dry-sump lubrication requiring an external oil tank. It has since gained some cachet in the modern custom bike world too because of the space savings it can afford and the reference to an earlier era.

Buell motorcycles employ a similar design — the oil is held in the swingarm, while the fuel is held in the frame.

Suspension

Plunger design suspensions, as on this BSA Bantam, were superseded by the swinging arm

Modern designs have the two wheels of a motorcycle connected to the chassis by a suspension arrangement, however 'chopper' style motorcycles often elect to forgo rear suspension, using a rigid frame.

The front suspension is usually built into the front fork and may consist of telescoping tubes called fork tubes which contain the suspension inside or some multibar linkage that incorporate the suspension externally.

The rear suspension supports the *swingarm*, which is attached via the *swingarm pivot bolt* to the frame and holds the axle of the rear wheel. The rear suspension can consist of several shock arrangements:

- Dual shocks, which are placed at the far ends of the swingarm
- Traditional monoshock, which is placed at the front of the swingarm, above the swingarm pivot bolt
- Softail style suspension, where the shock absorbers are mounted horizontally in front of the swingarm, below the swingarm pivot bolt and operate in extension.

Front fork

A motorcycle fork is the portion of a motorcycle that holds the front wheel and allows one to steer. For handling, the front fork is the most critical part of a motorcycle. The combination of rake and trail determines how stable the motorcycle is.

A fork generally consists of two fork tubes (sometimes also referred to as forks), which hold the front wheel axle, and a triple tree, which connects the fork tubes and the handlebars to the frame with a pivot that allows for steering.

Engine

Almost all commercially available motorcycles are driven by conventional gasoline internal combustion engines, but some small scooter-type models use an electric motor, and a very small number of diesel models exist (e.g., the USMC M1030 M1 version of the Kawasaki KLR650 and the Dutch-produced Track T-800CDI).

Opposed twin engine on a Ural

The displacement is defined as the total volume of air/fuel mixture an engine can draw in during one complete engine cycle. In a piston engine, this is the volume that is swept as the pistons are moved from top dead centre to bottom dead centre. To the layperson this is the "size" of the engine. Motorcycle engines range from less than 50 cc (cubic centimetres), commonly found in many small scooters, to 5735 cc, a Chevrolet V8 engine, currently used by Boss Hoss in its cruiser style motorcycle.

Motorcycles have mostly, but not exclusively, been produced with one to four cylinders, and designers have tried virtually every imaginable layout. The most common engine configurations today are the single and twin, the V-twin, the opposed twin (or boxer), and the in-line triple and in-line four. A number of others designs have reached mass production, including the V-4, the flat 6-cylinder, the flat 4-cylinder, the in-line 6-cylinder, and the Wankel engine. Exotic engines, such as a radial piston engine, sometimes appear in custom built motorcycles, though two firms Megola and Redrup put radial engined motorcycles into production.

A Sokół 1000 V-twin engine

Engines with more cylinders for the same displacement feel smoother to ride. Engines with fewer cylinders are cheaper, lighter, and easier to maintain. Liquid-cooled motorcycles have a radiator which is the primary way their heat is dispersed. Coolant or oil is constantly circulated between this radiator and the cylinder when the engine is running. Air-cooled motorcycles rely on air blowing past fins on the engine case to disperse heat. Liquid cooled motorcycles have the potential for greater power at a given displacement, tighter tolerances, and longer operating life, whereas air cooled motorcycles are potentially cheaper to purchase, less mechanically complex and lighter weight.

An air cooled engine contracts and expands with its wider temperature range, requiring looser tolerances, and giving shorter engine life. The temperature range of an air cooled two stroke is even more extreme and component life even shorter than in an air cooled four stroke.

As applied to motorcycles, two-stroke engines have some advantages over equivalent four-strokes: they are lighter, mechanically much simpler, and produce more power when operating at their best. But four-stroke engines are cleaner, more reliable, and deliver power over a much broader range of engine speeds. In developed countries, two-stroke road-bikes are rare, because—in addition to the reasons above—modifying them to meet

contemporary emissions standards is prohibitively expensive. Almost all modern two-strokes are single-cylinder, liquid-cooled, and under 600 cc.

In November 2006, the Dutch company E.V.A. Products BV Holland announced that its diesel-powered motorcycle, the Track T-800CDI, achieved production status. The Track T-800CDI uses a 800 cc three-cylinder Daimler Chrysler diesel engine. Other manufacturers, including Royal Enfield, had been producing diesel-powered bikes since at least the 1980s. Also, Intelligent Energy, a British alternative-fuel company, is developing a motorcycle powered by a detachable hydrogen-powered fuel cell, which it calls an Emissions Neutral Vehicle (ENV). According to reports, the vehicle can sustain speeds of 50 mph (80 km/h) while making virtually no noise, and can run for up to four hours without refueling.

Transmission

The transmission on this 1921 ABC motorcycle is located behind the engine and shifts by a long hand-operated lever on its right side.

A typical 5-gear, foot-shift transmission on an HD Sportster

Modern motorcycles (excepting scooters) all change gears (of which they will increasingly have five or six) by foot lever. The weight of the largest touring motorcycles (sometimes in excess of 360 kg or 800 lbs) is such that they cannot effectively be pushed backwards by a seated rider, and they are fitted with a reverse gear as standard. In some cases, including the Honda Gold Wing and BMW K1200LT, this is not really a reverse gear, but a feature of the starter motor which when reversed, performs the same function. In earlier times pre WWII, hand-operated gear changes were common, a lever was provided to the side the fuel tank. British and many other motorcycles after WWII used a lever on the right but today gear-changing is standardised on a foot-operated lever to the left.

All two-wheelers use a sequential gearbox. On a motorcycle either first or second gear can be selected from neutral, but higher gears may only be accessed in order - it is not possible to shift from second gear to fourth gear without shifting through third gear. A five-speed of this configuration would be known as "one down, four up" because of the placement of the gears with relation to neutral. Neutral is to be found "half a click" away from first and second gears, so shifting directly between the two gears can be made in a single movement.

Traditional scooters still have manual gear-changing by a twist grip on the left hand side of the handlebar, with a clutch on a lever also rotating. Increasingly they may be fitted with a continuously variable transmission or CVT instead, a kind of automatic

transmission (as once used in the DAF car) that is stepless. Step-through motorcycles often have a three-speed foot change, but the clutch is automatic.

The clutch is typically an arrangement of plates stacked in alternating fashion, one geared on the inside to the engine and the next geared on the outside to the transmission input shaft. Whether wet (rotating in engine oil) or dry, the plates are squeezed together by a spring, causing friction build up between the plates until they rotate as a single unit, driving the transmission directly. A lever on the handlebar exploits mechanical advantage through a cable or hydraulic arrangement to release the clutch spring, allowing the engine to freewheel with respect to the transmission.

Final drive

A shaft final drive is housed within a rear swingarm of a BMW R1200GS

Power transfer from the gearbox to the rear wheel is accomplished by different methods.

Chain drive uses sprockets and a roller chain, which requires both lubrication and adjustment for elongation (stretch) that occurs through wear. The lubricant is subject to being thrown off the fast-moving chain and results in grime and dirt build up. Chains do deteriorate, and excessive wear on the front and rear sprockets can be dangerous. In a chain drive the power is transmitted into the real wheel via a cush drive. Virtually all high performance racing motorcycles use chain drive.

A belt drive is still subject to stretch but operates very quietly, cleanly, and efficiently. However, belt drives are limited in the amount of power they can transmit. A toothed belt is frequently used.

A shaft drive is usually completely enclosed; the visual cue is a tube extending from the rear of the transmission to a bell housing on the rear wheel. Inside the bell housing a bevelled gear on the shaft mates with another on the wheel mount. This arrangement is superior in terms of noise and cleanliness and is virtually maintenance free, with the exception of occasional fluid changes. However, the additional gearsets are a source of power loss and added weight. A shaft-equipped motorcycle may also be susceptible to shaft effect.

