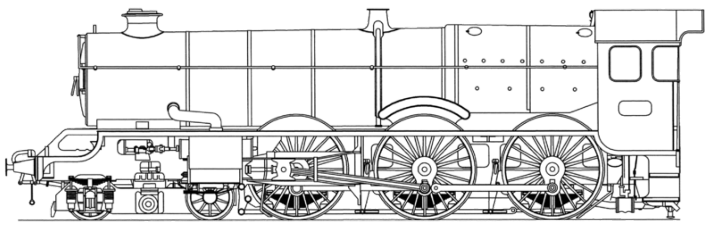
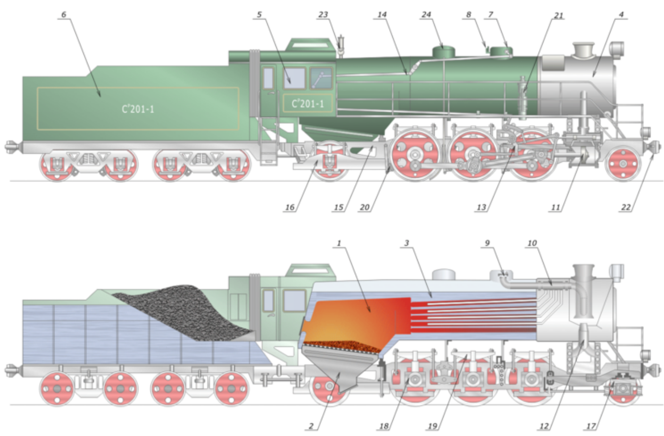
Steam locomotive

A **steam locomotive** is a locomotive powered by a steam engine. The term usually refers to its use on railways, but can also refer to a "road locomotive" such as a traction engine or steamroller.



Drawing of a Great Western Railway *King* class locomotive

Beginning in Britain, steam locomotives dominated railway usage from the start of the 19th century, until the middle of the 20th Century. They were gradually improved and developed in their over 150 years of development and use. Starting in about 1930 other types of engines were developed and steam locomotives were gradually superseded by diesel and electric locomotives.

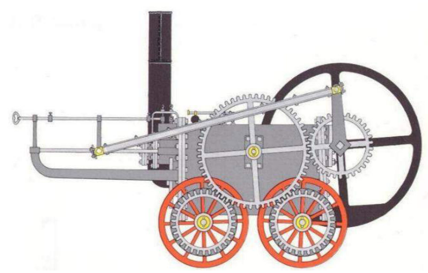


The main components of a steam locomotive

Origins

See also: History of rail transport, Category:Early steam locomotives

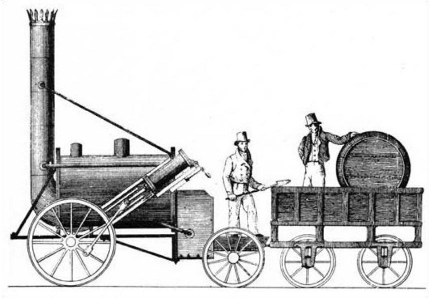
The earliest railways employed horses to draw carts along railed tracks.



Trevithick's locomotive, 1804 the first successful steam locomotive

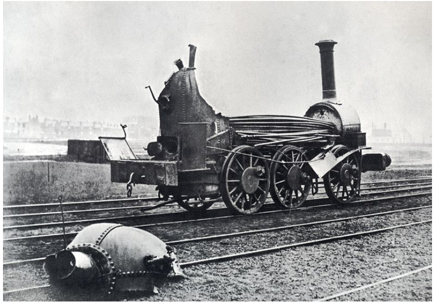
As the development of steam engines progressed through the 1700s, various attempts were made to apply them to road and railway use.[1] In 1784 William Murdoch, a Scottish inventor, built a prototype steam road locomotive.[2] An early working model of a steam rail locomotive was designed and constructed by Steamboat Pioneer John Fitch in the United States probably during the 1780s or 1790s.[3] His steam locomotive used interior bladed wheels guided by rails or tracks. The model still exists at the Ohio Historical Society Museum in Columbus.[4]

The first full scale working railway steam locomotive was built by Richard Trevithick in the United Kingdom, and on 21 February 1804 the world's first railway journey took place as Trevithick's unnamed steam locomotive hauled a train along the tramway of the Penydarren ironworks, near Merthyr Tydfil in south Wales [5] [6] Accompanied with Andrew Vivian, it ran with mixed success.[1] Then followed the successful twin cylinder locomotive Salamanca by Matthew Murray for the edge railed rack and pinion Middleton Railway in 1812.[7] In 1825 George Stephenson built the *Locomotion* for the Stockton and Darlington Railway, north east England, which was the first public steam railway in the world. In 1829 he built *The Rocket* which was entered in and won the Rainhill Trials. This success led to Stephenson establishing his company as the pre-eminent builder of steam locomotives used on railways in the United Kingdom, United States and much of Europe.[8] The Liverpool and Manchester Railway opened a year later making exclusive use of steam power for both passenger and freight trains.



Stephenson's *Rocket* 1829, the winner of the Rainhill Trials

The United States started developing steam locomotives in 1829 with the Baltimore and Ohio Railroad's *Tom Thumb*. This was the first locomotive to run in America, although it was intended as a demonstration of the potential of steam traction, rather than as a revenue-earning locomotive. The first successful steam railway in the US was the South Carolina Railroad whose inaugural train ran on December 25, 1830 hauled by the *Best Friend of Charleston*. Many of the earliest locomotives for American railroads were imported from England, including the *Stourbridge Lion* and the *John Bull*, but a domestic locomotive manufacturing industry was quickly established, with locomotives like the *DeWitt Clinton* being built in the 1830s.[9]

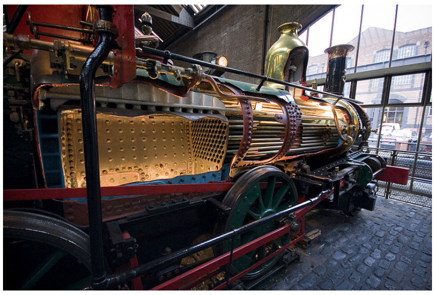


Aftermath of a boiler explosion on a railway locomotive circa 1850.

The first railway service in Continental Europe (or for that matter, outside the United Kingdom and the United States) was opened on May 5, 1835 in Belgium, between Mechelen and Brussels. The name of the locomotive used was *The Elephant*.

Basic form

Boiler



A steam locomotive with the boiler and firebox exposed

The typical steam locomotive employs a steel fire-tube boiler that contains pressurized water and steam. A firebox is normally located in the rear of the boiler (chimney in front). The firebox has a water filled steel chamber surrounding the top and sides of the flame in the firebox. If wood or coal is used to make the fire in the firebox it is built on a set of grates where ashes may be separated from the burning fuel. These ashes must periodically be removed from the engine. If wood or coal are the fuel used in the firebox there is a door at the rear of the firebox that is opened to add more fuel. If oil is used there nearly always is a door for adjusting the air flow, maintenance or for cleaning the oil jets. To extract even more heat, the smoke and hot air from the combustibles in the firebox travel horizontally through a bundle of parallel tubes submerged in the water in the boiler from the front of the firebox to the front of the boiler. The heat extracted in the firebox and tubes in the boiler converts the water to pressurized steam in the boiler. To minimize heat loss from the boiler it is normally surrounded with layers of insulation. The water and steam in the boiler are kept pressurized to raise the boiling temperature of the water and generate high pressure steam. The amount of pressure in the boiler is monitored by the engineer or fireman by a gauge mounted in the cab. Excess steam pressure can be released manually or may blow a safety valve. Too much pressure may cause the boiler to burst potentially killing the crew as well as disabling the engine.

At the front of the boiler is the smokebox, where steam is ejected into the chimney (US: "smoke stack") drawing the smoke and hot air through the fire tubes in the boiler and out the top of the chimney. The combustion in a typical steam engine is not very complete leading to a prodigious amount of smoke and often sparks being produced. This made these engines very dirty to live around as well as being an acute hazard while passing through a forest, tunnel or snow shed.

The steam generated in the boiler is used to drive the locomotive and also for other purposes (whistles, brakes, pumps, air flow, etc.). This constant use of steam requires the boiler to have water continually pumped (usually automatically) into it. The source of this water is an unpressurized tank, which is periodically topped up at water stops. The water level is normally monitored with a transparent tube or gauge. If the boiler runs out of water the fire may melt a hole in it, possibly causing an explosion. In a wreck or accident the boiler may burst, potentially hurting or killing the crew. Scale may build up in boiler to prevent good heat transfer, and corrosion eventually makes the boiler unsafe and it has to be rebuilt or replaced. Start up on a large engine may take an hour or more of preliminary heating of the water in the boiler before it is ready to go. These are several of the serious disadvantages of steam engines, which have led to their eventual replacement by safer and cleaner engines requiring less maintenance.

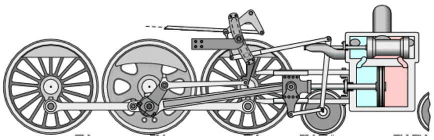
The boiler is typically placed horizontally. For locomotives designed to work on steep slopes, it may be placed vertically or mounted at an angle instead.

Steam circuit

The steam generated in the boiler fills the steam space above the water in the partially-filled boiler. Its maximum working pressure is limited by spring-loaded safety valves. It is then collected either in a perforated tube fitted above the water level or from a dome that often houses the regulator valve, or throttle, the purpose of which is to control the amount of steam leaving the boiler. The steam then either travels directly along and down a steam pipe to the engine unit or may first pass into the wet header of a superheater, the role of the latter being to improve thermal efficiency and eliminate water droplets suspended in the "saturated steam", the state in which it leaves the boiler. On leaving the superheater, the steam exits the dry header of the superheater and passing down a steam pipe entering the steam chests adjacent to the cylinders of a reciprocating engine. Inside each steam chest is a sliding valve that distributes the steam via ports that connect the steam chest to the ends of the cylinder space. The role of the valves is twofold: admission of each fresh dose of steam and exhaust of the used steam once it has done its work.

The cylinders are double acting, with steam admitted to each side of the piston in turn. In a two-cylinder locomotive, one cylinder is located on each side of the locomotive. The cranks are set 90° out of phase. During a full rotation of the driving wheel, steam provides four power strokes; each cylinder receives two injections of steam per revolution. The first stroke is to the front of the piston and the second stroke to the rear of the piston; hence two working strokes. Consequently two deliveries of steam onto each piston face in two cylinders generates a full revolution of the driving wheel. Each piston is connected to the driving axle on each side by a connecting rod, the driving wheels are connected together by coupling rods to transmit power from the main driver to the other wheels. Note that at the two "dead centres", when the connecting rod is on the same axis as the crankpin on the driving wheel, the connecting rod applies no torque to the wheel. Therefore, if both cranksets could be at "dead centre" at the same time, and the wheels should happen to stop in this position, the locomotive could not be started moving. Therefore the crankpins are attached to the wheels at a 90° angle to each other, so only one side can be at dead centre at a time.

Each piston transmits power directly through a connecting rod (US: main rod) and a crankpin (US: wristpin) on the driving wheel (US main driver) or to a crank on a driving axle. The movement of the valves in the steam chest is controlled through a set of rods and linkages called the valve gear, actuated from the driving axle or else from the crankpin; the valve gear includes devices that allow reversing the engine, adjusting valve travel and the timing of the admission and exhaust events. The cut-off point determines the moment when the valve blocks a steam port, "cutting off" admission steam and thus determining the proportion of the stroke during which steam is admitted into the cylinder; for example a 50% cut-off admits steam for half the stroke of the piston. The remainder of the stroke is driven by the expansive force of the steam. Careful use of cut-off provides economical use of steam and, in turn, reduces fuel and water consumption. The reversing lever (US: Johnson bar), or screw-reverser, (if so equipped) that controls the cut-off therefore performs a similar function to a gearshift in an automobile - maximum cut-off, providing maximum tractive effort at the expense of efficiency, is used to pull away from a standing start, whilst a cut-off as low as 10% is used when cruising, providing reduced tractive effort with lower fuel/water consumption.[10]



Walschaerts valve gear in a steam locomotive. In this animation, the red colour represents live steam entering the cylinder, blue represents expanded (spent) steam being exhausted from the cylinder. Note that the cylinder receives two steam injections during each full rotation; the same occurs in the cylinder on the other side of the engine.

Exhaust steam is directed upwards to the atmosphere through the chimney, by way of a nozzle called a blastpipe that gives rise to the familiar "chuffing" sound of the steam locomotive. The blastpipe is placed at a strategic point inside the smokebox that is at the same time traversed by the combustion gases drawn through the boiler and grate by the action of the steam blast. The combining of the two streams, steam and exhaust gases, is crucial to the efficiency of any steam locomotive and the internal profiles of the chimney, (or more strictly speaking, the *ejector*) require careful design and adjustment. This has been the object of intensive studies by a number of engineers (and almost totally ignored by others with sometimes catastrophic effect). The fact that the draught depends on the exhaust pressure means that power delivery and power generation are automatically self-adjusting and among other things, a balance has to be struck between obtaining sufficient draught for combustion whilst giving the exhaust gases and particles sufficient time to be consumed. In the past, fierce draught could lift the fire off the grate, or cause the ejection of unburnt particles of fuel, dirt and pollution for which steam locomotives had an unenviable reputation in the past. Moreover, the pumping action of the exhaust has the counter effect of exerting *back pressure* on the side of the piston receiving steam, thus slightly reducing cylinder power. Designing the exhaust ejector has become a specific science in which Chapelon, Giesl [11] and Porta were successive masters, and was largely responsible for spectacular improvements in thermal efficiency and a significant reduction in maintenance time[12] and pollution. [13] A similar system was used by some early gasoline/kerosene tractor manufacturers (Advance-Rumely/Hart-Parr) – the exhaust gas volume vented through a cooling tower meant that the steam exhaust helped draw more air past the radiator.

Chassis

The chassis or locomotive frame is the principal structure onto which the boiler is mounted and which incorporates the various elements of the running gear. The boiler is rigidly mounted on a *"saddle"* beneath the smokebox and front of the boiler barrel, but the firebox at the rear is allowed to slide forward and back, to allow for expansion when hot.


The Jacobite Steam Train in September 2003.

European locomotives usually use *"plate frames"*, where two vertical flat plates form the main chassis, with a variety of spacers and a buffer beam at each end to keep them apart. When inside cylinders are mounted between the frames, these are a single large casting that forms a major support to the frames. The axleboxes slide up and down to give some sprung suspension, against thickened webs attached to the frame, called *"hornblocks"*.

For many years, in American practice, the boiler was the main structural element, with built-up bar frames, "smokebox saddle/cylinder" structure and *"drag beam"* integrated therein; but from the late 1920s with the introduction of "superpower", the "cast-steel locomotive bed" became the norm, incorporating frames, spring hangers, motion brackets, smokebox saddle and cylinder blocks incorporated into a single complex, sturdy but heavy casting. André Chapelon developed a similar structure but of welded construction with around 30% saving in weight for the still-born 2-10-4 locomotives the construction of which was begun then abandoned in 1946.

Running gear

This includes the brake gear, wheel sets, axleboxes, springing and the "motion" that includes connecting rods and valve gear. The transmission of the power from the pistons to the rails and the behaviour of the locomotive as a vehicle, able to negotiate curves, points and irregularities in the track is of paramount importance. Because reciprocating power has to be directly applied to the rail from 0 rpm upwards, this poses unique problems of "adhesion" of the driving wheels to the smooth rail surface. Adhesive weight is the portion of the locomotive's weight bearing on the driving wheels. This is made more effective if a pair of driving wheels is able to make the most of its "axle load" i.e. its individual share of the adhesive weight. Locomotives with "compensating levers" connecting the ends of plate springs have often been deemed a complication but locomotives fitted with them have usually been less prone to loss of traction due to wheel-slip.