Wheels

The wheel rims are usually steel or aluminium (generally with steel spokes and an aluminium hub) or mag-type cast or machined aluminium. Cast magnesium disks, produced by one-step hot forging from magnesium alloys ZK60 and MA-14, are also used for many motorcycle wheels.

At one time, motorcycles used spoke wheels built up from separate components, but, except for dirtbikes, one-piece wheels are more common now. Performance racing motorcycles often use carbon-fibre wheels, but the expense of these wheels is prohibitively high for general usage.

A wire wheel and pneumatic motorcycle tyre on a Ural

Wire wheels have a central hub connected to the rim of the wheel via spokes made of wire. These spokes are generally quite solid and will not easily bend as would typical

wire cord. Nevertheless, they mechanically function as wires under tension, holding the rim true and providing strength to the wheel.

Tires

Motorcycles mainly use pneumatic tires. However, in some cases where punctures are common (some enduros), the tyres are filled with a "mousse" which is unpunctureable. Both types of tyre come in many configurations. The most important characteristic of any tyre is the contact patch, the small area that is in contact with the road surface while riding. There are tyres designed for dirtbikes, touring, sport and cruiser bikes.

Dirtbike tyres have knobbly, deep treads for maximum grip on loose dirt, mud, or gravel; such tyres tend to be less stable on paved surfaces. Touring tyres are usually made of harder rubber for greater durability. They may last longer, but they tend to provide less outright grip than sports tyres at optimal operating temperatures. The payoff is that touring tyres typically offer more grip at lower temperatures, meaning they can be more suitable for riding in cold or winter conditions whereas a sport tyre may never reach the optimal operating temperature.

Sport/performance tyres provide amazing grip but may last 1,000 miles (1,600 km) or less. Cruiser and "sport touring" tyres try to find the best compromise between grip and durability. There is also a type of tyre developed specifically for racing. These tyres offer the highest of levels of grip for cornering. Because of the high temperatures at which these tyres typically operate, use on the street is unsafe because the tyres will typically not reach optimum temperature before a rider arrives, thus providing almost no grip *en route*. In racing situations, racing tyres would normally be brought up to temperature in advance by the use of tyre warmers.

Brakes

Front disk brakes with an ABS sensor ring on a BMW R1200RT

There are generally two independent brakes on a motorcycle, one set on the front wheel and one on the rear. However, some models have "linked brakes" whereby both can be applied at the same time using only one control.

Front brakes are generally much more effective than rear brakes: roughly two thirds of stopping power comes from the front brake—mainly as a result of weight transfer being much more pronounced compared to longer or lower vehicles, because of the motorcycle's short wheelbase relative to its center of mass height. This can result in brake dive.

Brakes can either be drum or disc based, with disc brakes being more common on large, modern or more expensive motorcycles for their far superior stopping power, particularly in wet conditions. There are many brake-performance-enhancing aftermarket parts available for most motorcycles, including brake pads of varying compounds and steel-braided brake lines.

In 1981, BMW introduced an antilock braking system (ABS) on a motorcycle. Other manufacturers have since also adopted this technology, although Harley Davidson only offers it on some police motorcycles and not on civilian motorcycles. ABS is normally found on motorcycles of 500 cc or greater engine capacity, although it is available on motor scooters down to 49 cc.

Instruments

Most road motorcycles have an instrument panel, usually consisting of speedometer, odometer and tachometer. Fuel gauges are becoming more common, but traditionally a reserve tank arrangement is used with a petcock (petrol tap) on the side of the motorcycle allowing the rider to switch to a reserve fuel supply when the main fuel supply is exhausted. There is not actually a separate reserve tank: The intake for the petcock has two pipes, one extending higher into the fuel tank than the other. When fuel no longer covers the longer pipe the engine will lose power/splutter and the rider switches the petcock to the "reserve" setting, which accesses the shorter pipe. Riders whose bikes lack a fuel gauge (most machines prior to the past few years) usually learn how far they can go with a full tank of fuel, and then use a trip meter if available to judge when they must refill the tank.

Chapter 6

Motorcycle Frame

A **motorcycle frame** includes the head tube that holds the front fork and allows it to pivot. Some motorcycles include the engine as a load-bearing, stressed member. The rear suspension is an integral component in the design. Traditionally frames have been steel, but titanium, aluminium, magnesium, and carbon-fibre, along with composites of these materials, have been used. Because of different motorcycles' varying needs of cost, complexity, weight distribution, stiffness, power output and speed, there is no single ideal frame design.

Frame materials

Steel

Norton Featherbed frame in a Triton.

Examples

- Norton Featherbed frame
- Early Honda CBR600

Aluminium

Examples

- Honda VFR750

Aluminium and carbon-fibre

Examples

- Bimota SB8K (composed of two aluminium alloy beams and carbon fibre plates)

Carbon fibre

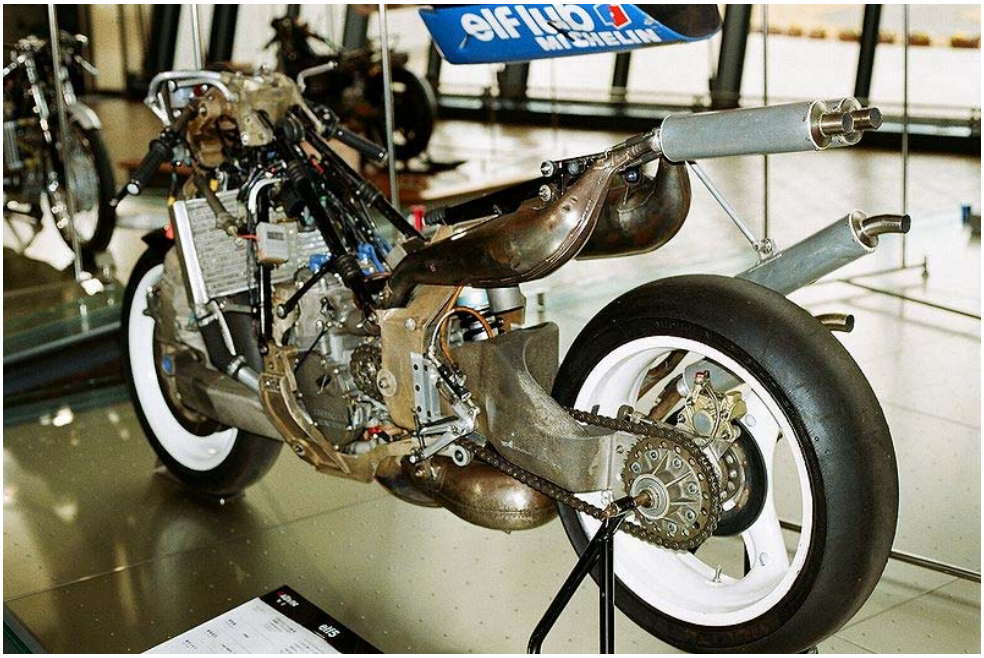
- Ducati Desmosedici
- MotoCzysz C1

Titanium

Examples

- 1971 Titanium Husqvarna Inter-AMA Motocross

Magnesium



Elf 5 at the Honda Collection Hall

Examples

- 1988 Elf ROC-Honda Elf5-NSR500 500 cc Grand Prix

Magnesium and aluminium

Examples

- MV Agusta F4 750 Serie Oro

Frame Types

Pressed frame

The frame is mass-produced by sheet metal pressed or stamped into shape. Typically a single-cradle structure is used.

Examples

- Honda Super Cub
- Ducati 65T

Single cradle

The motorcycle engine is held in a single cradle with a single spine.

Half-duplex cradle frame

The motorcycle engine is held in a double cradle with a single spine and single downtube.

Examples

- Suzuki GSX250
- Suzuki TS50ER

Full duplex cradle frame

The motorcycle engine is held in a full by two separate cradles, normally with a single spine.