Locomotives with total adhesion, *i.e.* where all the wheels are coupled together, generally lack stability at speed. This makes desirable the inclusion of unpowered carrying wheels mounted on two-wheeled trucks or four-wheeled bogies centred by springs that help to guide the locomotive through curves. These usually take the weight of the cylinders in front or of the firebox at the rear end when the width of this exceeds that of the mainframes. For multiple coupled wheels on a rigid chassis a variety of systems for controlled side-play exist.

Railroads typically wanted a locomotive with as few axles as possible. This would reduce the cost of maintenance. The number of axles required was dictated by the maximum axle loading of the railroad in question. A builder would typically add axles until the maximum weight on any one axle was acceptable to the railroad's maximum axle loading. A locomotive with a wheel arrangement of two lead axles, two drive axles, & one trailing axle was in actuality a high speed machine. Two lead axles were necessary to have good tracking at high speeds. Two drive axles had a lower reciprocating mass than three, four, five, or six coupled axles. They were thus able to turn very high speeds due to the lower reciprocating mass. A trailing axle was able to support a huge firebox. Hence most locomotives with the wheel arrangement of 4-4-2 (American Type Atlantic) were "free steamers" able to maintain steam pressure regardless of throttle setting.

Fuel and water

Water gauge. Here the water in the boiler is at the "top nut", the maximum working level.

Generally, the largest locomotives are permanently coupled to a tender that carries the water and fuel. Alternatively, locomotives working shorter distances carry the fuel in a bunker, and the water in tanks mounted on the engine, the latter placed either alongside the boiler or on top of it; these are called tank engines.

The fuel used depended on what was economically available to the railway at the time. In the UK and parts of Europe, plentiful supplies of coal made this the obvious choice from the earliest days of the steam engine. Until 1870 [14] the majority of locomotives in the USA burnt wood, but as the Eastern forests were cleared, coal gradually became more important. Thereafter, coal became and remained the dominant fuel worldwide until the end of general use of steam locomotives. Bagasse, a waste by-product of the refining process, was burned in sugar cane farming operations. In the USA, the ready availability of oil made it a popular steam locomotive fuel after 1900 for the southwestern railroads, particularly the Southern Pacific. In Victoria, Australia after World War II, many steam locomotives were converted to heavy oil firing. German, Russian, Australian and British railways experimented using coal dust to fire locomotives.

A number of tourist lines and heritage locomotives in Switzerland, Argentina and Australia have been using light diesel-type oil.[15]

Water was supplied at stopping places and locomotive depots from a dedicated water tower connected to water cranes or gantries. In the UK, the USA and France, water troughs (US track pans) were provided on some main lines to allow locomotives to replenish their water supply without stopping. This was achieved by using a 'water scoop' fitted under the tender or the rear water tank in the case of a large tank engine; the fireman remotely lowered the scoop into the trough, the speed of the engine forced the water up into the tank, and the scoop was raised again once it was full.

"Water is an essential element in the operation of a steam locomotive"
Here a locomotive is "taking-on water" – having its tanks refilled using a water crane.

Water is an essential element in the operation of a steam locomotive; because as Swengel argued:

> it has the highest specific heat of any common substance; that is more thermal energy is stored by heating water to a given temperature than would be stored by heating an equal mass of steel or copper to the same temperature. In addition, the property of vapourising (forming steam) stores additional energy without increasing the temperature...water is a very satisfactory medium for converting thermal energy of fuel into mechanical energy

Swengel went on to note that "at low temperature and relatively low boiler outputs" good water and regular boiler washout was an acceptable practise, even though such maintenance was high. As steam pressures increased, however, a problem of "foaming" or "priming" developed in the boiler, wherein dissolved solids in the water formed "tough-skinned bubbles" inside the boiler, which in turn were carried into the steam pipes and could blow off the cylinder heads. To overcome the problem, hot mineral concentrated water was deliberately wasted (blowing down) from the boiler from time to time. Higher steam pressures required more blowing down of water out of the boiler. Oxygen generated by boiling water attacks the boiler and with increased steam pressures the rate of rust (iron oxide) generated inside the boiler increases. One way to help overcome the problem was water treatment. Swengel suggested that the problems around water contributed to the interest in electrification of railways.[16]

In the 1970s L.D. Porta developed a sophisticated heavy duty chemical water treatment that not only keeps the inside of the boiler clean and prevents corrosion, but modifies the foam in such a way as to form a compact "blanket" on the water surface that filters the steam as it is produced, keeping it pure and preventing carry-over into the cylinders of water and suspended abrasive matter.

Crew

A steam locomotive is normally controlled from the backhead of the firebox and the crew is usually protected from weather by a cab. A crew of at least two people is normally required to operate a steam locomotive. One, the driver (US: engineer), is responsible for controlling the locomotive's starting, stopping and speed and the fireman is responsible for the fuel for the fire, steam pressure, and water levels in the boiler and storage tank(s). Due to the historical loss of operational infrastructure and staffing, preserved steam locomotives operating on the mainline will often have a support crew travelling with the train.

Fittings and appliances

All locomotives are fitted with a variety of appliances. Some of these relate directly to the operation of the steam engine; while others are for signalling, train control, or other purposes. In the United States the Federal Railroad Administration mandated the use of certain appliances over the years in response to safety concerns. The most typical appliances are as follows:

Steam pumps and injectors

Water must be forced into the boiler, to replace that which is exhausted after delivering a working stroke to the pistons. Early engines used pumps driven by the motion of the pistons. Later steam injectors replaced the pump, while some engines use turbopumps. Standard practice evolved to use two independent systems for feeding water to the boiler. Vertical glass tubes, known as water gauges or water glasses, show the level of water in the boiler.

Boiler lagging

Large amounts of heat are wasted if a boiler is not insulated. Early locomotives used shaped wooden battens fitted lengthways along the boiler barrel and held in place by metal bands. Improved insulating methods included: applying a thick paste containing a porous mineral, such as kieselgur or shaped blocks of insulating compound such as magnesia blocks[17] were attached. In the latter days of steam, "mattresses" of stitched asbestos cloth were fixed stuffed with asbestos fibre (but on separators so as not quite to touch the boiler); however in most countries, asbestos is nowadays banned for health reasons. The most common modern day material is glass wool, or wrappings of aluminium foil.

The lagging is protected by a close-fitted sheet-metal casing[18] known as boiler clothing or cleading.

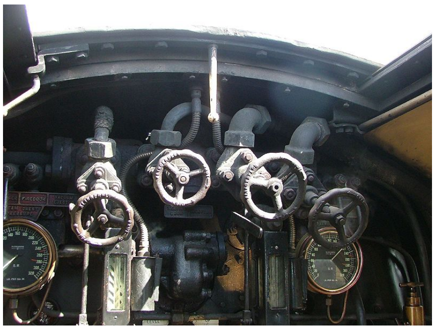
Effective lagging is particularly important for fireless locomotives; however in recent times under the influence of L.D. Porta, "exaggerated" insulation has been practised for all types of locomotive on all surfaces liable to dissipate heat, such as cylinder ends and facings between the cylinders and the mainframes. This considerably reduces engine warmup time with marked increase in overall efficiency.