Examples

- Norton Manx
- Suzuki TS50X

Double cradle frame on Honda CB750

Double cradle or perimeter frame

Two cradles follow the perimeter

Examples

- Early Suzuki GSX-R750,
- Suzuki GSX-R1100
- Suzuki RG250

Spine or backbone frame

The motorcycle engine is suspended from a single spine.

Examples

- Honda CB92 Benly
- Kawasaki Z1000

Frame of a 2011 Kawasaki ZX-10R.

Aluminum beam frame on Buell Lightning.

Beam

Twin beams join headstock to swingarm pivot in as straight and short a line as possible.

Examples

- 1885 Daimler *Reitwagen*
- Honda VFR750
- Yamaha FZR600

Monocoque

Supports structural load using the external skin of the frame.

1944 Piaggio MP5 monocoque chassis.

Examples

- 1944 Piaggio MP5
- Honda NR500

Steel trellis frame (red) on a Ducati Monster 1000. The engine is a stressed member.

Trellis

Similar to the beam frame, connecting the steering head and swingarm pivot point directly as possible. The frame is made up of a large number of short steel (or aluminium) tubes welded together to form a trellis.

Examples

- Most modern Ducatis
- Suzuki SV650
- Kawasaki Versys
- Honda VTR250

Engine as a stressed member

For rider comfort, a motorcycle's engine can be mounted on rubber bushings to isolate vibration from the rest of the machine. This strategy means the engine contributes little to frame stiffness, and absorbing rather than dissipating vibration can lead to stress damage to the frame, exhaust pipes, and other parts.

Instead, if the engine is rigidly mounted to the frame, vibrations pass to and are dissipated via the whole frame, and the rider. Rigid mounting allows the engine to contribute to the

overall stiffness of the frame. It also becomes possible to mount the swingarm directly to the engine rather than the frame, avoiding the need for frame members extending downward to the swingarm pivot. By increasing the number of mounting points between the engine and frame, vibrations and stress can be better dissipated in the frame, typically creating a triangle between the swingarm in the rear, the cylinder head at the top and the lower crankcase area at the front. If a rigidly mounted engine not only contributes to, but is critical to, the stiffness of the frame, and is an integral part of closing the triangle or trellis structure that transfers force from the headstock to the swingarm, to the point that without the engine the frame would be deformed, the engine is called a **stressed member**, or a **lifted engine**. Sharing the load between the engine and frame reduces the overall weight of the motorcycle.

During early testing of the 1983 Kawasaki GPZ900R, twin downtubes were included, creating a full cradle, but the downtubes were found to carry little load, so they were removed, relying entirely on the combination of the steel backbone and engine for chassis rigidity. BMW's R1100 series twins of 1994 relieved the frame of stress entirely, with the engine carrying the total load from the front Telever fork to the rear Monolever.

Chapter 7

Motorcycle Fork

1968 BMW R60US with conventional telescopic fork

Unusual "trailing bottom link" on a Honda Rune

A **motorcycle fork** connects a motorcycle's front wheel and axle to its frame, typically via a pair of triple clamps. It typically incorporates the front suspension and front brake, and allows the bike to be steered via handlebars attached to the upper triple tree.

The fork and its attachment points on the frame establish the critical geometric parameters of rake and trail, which play a major role in defining how a motorcycle handles and dives during braking.

Variations

Over more than one hundred years of motorcycle development a variety of front fork arrangements have been tried, several of which remain available today.

BMW's version of oil-damped telescopic fork, on a 1939 R12

Telescopic

A **telescopic fork** uses fork tubes which contain the suspension components (coil springs and damper) internally. This is the most common form of fork commercially available. It may or may not include gaiters for protection against abrasive elemts on the suspension cylinders.

The main advantage of the telescopic fork is that it is relatively simple in design and therefore relatively easy and inexpensive to manufacture and assemble. It is also relatively light compared to older designs based on external components and linkage systems.

Conventionally, the fork stanchions are at the top of the fork assembly, clamped to a triple tree, also called a yoke, pivoting around the headstock, and sliding in and out of the spring/damper unit at the bottom of the assembly. On many sport bikes, this system is inverted, with the spring/damper unit clamped to the yoke while the stanchions are at the bottom of the assembly. This is done for two reasons: to reduce unsprung weight by having the heavier components be suspended, and to improve the strength and rigidity of

the assembly by having the bulkier and stronger component being directly supported by the pivot. Such a system is referred to by many as **upside-down forks** or USD for short.

The disadvantage of the inverted design is that the entire reservoir of damping oil is stored directly over the slider seal such that, if the slider seal were to leak, the oil would drain out, reducing the effectiveness of the fork.

The first production motorcycle with hydraulically damped telescopic forks was the German BMW in 1935. However, undamped telescopic forks were used on bikes made by The Scott Motorcycle Company from the beginning of production in 1908, and the Danish Nimbus used them from 1934 on.

Trailing link

Trailing link fork on a 1928 Indian Big Chief

A trailing link fork, which may or may not be telescopic, suspends the wheel on a link (or links) with a pivot point forward of the wheel axle. Most famously used by Indian Motocycle; it was also used by BMW for its early bikes.

Ural's variant of the leading link fork

Leading link

A leading link fork, which may or may not be telescopic, suspends the wheel on a link (or links) with a pivot point aft of the wheel axle. Russian Ural motorcycles still use leading link forks on sidecar equipped motorcycles, and aftermarket leading link forks are often installed today on motorcycles when they are outfitted with sidecars, they are also very popular with trikes, improving the handling while steering or braking. The most common example of a leading link fork is that found on the early Honda 50.

Springer

Early Harley-Davidson with springer fork

The **springer fork** is an early type of leading link fork. A springer fork does not have the suspension built into the fork tubes, but instead has it mounted externally, where it may be integrated into the triple tree. This style of fork may be found on antique motorcycles or choppers, and is available today on Harley-Davidson's *Softail Springer*.

While it may have an exposed spring near the triple clamp, a springer fork is distinguishable from a girder fork by its two parallel sets of legs. The rear is firmly fixed to the bottom triple clamp (usually brazed or welded). A short leading link holds the wheel and the forward leg which actuates the springs (usually mounted on the triple clamp).

Earles fork on a 1968 BMW R60/2

Earles

The telescopic **Earles fork** was a variety of leading link fork where the pivot point was aft of the rear of the front wheel ─ this was the basis of the Earles' patent. Designed by Englishman Ernest Earles, this triangulated fork actually caused the front end of a motorcycle to rise when braking hard — the reverse of the action of a telescopic fork. It was designed to accommodate sidecars, and from 1955 to 1969, BMW used the fork even though most of its motorcycles were sold as solo bikes.

Girder

1934 Cotton with girder fork

One of the earliest types of motorcycle front suspension, the girder fork consists of a pair of uprights attached to the triple clamp by linkages with a spring usually between the top and bottom triple clamps. The design reached its peak in the "Girdraulics" used on "The Vincent" motorcycle.

While it may have an exposed spring near the triple clamp, a girder fork is distinguishable from a springer fork by the wheel being fixed firmly to the (usually a long diamond shape) upright. The pivot points are short links mounted to the top and bottom triple clamps. The spring is (usually) mounted to the girder and compressed against the upper triple clamp.

Saxon-Motodd (Telelever)

BMW Telelever fork on an R1200GS

The Saxon-Motodd (marketed as **Telelever** by BMW) has an additional swingarm that mounts to the frame and supports the spring. This causes the trail and castor angle (rake) to increase during braking instead of decreasing as with traditional telescopic forks. In the 21st century, BMW's boxer twins are equipped with Telelever forks.