Safety valves

The boiler safety valves lifting on 60163 *Tornado* creating a false smoke trail

Early locomotives were fitted with a valve controlled by a weight suspended from the end of a lever, the steam outlet being stopped by a cone-shaped valve. As there was nothing to prevent the weighted lever from bouncing when the locomotive ran over irregularities in the track, thus wasting steam, the weight was replaced by a more stable spring loaded column, often supplied by Salter, a well-known spring scale manufacturer. The danger of all these devices was that the driving crew could be tempted to add weight to the arm in order to increase pressure; most boilers were therefore from early times fitted with a tamper-proof "lockup" direct-loaded ball valve protected by a cowl. In the late 1850s, John Ramsbottom introduced an ingenious safety valve that became very popular in Britain during the latter part of the 19th Century. Not only was this valve tamper-proof, but any intervention on the part of the driver could only have the effect of easing pressure. Richardson's "pop" valve was an American invention introduced in 1867[19] and was so designed as to release the steam only at the moment when the pressure attained the maximum permitted. This type of valve is in almost universal use at present. The British Great Western Railway was a notable exception to this rule retaining the direct loaded type until the end of its separate existence because it was considered that such a valve lost less pressure between opening and closing.

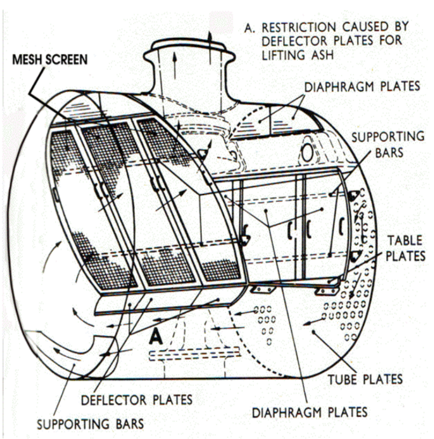
Pressure gauge



Pressure gauges on *Blackmore Vale*. The right-hand one shows boiler pressure, the one on the left steam chest pressure

The earliest locomotives did not show the pressure of steam in the boiler, but it was possible to estimate this by the position of the safety valve arm which often extended onto the firebox back plate; gradations marked on the spring column gave a rough indication of the actual pressure. The promoters of the Rainhill trials urged that each contender have a proper mechanism for reading the boiler pressure and Stephenson devised a nine-foot vertical tube of mercury with a sight-glass at the top, mounted alongside the chimney, for the Rocket. The Bourdon tube gauge, in which the pressure straightens an oval-section, coiled tube of brass or bronze connected to a pointer, was introduced in 1849 and quickly gained acceptance. This is the device used today.[20] Some locomotives have an additional pressure gauge in the steam chest. This helps the driver avoid wheel-slip at startup, by warning if the regulator opening is too great.

Spark arrestor and self cleaning smokebox



Typical self-cleaning smokebox design

Wood-burners emit large quantities of flying sparks which necessitate an efficient spark arresting device generally housed in the smokestack. Many types were fitted,[21] the most common early type being the Bonnet stack that incorporated a cone-shaped deflector placed before the mouth of the chimney pipe plus a wire screen covering the wide stack exit; more efficient was the Radley and Hunter centrifugal type patented in 1850, (generally known as the diamond stack) incorporating baffles so orientated as to induce a swirl effect in the chamber that encouraged the embers to burn out and fall to the bottom as ash. In the self-cleaning smokebox the opposite effect was achieved: by allowing the flue gasses to strike a series of deflector plates, angled in such a way that the blast was not impaired, the larger particles were broken into small pieces that would be ejected with the blast, rather than settle in the bottom of the smokebox to be removed by hand at the end of the run. As with the arrestor, a screen was incorporated to retain any large embers.[22]

Locomotives of the British Railways standard classes fitted with self-cleaning smokeboxes were identified by a small cast oval plate marked "S.C.", fitted at the bottom of the smokebox door. These engines required different disposal procedures and the 'S.C.' plate highlighted this need to depot staff.

Stokers

A factor that limits locomotive performance is the rate at which fuel is fed into the fire. In the early 20th century some locomotives became so large, that the fireman could not shovel coal fast enough.[18] In the United States, various steam-powered mechanical stokers became standard equipment and were adopted and used elsewhere including Australia and South Africa.

Feedwater heating

Introducing cold water into a boiler reduces power, and from the 1920s a variety of heaters were incorporated. The most common type for locomotives was the exhaust steam feedwater heater that piped some of the exhaust through small tanks mounted on top of the boiler or smokebox or else into the tender tank; the warm water then had to be delivered to the boiler by a small auxiliary steam pump. The rare economiser type differed in that it extracted residual heat from the exhaust gases. An example of this is the pre-heater drum(s) found on the Franco-Crosti boiler.

The use of live steam and exhaust steam injectors also assists in the pre-heating of boiler feed water to a small degree, though there is no efficiency advantage to live steam injectors. Such pre-heating also reduces the thermal shock that a boiler might experience when cold water is introduced directly. This is further helped by the top feed where water is introduced to the highest part of the boiler and made to trickle over a series of trays. G.J. Churchward fitted this arrangement to the high end of his domeless coned boilers Other British lines such as the LBSCR fitted a few locomotives with the top feed inside a separate dome forward of the main one.

Condensers and water re-supply


The conventional means of watering a locomotive was by refilling its tender or tank, from trackside water towers or standpipes.

Steam locomotives consume vast quantities of water because they operate on an open cycle, expelling their steam immediately after a single use rather than recycling it in a closed loop as stationary and marine steam engines do. Water was a constant logistical problem, and in some desert areas condensing engines were devised. These engines had huge radiators in their tenders and instead of exhausting steam out of the funnel it was captured and passed back to the tender and condensed. The cylinder lubricating oil was removed from the exhausted steam to avoid a phenomenon known as priming, a condition caused by foaming in the boiler which would allow water to be carried into the cylinders causing damage because of its incompressibility. The most notable engines employing condensers (Class 25, the "puffers which never puff"[23]) worked across the Karoo desert of South Africa, from the 1950 until the 1980s.

Some British and American locomotives were equipped with scoops which collected water from "water troughs" (US: "track pans") while in motion, thus avoiding stops for water. In the US, small communities often did not have refilling facilities. During the early days of railroading, the crew simply stopped next to a stream and filled the tender using leather buckets. This was known as “jerking water” and led to the term "jerkwater towns" (meaning a small town, a term which today is considered derisive).[24] In Australia and South Africa, locomotives in drier regions operated with large oversized tenders and some even had an additional water wagon, sometimes called a "canteen" or in Australia (particularly in New South Wales) a "water gin".

Steam locomotives working on underground railways (such as London's Metropolitan Railway) were fitted with condensing apparatus for a different, but obvious, reason. These were still being used between King's Cross and Moorgate into the early 1960s.

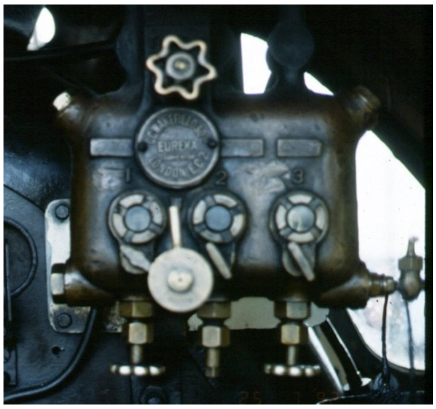
Braking

Locomotives have their own braking system, independent from the rest of the train. Locomotive brakes employ large shoes which press against the driving wheel treads. With the advent of air brakes, a separate system also allowed the driver to control the brakes on all cars. These systems require steam-powered compressors, which are mounted on the side of the boiler or on the smokebox front. Almost all of these compressors were of the Westinghouse single-stage or cross-compound variety. Such systems operated in the United States, Canada, Australia and New Zealand.

An alternative to the air brake is the vacuum brake, in which a steam-operated ejector is mounted on the engine instead of the air pump, to create vacuum and release the brakes. A secondary ejector or crosshead vacuum pump is used to maintain the vacuum in the system against the small leaks in the pipe connections between carriages and wagons. Vacuum systems existed on British, Indian and South African rail networks.