Duolever front fork

Hossack/Fior (Duolever)

The Hossack/Fior (marketed as **Duolever** by BMW) separates completely the suspension from steering forces. It was developed by Norman Hossack though used by Claude Fior and John Britten on racebikes. Hossack himself described the system as a 'steered upright'. In 2004 BMW announced the K1200S with a new front suspension that appears to be based upon the design. As of 2006, the Duolever is on the K1200S, K1200R, and K1200GT.

Coaxial steering front suspension

Developed by MotoCzysz for their C1 and awarded United States Patent 7111700 on September 26, 2006. It is a fork with "coaxial steering and suspension components, and having telescopic forks. Swing weight of the forks is dramatically reduced by removing their suspension components to the central location, coaxially within the steering tube. Ride height can be adjusted without loosening the forks in the triple clamps. A shock tube disposed substantially coaxially within the steering tube wherein the shock tube includes a passage therethrough substantially coaxial with the steering axis; an upper triple clamp and a lower triple clamp coupled to the shock tube; a pair of sliding-tube forks each having an upper fork tube coupled to the upper triple clamp and to the lower triple clamp, and a lower fork tube; a coil-over shock disposed within the shock tube; a front wheel rotatably coupled to the lower fork tubes; a pair of bearings rotatably coupling the shock tube to the steering tube; and a top bolt coupling the shock tube to the upper triple clamp and having a passage therethrough substantially coaxial with the steering axis; wherein the coil-over shock includes a setting adjustment mechanism which is accessible via the passages through the top bolt and the shock tube."

This particular fork, as implemented on the MotoCzysz C1, also has adjustable trail, from 89 mm to 101 mm.

Non-forks

There have been several attempts to implement front steering and suspension without using anything that could be described as a "fork". Examples include hub-center steering as implemented on the Bimota Tesi and used as early as 1920 on the Ner-a-Car, and the RADD by James Parker implemented on the Yamaha GTS1000. A single-sided girder "fork" was used by the German firm Imme between 1949 and 1951.

Fork tube

Telescopic upside down (USD) fork with stanchions at the bottom. The right fork tube can be seen held by the upper and lower triple clamp of the triple tree.

Generally employed in pairs, **fork tubes** link a motorcycle's front wheel to its frame. They typically house the front suspension and on telescopic fork systems compress and extend to adjust for inconsistencies in the road.

Inside most tubes are springs, fork oil, and air, creating a shock absorber. Some forks allow pressurized air to be added through a valve in the top of the fork to stiffen the

suspension. Another method employs a screw to compress fork spring to increase or decrease spring pre-load.

Some forks also allow damping through variably sized orifices controlling the flow of fork oil. The larger the orifice, the more free the flow and the less damped the fork. A selector atop the fork engages the desired hole size and corresponding damping rate.

Cartridge forks provide *regressive* damping. Self-contained cartridges within the forks contain spring-covered orificies regulating fork oil flow. The springs resist low forces and thus provide high damping rates. Higher forces compress the springs, allowing more oil flow and less damping. Thus the fork is stiffer when responding to small bumps but will soften as larger ones are encountered.

Triple tree

The upper triple clamp joins the top of the fork tubes and the handlebar to the frame of a Honda 919

A **triple tree** ("triple clamp" (US) or "yoke" (UK)) attaches the fork tubes to the frame. Most bikes have upper and lower triple trees, providing two solid points for connecting the forks to the frame.

Chapter 8

Bicycle and Motorcycle Geometry

Bicycle and motorcycle geometry is the collection of key measurements (lengths and angles) that define a particular bike configuration. Primary among these are wheelbase, steering axis angle, fork offset, and trail. These parameters have a major influence on how a bike handles.

Wheelbase

Wheelbase is the *horizontal* distance between the centers (or the ground contact points) of the front and rear wheels. Wheelbase is a function of rear frame length, steering axis angle, and fork offset. It is similar to the term wheelbase used for automobiles and trains.

Wheelbase has a major influence on the longitudinal stability of a bike, along with the height of the center of mass of the combined bike and rider. Short bikes are much more likely to perform wheelies and stoppies.

Steering axis angle

Telescopic forks on a BMW motorcycle reveal the head angle or rake

Example of a chopper with an unusually large rake

The **steering axis angle**, also called caster angle, is the angle that the steering axis makes with the horizontal or vertical, depending on convention. The **steering axis** is the axis about which the steering mechanism (fork, handlebars, front wheel, etc.) pivots. The steering axis angle usually matches the angle of the head tube.

In *bicycles*, the steering axis angle is called the **head angle** and is measured clock-wise from the horizontal when viewed from the right side. A 90° head angle would be vertical. For example, Lemond offers:

- a 2007 Filmore, designed for the track, with a head angle that varies from 72.5° to 74° depending on frame size
- a 2006 Tete de Course, designed for road racing, with a head angle that varies from 71.25° to 74°, depending on frame size.

In *motorcycles*, the steering axis angle is called the **rake** and is measured counter-clock-wise from the vertical when viewed from the right side. A 0° rake would be vertical. For example, Moto Guzzi offers:

- a 2007 Breva V 1100 with a rake of 25°30’ (25.5 degrees)
- a 2007 Nevada Classic 750 with a rake of 27.5° (27.5 degrees)

Fork offset

The **fork offset** is the *perpendicular* distance from the steering axis to the center of the front wheel.

In *bicycles*, fork offset is also called *fork rake*. Virtually all road racing bicycle forks have an offset of 43-45mm due to the almost-standard frame geometry and 700c wheels, so racing forks are widely interchangeable.

The terms "rake" and "offset" became confused when bicyclists misunderstood the reason for the curl at the fork end, shown in the adjoining diagram, believing its purpose was shock absorption. With the bare fork in hand, rake is undefined, although one might believe the term refers to similarity with a leaf rake whose tines curl in a similar manner. The term "rakish angle" means steep, rather than that the fork has a curl at its end. Today, some fork blades are straight, having their offset introduced by an angled fork crown.

Required rake angle arose from early times when lightweight bicycles suffered fork failures from road shock. Most fatigue failures of forks result in a fork blade breaking at the rear edge of the fork crown from repeated vertical road shocks. Before most roads were paved, fork rake had a lower angle so the fork would be loaded axially on rougher surfaces. As most roads became paved, bicycles forks were made steeper, which also gave lighter steering.

In *motorcycles* with telescopic fork tubes, fork offset can be implemented by either an *offset* in the triple tree, adding a *rake angle* (usually measured in degrees from 0) to the