Steam locomotives are nearly always fitted with sandboxes from which sand can be delivered to the rails to improve traction and braking in wet or icy weather. On American locomotives the sandboxes, or sand domes, are usually mounted on top of the boiler. In Britain, the limited loading gauge precludes this, so the sandboxes are mounted just above, or just below, the running plate.

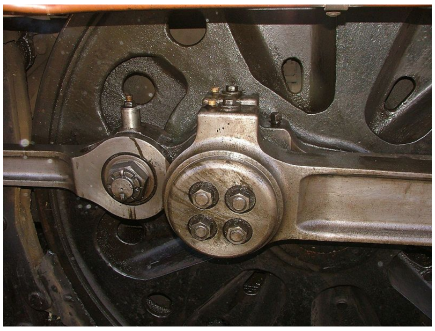
Lubrication



“Wakefield” brand displacement lubricator mounted on a locomotive boiler backplate. Through the right-hand sight glass a drip of oil (travelling upwards through water) can be seen.

The pistons and valves on the earliest locomotives were lubricated by the enginemen dropping a lump of tallow down the blast pipe.[25]

As speeds and distances increased, mechanisms were developed that injected thick mineral oil into the steam supply. The first, a displacement lubricator, mounted in the cab, uses a controlled stream of steam condensing into a sealed container of oil. Water from the condensed steam displaces the oil into pipes. The apparatus is usually fitted with sight-glasses to confirm the rate of supply. A later method uses a mechanical pump worked from one of the crossheads. In both cases, the supply of oil is proportional to the speed of the locomotive.



Big-end bearing (with connecting rod and coupling rod) of Blackmoor Vale showing pierced cork stoppers to oil reservoirs.

Lubricating the frame components (axle bearings, horn blocks and bogie pivots) depends on capillary action: trimmings of worsted yarn are trailed from oil reservoirs into pipes leading to the respective component.[26] The rate of oil supplied is controlled by the size of the bundle of yarn and not the speed of the locomotive, so it is necessary to remove the trimmings (which are mounted on wire) when stationary. However, at regular stops (such as a terminating station platform) oil finding its way onto the track can still be a problem.

Crank pin and crosshead bearings carry small cup-shaped reservoirs for oil. These have feed pipes to the bearing surface that start above the normal fill level, or are kept closed by a loose-fitting pin, so that only when the locomotive is in motion does oil enter. In United Kingdom practice the cups are closed with simple corks, but these have a piece of porous cane pushed through them to admit air. It is customary for a small capsule of pungent oil (aniseed or garlic) to be incorporated in the bearing metal to warn if the lubrication fails and excess heating or wear occurs.[27]

Blower

When the locomotive is running under power, a draught on the fire is created by the exhaust steam directed up the chimney by the blastpipe. Without draught, the fire will quickly die down and steam pressure will fall. When the locomotive is stopped, or coasting with the regulator closed, there is no exhaust steam to create a draught, so the draught is maintained by means of the *blower*. This is a ring placed either around the base of the chimney, or around the blast pipe orifice, containing several small steam nozzles directed up the chimney. These nozzles are fed with steam directly from the boiler, controlled by the *blower valve*. When the regulator is open, the blower valve is closed; when the driver intends to close the regulator, he will first open the blower valve. It is important that the blower be opened before the regulator is closed, since without draught on the fire, there may be backdraught – air from the atmosphere blows down the chimney, causing the flow of hot gases through the boiler tubes to be reversed, with the fire itself being blown through the firehole onto the footplate, with serious consequences for the crew. The risk of backdraught is higher when the locomotive enters a tunnel because of the pressure shock. The blower is also used to create draught when steam is being raised at the start of the locomotive's duty; at any time when the driver needs to increase the draught on the fire; and to clear smoke from the driver's line of vision.[28]

Buffers

In British and European practice, the locomotive usually had buffers at each end to absorb compressive loads ("buffets"[29]). The tensional load of drawing the train (draft force) is carried by the coupling system. Together these control slack between the locomotive and train, absorb minor impacts, and provide a bearing point for pushing movements.

In American practice all of the forces between the locomotive and cars are handled through the coupler and its associated draft gear, which allows some limited slack movement. Small dimples called "poling pockets" at the front and rear corners of the locomotive allowed cars to be pushed on an adjacent track using a pole braced between the locomotive and the cars. In Britain and Europe, American style 'buckeye' and other couplers that also handle forces between items of rolling stock have become increasingly popular.

Pilots

A pilot was usually fixed to the front end of locomotives, although in European and a few other railway systems, such as New South Wales, they were considered unnecessary. Plough-shaped, and called cow catchers, they were quite large and were designed to remove obstacles from the track such as cattle, bison, other animals or tree limbs. Though unable to "catch" stray cattle these distinctive items remained on locomotives until the end of steam. Switching engines usually replaced the pilot with small steps, known as *footboards*. Many systems used the pilot and other design features to produce a distinctive appearance.

Headlights

When night operations began, railway companies in some countries equipped their locomotives with lights to allow the driver to see what lay ahead of the train or to enable others to see the locomotive. Originally headlights were oil or acetylene lamps, but when electric arc lamps became available in the late 1880s, they quickly replaced the older types.

Preserved GWR locomotive *Bradley Manor*, with two oil lamps signifying an express passenger service, and between them a high-intensity electric lamp, added to comply with modern safety standards for mainline running.

Britain did not adopt bright headlights as they would affect night-adapted vision and so could mask the low-intensity oil lamps used in the semaphore signals and at each end of trains, increasing the danger of missing signals especially on busy tracks. In any case, trains' stopping distances were normally much greater than the range of headlights, and the railways were well-signalled and fully fenced to prevent livestock and people from straying onto them. Thus low-intensity oil lamps continued to be used, positioned on the front of locomotives to indicate the class of each train. Four 'lamp irons' were provided (brackets on which to place the lamps): one below the chimney and three evenly-spaced across the top of the buffer beam. The exception to this was the Southern Railway and its constituents, who added an extra lamp iron each side of the smokebox, and the arrangement of lamps (or in daylight, white circular plates) told railway staff the origin and destination of the train. (In all cases, equivalent lamp irons were also provided on the rear of the locomotive or tender for when the locomotive was running tender- or bunker-first.)

In some countries heritage steam operation continues on the national network. Some railway authorities have mandated powerful headlights on at all times, including during daylight. This was to further inform the public or track workers of any active trains.

Bells and whistles

Locomotives used bells and steam whistles from earliest days. In the United States, India and Canada bells warned of a train in motion. In Britain, where all lines are by law fenced throughout,[30] bells were only a requirement on railways running on a road (i.e., not fenced off), for example a tramway along the side of the road or in a dockyard. Consequently only a minority of locomotives in the UK carried bells. Whistles are used to signal personnel and give warnings. Depending on the terrain the locomotive was being used in the whistle could be designed for long distance warning of impending arrival, or more for localised use.

Early bells and whistles were sounded through pull-string cords and levers. Automatic bell ringers came into widespread use in the U.S. after 1910.[31]

Automatic control

This is a typical AWS *Sunflower* indicator. the Sunflower indicator can show a black disk or a yellow and black "exploding" disk.

From early in the twentieth century operating companies in such countries as Germany and Britain began to fit locomotives with in-cab signalling (AWS) which automatically applied the brakes when a signal was passed at "caution". In Britain these became mandatory in 1956.

Booster engines

In the United States and Australia the trailing truck was often equipped with an auxiliary steam engine which provided extra power for starting. This booster engine was set to cut out automatically at a certain speed. On the narrow gauged New Zealand railway system, six Kb 4-8-4 locomotives had boosters; the only 3 ft 6 in (1067 mm) gauge engines in the world to have such equipment.

Variations

Numerous variations to the simple locomotive occurred as railways attempted to develop more powerful, more efficient and fast steam locomotives.

Cylinders

Some locomotives received extra cylinders and experiments combined two locomotives in one (e.g. the Mallet and Garratt locomotives). Some locomotives carried their cylinders vertically alongside the boiler and drove the wheels through a system of shafts and gears (e.g. the Shay locomotive; see "geared steam locomotive").

From about 1930, most new British express passenger locomotives were 4-6-0 or 4-6-2 types with three or four cylinders. Examples include:

- GWR 6000 Class, four-cylinder 4-6-0s
- LMS Coronation Class, four-cylinder 4-6-2s
- SR West Country and Battle of Britain Classes, three cylinder 4-6-2s
- LNER Gresley Class A3 and Class A4, three cylinder 4-6-2s
- LNER Peppercorn Class A1, three cylinder 4-6-2s
- GWR 4073 Class, four-cylinder 4-6-0s
- LMS Royal Scot Class, three-cylinder 4-6-0s

Cab forward

In the United States on the Southern Pacific Railroad a series of cab forward locomotives had the cab and the firebox at the front of the locomotive and the tender behind the smokebox, so that the engine appeared to run backwards. This was only possible by using oil-firing. Southern Pacific selected this design to provide smoke-free breathing for the locomotive's engineer as they went through the SP's numerous mountain tunnels and snow sheds. Another variation was the Camelback locomotive with the cab half-way along the boiler. In England, Oliver Bulleid developed the SR Leader Class locomotive during the nationalisation process in the late 1940s. The locomotive was heavily tested but several design faults (like coal firing and sleeve valves) meant this locomotive and the other part-built locomotives were scrapped. The cab-forward design was taken by Bulleid to Ireland when he moved to after nationalisation where he developed the 'turfburner'. This locomotive was more successful but was scrapped with the dieselisation of the Irish railways.

The only preserved cab forward locomotive is Southern Pacific 4294 in Sacramento, California, US.

Steam turbines

Steam turbines were one of the experiments in improving the operation and efficiency of steam locomotives. Experiments with steam turbines using direct-drive and electrical transmissions, in different countries, proved mostly unsuccessful.[18] The LMS also built Turbomotive, a largely successful attempt to prove the efficiency of steam turbines.[18] Had it not been for the outbreak of WW2, more may have been built. The Turbomotive ran from 1935–49, when it was rebuilt into a conventional locomotive because replacement of many parts was required, an uneconomical proposition for a 'one-off' locomotive. In the United States the Union Pacific, Chesapeake and Ohio, and Norfolk & Western railways all built turbine-electric locomotives. The Pennsylvania Railroad (PRR) also built turbine locos but with a direct-drive gearbox. However, all designs failed due to dust, vibration, design flaws, or inefficiency below speed. The last one in service was the N&W's being retired in January 1958. The only truly successful design was the TGOJ MT3, used for hauling Iron ore from Grängesberg to the ports of Oxelösund. Technically well-working, only three were built. Two of them are saved in working order at museums in Sweden

Valve gear

Numerous technological advances improved the steam engine. Early locomotives used simple valve gear that gave full power in either forward or reverse.[20] Soon Stephenson valve gear allowed the driver to control cut-off; this was largely superseded by Walschaerts valve gear and similar patterns. Early locomotive designs using slide valves and outside admission were easy to construct, but inefficient and prone to wear.[20] Eventually, slide valves were superseded by inside admission piston valves, though there were attempts to apply poppet valves (common by then on stationary engines) in the 20th century. Stephenson valve gear was generally placed within the frame and was difficult to access for maintenance; later patterns applied outside the frame, were readily visible and maintained.

Compounding

From 1876, compound locomotives came on the scene, which used the engine's steam twice. There were many compound locomotives especially where long periods of continuous efforts were needed. Compounding was an essential ingredient of the quantum leap in power achieved by André Chapelon's rebuilds from 1929. A common application was to articulated locomotive, the most common being that of Anatole Mallet in which the high pressure stage was attached directly to the boiler frame; in front of this was pivoted a low pressure engine on its own frame, taking the exhaust from the rear engine.[32]

Articulated and Duplex types

Articulation itself proved very popular, and there were numerous variations, both compound and simple. Duplex locomotives with two engines in one rigid frame were also tried, but were not notably successful. For example, the 4-4-4-4 Pennsylvania Railroad's T1 class, designed for very fast running, suffered recurring and ultimately unfixable slippage problems throughout their careers.[33]

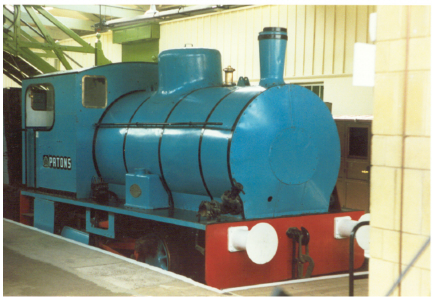
Hybrid power

Mixed power locomotives, utilising steam and diesel propulsion, have been produced in Russia, Britain and Italy.

Under severely unusual conditions (lack of coal, plenty of hydroelectricity) some locomotives in Switzerland were modified to use electricity to heat the boiler, making them electric-steam locomotives.[34]

Fireless locomotive

In a fireless locomotive the boiler is replaced by a steam accumulator which is charged with steam from a stationary boiler. Fireless locomotives were used where there was a high fire risk (e.g. in oil refineries) or where cleanliness was important (e.g. in food factories).


Fireless locomotive

Manufacture

Most Manufactured Classes

The largest single class of steam locomotive in the world is the 0-10-0 Russian / Soviet Class E steam locomoive with around 11,000 manufactured both in Russia and other countries such as Czechoslovakia, Germany, Sweden, Hungary and Poland. This class even far outnumbered the German DRB Class 52 2-10-0 Kriegslok which consisted of approximate 7000 units. The British LMS Stanier Class 5 4-6-0 (Black Five) steam locomotive numbered 842 units. .

United States

Railroad locomotive engines in the United States have nearly always been built in and for United States railroads with very few imports. This is true because of the basic differences of markets in the United States which initially had many small markets located large distances apart; much different than Europe's much higher density markets. Locomotives that were cheap and rugged and could go over large distances over cheaply built and maintained tracks were the early requirements. Once the manufacture of engines was established on a wide scale there was very little advantage to buying an engine somewhere else that would have to be customized anyway to fit the local requirements and track conditions. Improvements in engine design of both European and U.S. origin could be and were incorporated by manufacturers when they could be justified in a generally very conservative and slow changing market. With the notable exception of the USRA standard locomotives, set during WW1, in the United States, steam locomotive manufacture was always semi-customised. Railroads ordered locomotives tailored to their specific requirements, though basic design features were always present. Railroads developed some specific characteristics; for example, the Pennsylvania Railroad and the Great Northern had a preference for the Belpaire firebox,[35] while the Delaware and Hudson Railroad was famous for its elaborately flanged smokestacks. In the United States, large scale manufacturers constructed locomotives for nearly all rail companies, although nearly all major railroads had shops capable of heavy repairs and some railroads (for example the Norfolk and Western Railway) constructed complete locomotives in their own shops. Companies Manufacturing locomotives in the US included Baldwin

Locomotive Works, American Locomotive Works (ALCO), Lima Locomotive Works, and others. It was not uncommon for an entire group of locomotives to be sold from one railroad to another.

Steam locomotives required regular, and compared to a Diesel-Electric Engine, frequent service and overhaul (often at government-regulated intervals in Europe). Many alterations and upgrades regularly occurred during overhauls. New appliances were added, unsatisfactory features removed, cylinders improved or replaced. Almost any part of the locomotive, including boilers were replaced or upgraded. When the service or upgrades got too expensive the locomotive was traded off or retired. On the Baltimore and Ohio Railroad two 2-10-2 locomotives were dismantled; the boilers were placed onto two new Class T 4-8-2 locomotives and the residue wheel machinery made a pair of Class U 0-10-0 switchers with new boilers. Union Pacific's fleet of 3 cylinder 4-10-2 engines were converted into two cylinder engines in 1942, because of high maintenance problems.