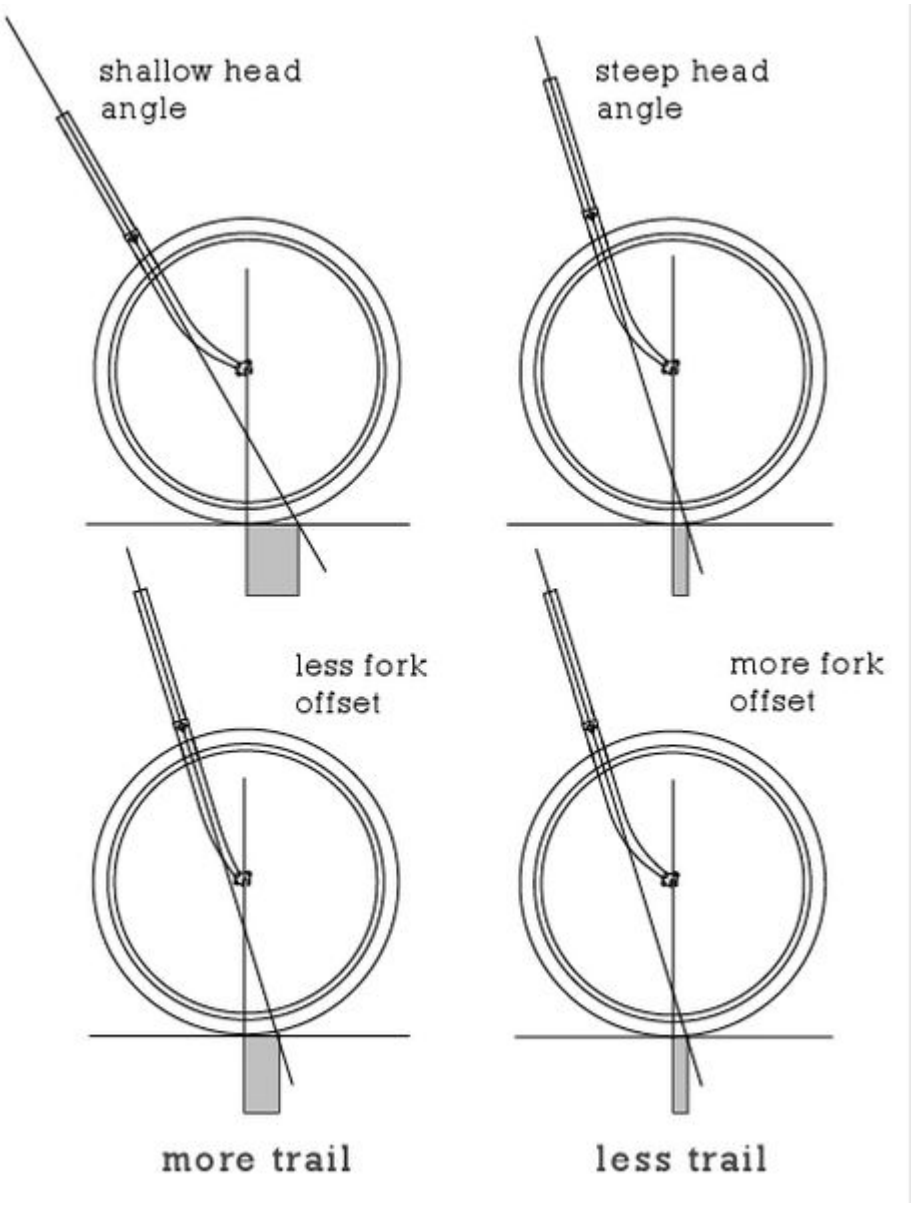
fork tubes as they mount into the triple tree, or a combination of the two. Other, less-common motorcycle forks, such as trailing link or leading link forks, can implement offset by the length of link arms.

Fork length

The length of a fork is measured parallel to the steer tube from the lower fork crown bearing to the axle center.

Trail

Trail, or caster, is the *horizontal* distance from where the steering axis intersects the ground to where the front wheel touches the ground. The measurement is considered *positive* if the front wheel ground contact point is behind (towards the rear of the bike) the steering axis intersection with the ground. Most bikes have positive trail, though a few, such as the Python Lowracer have negative trail.



The relationship between head angle, rake and trail in a bicycle

Trail is often cited as an important determinant of bicycle handling characteristics , and is sometimes listed in bicycle manufacturers' geometry data, although Wilson and Papodopoulos argue that mechanical trail may be a more important and informative variable.

Trail is a function of head angle, fork offset or rake, and wheel size. Their relationship can be described by this formula:

$$Trail = \frac{R_w \cos(A_h) - O_f}{\sin(A_h)}$$

where R_w wheel radius, A_h is the head angle measured clock-wise from the horizontal and O_f is the fork offset or rake. Trail can be increased by increasing the wheel size, decreasing or slackening the head angle, or decreasing the fork rake or offset. Trail decreases as head angle increases (becomes steeper), as fork offset increases, or as wheel diameter decreases.

Motorcyclists tend to speak of trail in relation to rake angle. The larger the rake angle the larger the trail. Note that, on a bicycle, as rake angle increases, head angle decreases.

Trail can vary as the bike leans or steers. In the case of traditional geometry, trail decreases (and wheelbase increases if measuring distance between ground contact points and not hubs) as the bike leans and steers in the direction of the lean. Trail can also vary as the suspension activates, in response to braking for example. As telescopic forks compress due to load transfer during braking, the trail and the wheelbase both decrease. At least one motorcycle, the MotoCzysz C1, has a fork with adjustable trail, from 89 mm to 101 mm.

Mechanical trail

Mechanical trail is the *perpendicular* distance between the steering axis and the point of contact between the front wheel and the ground. It may also be referred to as *normal trail*.

Although the scientific understanding of bicycle steering remains incomplete, mechanical trail is certainly one of the most important variables in determining the handling characteristics of a bicycle. A higher mechanical trail is known to make a bicycle easier to ride "no hands" and thus more subjectively stable, but skilled and alert riders may have more path control if the mechanical trail is lower.

Wheel Flop

Wheel flop refers to steering behavior in which a bicycle or motorcycle tends to turn more than expected due to the front wheel "flopping" over when the handlebars are rotated. Wheel flop is caused by the lowering of the front end of a bicycle or motorcycle as the handlebars are rotated away from the "straight ahead" position. This lowering phenomenon occurs according to the following equation:

$f = b \sin \partial \cos \partial$

Where:

f = "wheel flop factor," the distance that the center of the front wheel axle is lowered when the handlebars are rotated from the straight ahead position to a position 90 degrees away from straight ahead

b = trail

∂ = head angle

Because wheel flop involves the lowering of the front end of a bicycle or motorcycle, the force due to gravity will tend to cause handlebar rotation to continue with increasing rotational velocity and without additional rider input on the handlebars. Once the handlebars are turned, the rider needs to apply torque to the handlebars to bring them back to the straight ahead position and bring the front end of the bicycle or motorcycle back up to the original height. The rotational inertia of the front wheel will lessen the severity of the wheel flop effect because it results in opposing torque being required to initiate or accelerate changing the direction of the front wheel.

According to the equation listed above, increasing the trail and/or decreasing the head angle will increase the wheel flop factor on a bicycle or motorcycle, which will increase the torque required to bring the handlebars back to the straight ahead position and increase the vehicle's tendency to veer suddenly off the line of a curve. Also, increasing the weight born by the front wheel of the vehicle, either by increasing the mass of the vehicle, rider and cargo or by changing the weight ratio to shift the center of mass forward, will increase the severity of the wheel flop effect. Increasing the rotational inertia of the front wheel by increasing the speed of the vehicle and the rotational speed of the wheel will tend to counter the wheel flop effect.

A certain amount of wheel flop is generally considered to be desirable. In the magazine Bicycle Quarterly, bicycle dynamics expert Jan Heine wrote, "A bike with too little wheel flop will be sluggish in its reactions to handlebar inputs. A bike with too much wheel flop will tend to veer off its line at low and moderate speeds."

Modifications

Forks may be modified or replaced, thereby altering the geometry of the bike.

Changing fork length

Increasing the length of the fork, for example by switch from rigid to suspension, raises the front of the bike and decreases the head angle.

A rule of thumb is a 10mm change in fork length gives a half degree change in the head angle.

Changing fork offset

Increasing the offset of a fork reduces the trail, and if performed on an existing fork without lengthening the blades, shortens the fork.

Legal requirements

The state of North Dakota (USA) actually has minimum and maximum requirements on rake and trail for "manufacture, sale, and safe operation of a motorcycle upon public highways."

"4. All motorcycles, except three-wheel motorcycles, must meet the following specifications in relationship to front wheel geometry:

> MAXIMUM: Rake: 45 degrees - Trail: 14 inches [35.56 centimeters] positive
> MINIMUM: Rake: 20 degrees - Trail: 2 inches [5.08 centimeters] positive

Manufacturer's specifications must include the specific rake and trail for each motorcycle or class of motorcycles and the terms "rake" and "trail" must be defined by the director by rules adopted pursuant to chapter 28-32."

Chapter 9

Motorcycle Handlebar and Hub-Center Steering

Motorcycle handlebar

A right clip-on handlebar with twist throttle control, brake lever, and ignition switches.

One-piece handlebars on a Ducati bolted to the triple tree with a short riser.