Great Western Railway No. 6833 *Calcot Grange*, a 4-6-0 Grange class steam locomotive, at Bristol Temple Meads station, Bristol, England. Note the Belpaire (square-topped) firebox.

United Kingdom

Before the 1923 Grouping Act, the picture in the UK was mixed. The larger railway companies built locomotives in their own workshops but the smaller ones and industrial concerns ordered them from outside builders. A large market for outside builders was abroad because of the home-build policy exercised by the main railway companies. An example of a pre grouping works was the one at Melton Constable that maintained and built some of the locomotives for the Midland and Great Northern Joint Railway. Other works included one at Boston (an early GNR building) and Horwich works.

Preserved British Railways Standard Class 7MT 4-6-2 70013 *Oliver Cromwell* on the North Norfolk Railway heritage line on 11 March 2010.

Between 1923 and 1947, the "Big Four" railway companies (the Great Western Railway, the London, Midland and Scottish Railway, the London and North Eastern Railway and the Southern Railway) all built most of their own locomotives. Generally speaking, they only bought locomotives from outside builders when their own works were fully occupied (or as a result of government-mandated standardisation during wartime).

From 1948, British Railways allowed the former "Big Four" companies (now designated "Regions") to continue to build their own designs, but also created a range of standard locomotives which supposedly combined the best features from each region. Although a policy of "dieselisation" was adopted in 1955, BR continued to build new steam locomotives until 1960 (the last being named *Evening Star*).

Some independent manufacturers produced steam locomotives for a few more years, the last British-built industrial steam locomotive being constructed by Hunslet in 1971. Since then, a few specialised manufacturers have continued to produce small locomotives for narrow gauge and miniature railways, but as the prime market for these is the tourist and heritage railway sector, the demand for such locomotives is limited. In November 2008, a new new build main line steam locomotive, the 60163 *Tornado*, was tested on UK mainlines for eventual charter and tour use.

Australia

The 200th steam locomotive built by Clyde Engineering (TF 1164) from The Powerhouse Museum collection

In Australia, Clyde Engineering of Sydney and also the Eveleigh Workshops built steam locomotives for the New South Wales Government Railways. These include the C38 class 4-6-2; the first five were built at Clyde with streamlining, the other 25 locomotives were built at Eveleigh (13) in Sydney, and Cardiff Workshops (12) near Newcastle. In Queensland, steam locomotives were locally constructed by Walkers. Similarly the South Australian state government railways also manufactured steam locomotives locally at Islington in Adelaide. The Victorian Railways constructed most of their locomotives at their Newport Workshops and Bendigo while in the early days locomotives were built at the Phoenix Foundry in Ballarat. Locomotives constructed at the Newport shops ranged from the nA class 2-6-2T built for the narrow gauge, up to the H class 4-8-4, the largest conventional locomotive ever to operate in Australia, which weighed 260 tons. However, the title of largest locomotive in Australia goes to the 263-ton NSWGR AD60 class 4-8-4+4-8-4 Garratt (Oberg:1975), which were built by Beyer-Peacock in the United Kingdom.

Sweden

In the 19th century and early 20th century, most Swedish steam locomotives were manufactured in England. But later on, most steam locomotives were built by local factories including NOHAB in Trollhättan and ASJ in Falun. One of the most successful types was the class "B" (4-6-0), inspired by the Prussian class P8. Many of the Swedish steam locomotives were preserved during the Cold War in case of war. During the 1990s, these steam locomotives were sold to non-profit associations or abroad, which is why the Swedish class B, class S (2-6-4) and class E2 (2-8-0) locomotives can now be seen in England, the Netherlands, Germany and Canada.

Categorisation

Steam locomotives are categorised by their wheel arrangement. The two dominant systems for this are the Whyte notation and UIC classification.

The *Gov. Stanford*, a 4-4-0 (in Whyte notation) locomotive typical of 19th century American practice

The Whyte notation, used in most English speaking and Commonwealth countries, represents each set of wheels with a number. Different arrangements were given names which usually reflect the first usage of the arrangement; for instance the "Santa Fe" type (2-10-2) is so called because the first examples were built for the Atchison, Topeka and Santa Fe Railway. These names were informally given and varied according to region and even politics.

The UIC classification is used mostly in European countries apart from the United Kingdom. It designates consecutive pairs of wheels (informally "axles") with a number for non-driving wheels and a capital letter for driving wheels (A=1, B=2 etc.). So a Whyte 4-6-2 designation would be an equivalent to a 2-C-1 UIC designation.

On many railroads, locomotives were organised into classes. These broadly represented locomotives which could be substituted for each other in service, but most commonly a class represented a single design. As a rule classes were assigned some sort of code, generally based on the wheel arrangement. Classes also commonly acquired nicknames, such as 'Pugs', representing notable (and sometimes uncomplimentary) features of the locomotives.[36] [37]

Performance

Measurement

In the steam locomotive era, two measures of locomotive performance were generally applied. At first, locomotives were rated by tractive effort This can be roughly calculated by multiplying the total piston area by 85% of the boiler pressure (a rule of thumb reflecting the slightly lower pressure in the steam chest above the cylinder) and dividing by the ratio of the driver diameter over the piston stroke. However, the precise formula is:

Tractive Effort is defined as the average force developed during one revolution of the driving wheels at the rail head.[16] This is expressed as:

$$t = \frac{cPd^2s}{D}.$$

where d is bore of cylinder (diameter) in inches, s is cylinder stroke, in inches, P is boiler pressure in pound per square inch, D is driving wheel diameter in inches, c is a factor that depends on the effective cut-off.[38] In the US "c" is usually set at 0.85, but lower on engines that have maximum cutoff limited to 50-75%.

It is critical to appreciate the use of the term 'average', as not all effort is constant during the one revolution of the drivers for at some points of the cycle only one piston is exerting turning moment and at other points both pistons are working. Not all boilers deliver full power at starting and also the tractive effort decreases as the rotating speed increases.[16]

Tractive effort is a measure of the heaviest load a locomotive can start or haul at very low speed over the ruling grade in a given territory.[16]

However, as the pressure grew to run faster freight and heavier passenger trains, tractive effort was seen to be an inadequate measure of performance because it did not take into account speed.

Therefore in the 20th century, locomotives began to be rated by power output. A variety of calculations and formulas were applied, but in general railroads used dynamometer cars to measure tractive force at speed in actual road testing. This measure was termed **drawbar horsepower** in the United States and remained the standard measure of performance to the end of mainline usage.

British railway companies have been reluctant to disclose figures for drawbar horsepower and have usually relied on continuous tractive effort instead.

Relation to wheel arrangement

Whyte classification is connected to locomotive performance, but through a somewhat circuitous path. Given adequate proportions of the rest of the locomotive, power output is determined by the size of the fire, and for a bituminous coal-fuelled locomotive, this is determined by the grate area. Modern non-compound locomotives are typically able to produce about 40 drawbar horsepower per square foot of grate. Tractive force, as noted earlier, is largely determined by the boiler pressure, the cylinder proportions, and the size of the driving wheels. However, it is also limited by the weight on the driving wheels (termed **adhesive weight**), which needs to be at least four times the tractive effort.[18]

The weight of the locomotive is roughly proportional to the power output; the number of axles required is determined by this weight divided by the axleload limit for the trackage where the locomotive is to be used. The number of driving wheels is derived from the adhesive weight in the same manner, leaving the remaining axles to be accounted for by the leading and trailing bogies.[18] Passenger locomotives conventionally had two-axle leading bogies for better guidance at speed; on the other hand, the vast increase in the size of the grate and firebox in the 20th century meant that a trailing bogie was called upon to provide support. On the European continent, some use was made of several variants of the *Bissel bogie* in which the swivelling movement of a single axle truck controls the lateral displacement of the front driving axle (and in one case the second axle too). This was mostly applied to 8-coupled express and mixed traffic locomotives and considerably improved their ability to negotiate curves whilst restricting overall locomotive wheelbase and maximising adhesion weight.