Ape Hangers

Motorcycle handlebar refers to the steering mechanism for motorcycles. Handlebars often support part of the rider's weight, and provide a mounting place for controls such as brake, throttle, clutch, horn, light switch, and rear view mirrors.

Types of handlebar

Handlebars come in a variety of types designed for particular types of riding.

- Ape hanger handlebars rise far above the mounting location so that the rider must reach up to use them, hence the name. They are popular on chopper motorcycles. They are available in heights up to 20 inches. Some jurisdictions have regulations on how high the handgrips may be above the seat.
- Z-bar, any sharply angled handlebar with either long or short straight rise sections, which are sharply angled upward from the mounting points and again sharply angled to the handgrip and control area. Z-bars can be ape hangers, but not all ape hangers are Z-bars.
- Beach bars, similar to cruiser bars, slope back toward the rider to allow a relaxed riding position.

- Clip-ons are popular on sport bikes, in which two separate short handles are attached directly to the fork tubes, as opposed to a standard one-piece handlebar attached to the top of the triple tree.
- Clubman bars are common on cafe bikes. They clamp to the triple tree and are angled forward to give the rider a more aggressive riding position.
- Cruiser handlebars tend to be long and slope towards the rear of the motorcycle so that the rider can sit upright.
- Buckhorn handlebars are a variation on the ape hanger, but shorter, and always with a curved back section directly before the part of the bar that mounts the handgrips and controls. These are often thought to be one of the most comfortable type of handlebar, keeping the arms in a very natural and relaxed position in front of the rider. They are often called "mini-apes" (miniature ape hangers), but a true buckhorn must be rounded on top, never with the sharp angles of a Z-bar on the top.
- Drag bars are nearly straight across to create a forward-leaning and aerodynamic riding position.
- Motocross bars are tubular bars that are clamped onto the triple tree. They are common on motocross and off-road motorcycles, as well as dual-sport, streetfighter, and supermoto bikes.

Construction

Handlebars are made from hollow metal tubing, typically aluminium alloys or chrome plated steel but also of carbon fibre and titanium, shaped to the desired contour. Holes may be drilled for the internal routing of control cables such as brake, throttle, and clutch. Risers hold the handlebars above their mounting position on the upper triple tree or the top of the fork, and may be integrated into the bar itself or separate items.

Bar-end weights are often added to either end of the handlebar to damp vibration by moving the bars' resonant frequency away from that generated by the engine. Electrical heating elements may be added under the handlebar grips to provide comfort to the user in cold weather.

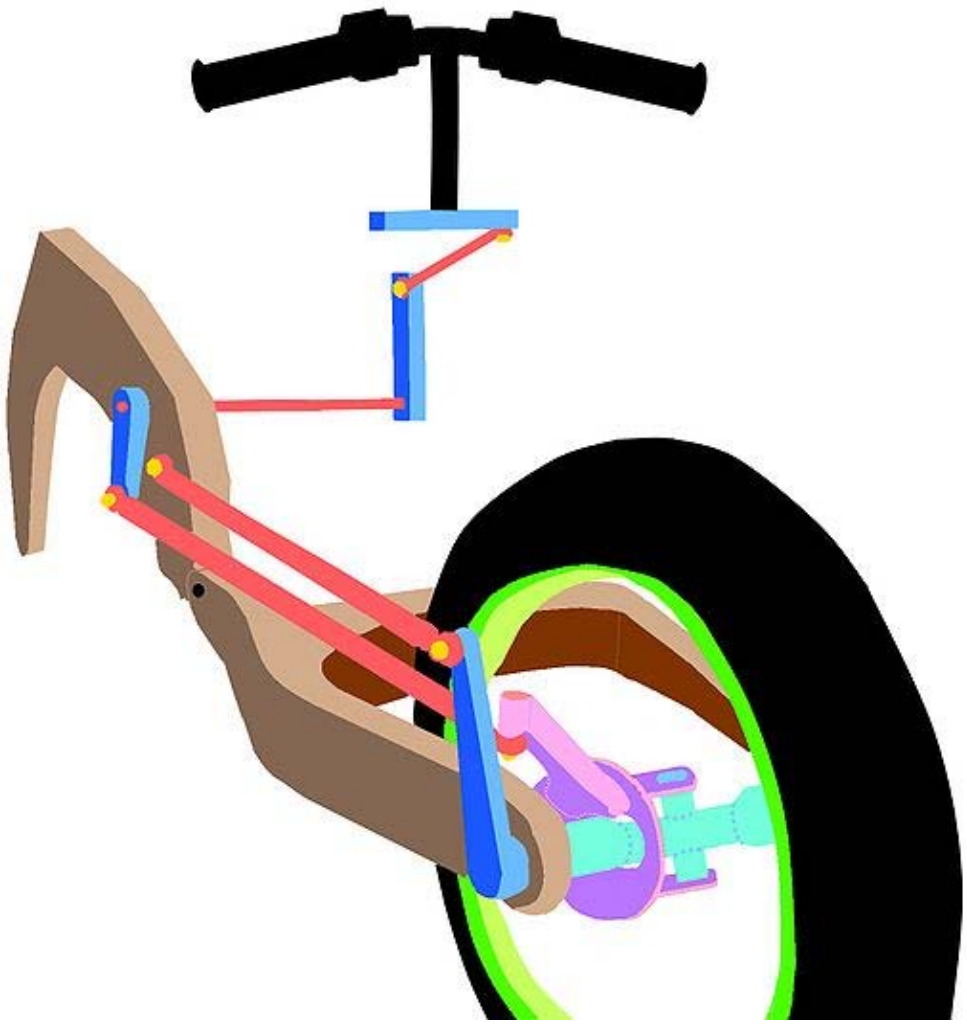
Sizes

There are several size parameters that describe most motorcycle handlebars.

- Width from grip to grip may vary from 30.5 inches to 37 inches.
- Rise above mounting location may vary from 0 inches to 20 inches.
- Pullback, the distance grips are behind their mounting location, may vary from 4.25 inches to 17 inches.
- Diameters vary, commonly 7/8 inch, 1 inch, and 1¼ inches, though oversized bars of 1¼, 1½ and 1¾ inches may reduce to 1 inch at the grips so standard controls may be mounted.

Hub-Center steering

The Vyrus 985 C3 features hub-center steering.



Hub-center steering in Bimota Tesi

Hub-center steering (HCS) is one of several different types of front end suspension/steering mechanisms used in motorcycles. Hub-center steering is characterized by a swingarm that extends from the bottom of the engine/frame to the centre of the front wheel instead of two forks.

The advantages of using a hub-center steering system instead of a more conventional motorcycle fork are that hub-center steering separates the steering, braking, and suspension functions.

With a fork the braking forces are put through the suspension, a situation that leads to the suspension being compressed, using up a large amount of suspension travel which makes dealing with bumps and other road irregularities extremely difficult. As the forks dive the

steering geometry of the bike also changes making the bike more nervous, and inversely on acceleration becomes more lazy. Also, having the steering working through the forks causes problems with stiction, decreasing the effectiveness of the suspension. The length of the typical motorcycle fork means that they act as large levers about the headstock requiring the forks, the headstock, and the frame to be very robust adding to the bike's weight.

Hub-center steering systems use an arm, or arms, on bearings to allow upward wheel deflection, meaning that there is no stiction, even under braking. Braking forces can be redirected horizontally along these arms (or tie rods) away from the vertical suspension forces, and can even be put to good use to counteract weight shift. Finally, the arms typically form some form of parallelogram which maintains steering geometry over the full range of wheel travel, allowing agility and consistency of steering that forks currently cannot get close to attaining. The hub center steering's achilles heel, however, has been steering feel. Complex linkages tend to be involved in the steering process, and this can lead to slack, vague, or inconsistent handlebar movement across its range.

Hub-center steering systems have only appeared on a very few production motorcycles, and not with any great success. Evolution, rather than revolution, tends to drive advancements in new models, and dictate sales. After so many years of telescopic forks, people are used to riding a bike that handles in a specific way, and almost expect the limitations, and compensation is part of the experience. Also there is a depth of knowledge known about fork based chassis design that attempts each year to get around the limitations through technological advances on the current system. Thicker and thicker fork tubes are used to reduce flex, special coatings are used to aid stiction, and greater and greater steering angles are used to counteract dive.

The hub-center steer concept is a very old one used as early as 1920 by Ner-a-Car, and enjoyed an aftermarket vogue in the 1970s through the work of Jack Difazio in the UK. The late Mike Tomkinson (of Mead & Tomkinson), aided by sons Chris and Patrick, pioneered the use of hub-centre steering in 24-hour motorcycle endurance racing. Their first machine, "Nessie" (qv), was powered by a Laverda 1000cc triple; but they later designed a Kawasaki-engined bike that became known as Nessie II. The Tomkinson's efforts encouraged Elf in the 1980s to create a succession of GP race bikes. In the 90's there was a flurry of action, first was the Bimota Tesi 1D in 1991 (designed by a young Massimo Tamburini of 916 fame) however this was expensive and was only ever produced in small numbers. Then in 1993 Yamaha launched the GTS1000 based on James Parker's RADD design. It raced at the Isle of Man TT but was always blighted with a reputation for being a bit heavy and clumsy in use. In 1995 Michael Tryphonos built a prototype based on the Defazio system that did race at the Isle of Man with some success reaching 11th in the Senior TT.

Royce Creasey, designer of feet forwards motorcycles, is an ardent advocate of HCS.

Currently, Bimota's Tesi 3D and the Vyrus 984C^3 2V and the 985C^3 4V are the only production motorcycles using hub-center steering systems, however Italjet also use hub-

center steering on their top of the range scooters with much success. Sidecar manufacturers occasionally employ hub-center steering in their designs. A notable example being the GG Duetto.

Chapter 10

Motorcycle Tyre

A rear motorcycle tyre for street use

Studded front tyre with spikes used on Ice speedway

Motorcycle tyres provide the only contact with the ground, via the contact patch under normal conditions, and so have a very large influence over motorcycle handling characteristics. Motorcycle tyres have a round cross section to facilitate the leaning necessary when a motorcycle turns. The unworn portion of tyre near the outer edge my be referred to as chicken strips.

Motorcycles mainly use pneumatic tyres. However, in some cases where punctures are common (some enduros), the tyres are filled with a "mousse" which is unpunctureable. Both types of tyre come in many configurations.

Types

Motorcycle tyres are available for many different applications, including: Sport, Sport Touring, Touring, Cruiser, Scooter, On/Off Road, Dual-Sport, Enduro, Motocross and Racing. There are tyres designed for dirtbikes, touring, sport and cruiser bikes.

Sport/performance tyres provide amazing grip but may last 1,000 miles (1,600 km) or less. Cruiser and "sport touring" tyres try to find the best compromise between grip and durability. There is also a type of tyre developed specifically for racing. These tyres offer the highest of levels of grip for cornering. Because of the high temperatures at which these tyres typically operate, use on the street is unsafe because the tyres will typically not reach optimum temperature before a rider arrives at the destination, thus providing almost no grip *en route*. In racing situations, racing tyres would normally be brought up to temperature in advance by the use of tyre warmers.

Sport Touring tyres are generally not used for high cornering loads, but for long straights, good for riding across the country.

Sport Street tyres are for aggressive street riders that spend most of their time carving corners on public roadways. These tyres do not have a long life, but in turn have better traction in high speed cornering. Street and sport street tyres have good traction even when cold, but when warmed too much, can actually lose traction as their internal temperature increases.

Track or **Slick** tyres are for track days or races. They have more of a triangular form, which in turn gives a larger contact patch while leaned over. These tyres are not recommended for the street by manufactures, and are known to have a shorter life on the street. Due to the triangulation of the tyre, there will be less contact patch in the centre, causing the tyre to develop a flat spot quicker when used to ride on straightaways for long periods of time and have no tread so they lose almost all grip in the wet. Racing slicks are always made of a softer rubber compound and do not provide as much traction as street tyres until warmed to a higher internal temperature than street tyres normally operate at. Most street riding will not put a sufficient amount of friction on the tyre to maintain the slick's optimal tyre temperature, especially in colder climates and in spring and fall.

Off road tyres have knobbly, deep treads for maximum grip on loose dirt, mud, sand, or gravel; such tyres tend to be less stable on paved surfaces.

Touring tyres are usually made of harder rubber for greater durability. They may last longer, but they tend to provide less outright grip than sports tyres at optimal operating temperatures. The tradeoff is that touring tyres typically offer more grip at lower temperatures, meaning they can be more suitable for riding in cold or winter conditions whereas a sport tyre may never reach the optimal operating temperature.

Speed and construction

As with four-wheeled vehicles, tyres for motorcycle have a tyre code, which describes a tyre's width, height/width aspect ratio, wheel diameter, load index and speed rating. The most common are:

- **3 digit number**: The "nominal section width" of the tyre in millimetres; the widest point from both outer edges.
- /: Slash character for character separation.
- **2 or 3 digit number**: The "aspect ratio" of the sidewall height to the total width of the tyre, as a percentage.
- An optional letter indicating construction of the fabric carcass of the tire:
  - **B**: bias belt (where the sidewalls are the same material as the tread, leading to a rigid ride)
  - **D**: diagonal
  - **R**: radial
    - if omitted, then it is a cross ply tyre
- **2 digit number**: Diameter in inches of the wheel that the tyre is designed to fit.
- **2 or 3 digit number**: Load index
- **1 or 2 digit/letter combo**: Speed rating

Load index

LI	kg	LI	kg	LI	kg	LI	kg	LI	kg
19	77,5	36	125,0	53	206	70	335,0	87	545,0
20	80,0	37	128,0	54	212,0	71	345,0	88	560,0
21	82,5	38	132,0	55	218,0	72	355,0	89	580,0
22	85,0	39	136,0	56	224,0	73	365,0	90	600,0
23	87,5	40	140,0	57	230,0	74	375,0	91	615,0
24	90,0	41	145,0	58	236,0	75	387,0	92	630,0
25	92,0	42	150,0	59	243,0	76	400,0	93	650,0
26	95,0	43	155,0	60	250,0	77	412,0	94	670,0
27	97,5	44	160,0	61	257,0	78	425,0	95	690,0
28	100,0	45	165,0	62	265,0	79	437,0	96	710,0
29	103,0	46	170,0	63	272,0	80	450,0	97	730,0
30	106,0	47	175,0	64	280,0	81	462,0	98	750,0
31	109,0	48	180,0	65	290,0	82	475,0	99	775,0
32	112,0	49	185,0	66	300,0	83	487,0	100	800,0
33	115,0	50	190,0	67	307,0	84	500,0	-	-
34	118,0	51	195,0	68	315,0	85	510	-	-

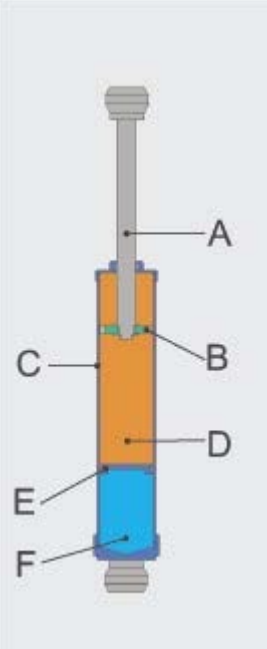
35	121,0	52	200,0	69	325	86	530,0	-	-

Speed rating

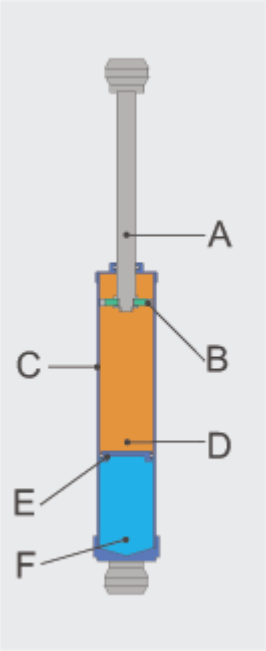
Rating	Speed (km/h)	Speed (mph)
Moped	50	30
J	100	62
K	110	69
L	120	75
M	130	81
P (or-)	150	95
Q	160	100
R	170	105
S	180	113
T	190	118
U	200	125
H	210	130
V	240	150
W	270	168
ZR	over 240	over 150

Chapter 11

Shock Absorber



Shock absorber with internal reservoir. The components are:
A - rod,
B - the piston with seals,
C - the cylinder,
D - oil reservoir,
E - floating piston,



F - air chamber.

A **shock absorber** is a mechanical device designed to smooth out or damp shock impulse, and dissipate kinetic energy. It is a type of dashpot.

Nomenclature

- The device's name in common parlance (among the general public and auto mechanics) is *shock absorber* or simply *shock*.
- Technical names include *damper* and *dashpot*.
- During the early 20th century in the U.S., the then-well-known Houdaille brand (pronounced WHO-dye) was in some places a genericized trademark for the device, but has since disappeared from use.

Description

Pneumatic and hydraulic shock absorbers commonly take the form of a cylinder with a sliding piston inside. The cylinder is filled with a fluid (such as hydraulic fluid) or air. This fluid-filled piston/cylinder combination is a dashpot. Shock absorbers include cushions and springs.

Explanation

The shock absorber's function is to absorb or dissipate energy. One design consideration, when designing or choosing a shock absorber, is where that energy will go. In most dashpots, energy is converted to heat inside the viscous fluid. In hydraulic cylinders, the

hydraulic fluid heats up, while in air cylinders, the hot air is usually exhausted to the atmosphere. In other types of dashpots, such as electromagnetic types, the dissipated energy can be stored and used later. In general terms, shock absorbers help cushion vehicles on uneven roads.

Applications

Shock absorbers are an important part of automobile and motorcycle suspensions, aircraft landing gear, and the supports for many industrial machines. Large shock absorbers have also been used in structural engineering to reduce the susceptibility of structures to earthquake damage and resonance. A transverse mounted shock absorber, called a yaw damper, helps keep railcars from swaying excessively from side to side and are important in passenger railroads, commuter rail and rapid transit systems because they prevent railcars from damaging station platforms. The success of passive damping technologies in suppressing vibration is demonstrated by its market size—around US$4.5 billion.

Rear shock absorber and spring of a BMW R75/5 motorcycle

Vehicle suspension

In a vehicle, shock absorbers reduce the effect of traveling over rough ground, leading to improved ride quality and increase in comfort. While shock absorbers serve the purpose of limiting excessive suspension movement, their intended sole purpose is to dampen spring oscillations. Shock absorbers use valving of oil and gasses to absorb excess energy from the springs. Spring rates are chosen by the manufacturer based on the weight of the vehicle, loaded and unloaded. Some people use shocks to modify spring rates but this is not the correct use. Along with hysteresis in the tire itself, they dampen the energy stored in the motion of the unsprung weight up and down. Effective wheel bounce damping may require tuning shocks to an optimal resistance.

Spring-based shock absorbers commonly use coil springs or leaf springs, though torsion bars are used in torsional shocks as well. Ideal springs alone, however, are not shock absorbers, as springs only store and do not dissipate or absorb energy. Vehicles typically employ both hydraulic shock absorbers and springs or torsion bars. In this combination, "shock absorber" refers specifically to the hydraulic piston that absorbs and dissipates vibration.

Structures

Applied to a structure such as a building or bridge it may be part of a seismic retrofit or as part of new, earthquake resistant construction. In this application it allows yet restrains motion and absorbs resonant energy, which can cause excessive motion and eventual structural failure.

Electrical Generation

Modern hybrid cars may eventually be able to generate useful energy from the displacement of the fluid in a shock absorber.

Types of shock absorbers

There are several commonly-used approaches to shock absorption:

- Hysteresis of structural material, for example the compression of rubber disks, stretching of rubber bands and cords, bending of steel springs, or twisting of torsion bars. Hysteresis is the tendency for otherwise elastic materials to rebound with less force than was required to deform them. Simple vehicles with no separate shock absorbers are damped, to some extent, by the hysteresis of their springs and frames.

- Dry friction as used in wheel brakes, by using disks (classically made of leather) at the pivot of a lever, with friction forced by springs. Used in early automobiles such as the Ford Model T, up through some British cars of the 1940s. Although now considered obsolete, an advantage of this system is its mechanical simplicity; the degree of damping can be easily adjusted by tightening or loosening the screw clamping the disks, and it can be easily rebuilt with simple hand tools. A disadvantage is that the damping force tends not to increase with the speed of the vertical motion.

- Solid state, tapered chain shock absorbers, using one or more tapered, axial alignment(s) of granular spheres, typically made of metals such as nitinol, in a casing. ,

- Fluid friction, for example the flow of fluid through a narrow orifice (hydraulics), constitute the vast majority of automotive shock absorbers. An advantage of this type is that using special internal valving the absorber may be made relatively soft

to compression (allowing a soft response to a bump) and relatively stiff to extension, controlling "rebound", which is the vehicle response to energy stored in the springs; similarly, a series of valves controlled by springs can change the degree of stiffness according to the velocity of the impact or rebound. Specialized shock absorbers for racing purposes may allow the front end of a dragster to rise with minimal resistance under acceleration, then strongly resist letting it settle, thereby maintaining a desirable rearward weight distribution for enhanced traction. Some shock absorbers allow tuning of the ride via control of the valve by a manual adjustment provided at the shock absorber. In more expensive vehicles the valves may be remotely adjustable, offering the driver control of the ride at will while the vehicle is operated. The ultimate control is provided by dynamic valve control via computer in response to sensors, giving both a smooth ride and a firm suspension when needed. Many shock absorbers contain compressed nitrogen, to reduce the tendency for the oil to foam under heavy use. Foaming temporarily reduces the damping ability of the unit. In very heavy duty units used for racing and/or off-road use, there may even be a secondary cylinder connected to the shock absorber to act as a reservoir for the oil and pressurized gas. Another variation is the magneto rheological damper which changes its fluid characteristics through an electromagnet.

- Compression of a gas, for example pneumatic shock absorbers, which can act like springs as the air pressure is building to resist the force on it. Once the air pressure reaches the necessary maximum, air dashpots will act like hydraulic dashpots. In aircraft landing gear air dashpots may be combined with hydraulic damping to reduce bounce. Such struts are called *oleo struts* (combining oil and air) .

- Magnetic effects. Eddy current dampers are dashpots that are constructed out of a large magnet inside of a non-magnetic, electrically conductive tube.

- Inertial resistance to acceleration, for example prior to 1966 the Citroën 2CV had shock absorbers that damp wheel bounce with no external moving parts. These consisted of a spring-mounted 3.5 kg (7.75 lb) iron weight inside a vertical cylinder and are similar to, yet much smaller than versions of the tuned mass dampers used on tall buildings.

- Composite hydropneumatic devices which combine in a single device spring action, shock absorption, and often also ride-height control, as in some models of the Citroën automobile.

- Conventional shock absorbers combined with composite pneumatic springs which allow ride height adjustment or even ride height control, seen in some large trucks and luxury sedans such as certain Lincoln and most Land Rover automobiles. Ride height control is especially desirable in highway vehicles intended for occasional rough road use, as a means of improving handling and reducing

aerodynamic drag by lowering the vehicle when operating on improved high speed roads.

- The effect of a shock absorber at high (sound) frequencies is usually limited by using a compressible gas as the working fluid and/or mounting it with rubber bushings.