As a rule, "shunting engines" (US "switching engines") omitted leading and trailing bogies, both to maximise tractive effort available and to reduce wheelbase. Speed was unimportant; making the smallest engine (and therefore smallest fuel consumption) for the tractive effort paramount. Driving wheels were small and usually supported the firebox as well as the main section of the boiler. Banking engines (US "helper engines") tended to follow the principles of shunting engines, except that the wheelbase limitation did not apply, so banking engines tended to have more driving wheels. In the US, this process eventually resulted in the Mallet type with its many driven wheels, and these tended to acquire leading and then trailing bogies as guidance of the engine became more of an issue.

As locomotive types began to diverge in the late 1800s, freight engine designs at first emphasised tractive effort, whereas those for passenger engines emphasised speed. Over time, freight locomotive size increased, and the overall number of axles increased accordingly; the leading bogie was usually a single axle, but a trailing truck was added to larger locomotives to support a larger firebox that could no longer fit between or above the driving wheels. Passenger locomotives had leading bogies with two axles, fewer driving axles, and very large driving wheels in order to limit the speed at which the reciprocating parts had to move.

In the 1920s the focus in the United States turned to horsepower, epitomised by the "super power" concept promoted by the Lima Locomotive Works, although tractive effort was still the prime consideration after World War One to the end of steam. Freight trains were to run faster; passenger locomotives needed to pull heavier loads at speed. In essence, the size of grate and firebox increased without changes to the remainder of the locomotive, requiring the addition of a second axle to the trailing truck. Freight 2-8-2s became 2-8-4s while 2-10-2s became 2-10-4s. Similarly, passenger 4-6-2s became 4-6-4s. In the United States this led to a convergence on the dual-purpose 4-8-4 and the 4-6-6-4 articulated configuration, which was used for both freight and passenger service.[39] Mallet locomotives went through a similar transformation and evolved from bank engines into huge mainline locomotives with gargantuan fireboxes; their driving wheels being increased in size in order to allow faster running.

The end of steam in general use

The introduction of electric locomotives at the turn of the 20th century and later diesel-electric locomotives spelled the beginning of the end for steam locomotives, although that end was long in coming.[40] As Diesel power, more especially with electric transmission, became more reliable in the 1930s it gained a foothold in North America.[41] The full changeover took place there during the 1950s. In continental Europe large-scale electrification had displaced steam power by the 1970s. Steam had in its favour familiar technology, adapted well to local facilities and consumed a wide variety of fuels; this led to its continued use in many countries to the end of the 20th Century. They have considerably less thermal efficiency than modern diesels, requiring constant maintenance and labour to keep them operational. Water is required at many points throughout a rail network and becomes a major problem in desert areas, as are found in some regions within the United States, Australia and South Africa. In other localities the local water is unsuitable. The reciprocating mechanism on the driving wheels of a two-cylinder single expansion steam locomotive tended to pound the rails (see "hammer blow"), thus requiring more maintenance. Raising steam from coal took a matter of hours which brought serious pollution problems. Coal-burning locomotives required fire cleaning and ash removal between turns of duty. This was all done in the open air by hand in deplorable working conditions. Diesel or electric locomotives, by comparison, drew benefit from new custom built servicing facilities. Finally, the smoke from steam locomotives was deemed objectionable; in fact, the first electric and diesel locomotives were developed to meet smoke abatement requirements[42] although this did not take into account the high level of invisible pollution in diesel exhaust smoke especially when idling. It should also be remembered that the power for electric trains is, for the most part, derived from steam generated in a power station — often fuelled with coal.

US decline


Northwestern Steel and Wire locomotive number 80, July 1964

Mainline diesel-electric locomotives first appeared on the Baltimore and Ohio Railroad, in 1935 as locomotive No. 50. The diesel reduced maintenance costs dramatically, while increasing locomotive availability. On the Chicago, Rock Island and Pacific Railroad the new units delivered over 350000 miles (560000 km) a year, compared with about 120,000–150,000 for a mainline steam locomotive.[18] World War II delayed dieselisation in the U.S.A, but the pace picked up in the 1950s. Among large railroads, the Gulf, Mobile and Ohio Railroad was among the first to completely retire steam power. 1960 is normally considered the last year for regular class 1 Main Line standard gauge steam operations in the United States, with operations on the Grand Trunk Western, Illinois Central, Norfolk and Western, and Duluth Missabe and Iron Range Railroads. The last standard gauge class 1 regular service steam was the was on the Leadville branch of the Colorado and Southern (Burlington Lines) October 11, 1962. The Union Pacific is the only Class I railroad in the U.S. to have never completely dieselized. It has always had at least one operational steam locomotive, Union Pacific 844, on its roster.[43] Some U.S. shortlines continued steam operations into the 1960s, and the Northwestern Steel and Wire mill in Sterling, IL, continued to operate steam locomotives until December 1980.[44] The Silverton branch of the Denver and Rio Grande Western, which in 1982 became the Durango and Silverton Narrow Gauge Railroad, continues to use steam locomotives, as it has since construction in 1882.

Cleaning an "H" class locomotive, Chicago and North Western Railway, 1943

British decline

Trials of diesel locomotives and railcars began in Britain in the 1930s but made only limited progress. One problem was that British diesel locomotives were often seriously under-powered, compared with the steam locomotives against which they were competing.

After 1945, problems associated with post-war reconstruction and the availability of cheap domestic-produced coal kept steam in widespread use throughout the two following decades. However the ready availability of cheap oil led to new dieselisation programmes from 1955 and these began to take full effect from around 1962. Towards the end of the steam era, which came about in 1968, steam motive power was allowed to fall into a dire state of repair; this along with the absence of attention given to the attendant staff working conditions could only accelerate the decline to such a degree that British Railways estimated that its steam locomotives accounted for around four times more in running costs than diesels. The use of steam locomotives in British industry continued on an ever-reducing scale into the late 1980s, but the poor availability of replacement parts, coupled with the decline of the coal mining industry, led to the disappearance of steam power for commercial uses.

Russia

In the USSR, although the first mainline diesel-electric locomotive was built in USSR in 1924, the last steam locomotive (model П36, serial number 251) was built in 1956; it is now in the Museum of Railway Machinery at former Warsaw Rail Terminal, Saint Petersburg. In the European part of the USSR, almost all steam locomotives were replaced by diesel and electric locomotives in the 1960s; in Siberia with its cheap coal, steam locomotives were in active use till the mid-1970s. However, some photographs exist of Russian steam locomotives at work into the 1980s, and many accurate historical records state that Russian Decapods, L-class 2-10-0s, and LV-class 2-10-2s were not retired until 1980-1985, implying that the best of Russian steam, such as the P36 class, remained on the active rosters into the 1990s. Until 1994, Russia had at least 1,000 steam locomotives stored in operable condition in case of "national emergencies" - as a result, more than 200 steam locomotives are still in working condition.


P36-0251 — last steam passenger locomotive built in Russia. Museum in Saint Petersburg

[45] [46] [47] [48]

South Africa

In South Africa an oil embargo combined with an abundance of cheap local coal and a cheap labour force, ensured steam locomotives survived into the 1990s. Locomotive engineer L. D. Porta's designs appeared on a Class 19D engine in 1979, then a former Class 25 4-8-4 engine, became a Class 26, termed the "Red Devil" No. 3450, which demonstrated an improved overall performance with decreased coal and water consumption. The single class 26 locomotive operated until the end of steam. Another class 25NC locomotive, No. 3454, nicknamed the "Blue Devil" because of its colour scheme, received modifications including a most obvious set of double side-by-side exhaust stacks. In southern Natal, two former South African Railway 2 ft (610 mm) gauge NGG16 Garratts operating on the privatised Port Shepstone and Alfred County Railway (ACR) received some L. D. Porta modifications in 1990 becoming a new NGG16A class.[49]

By 1994 almost all commercial steam locomotives were put out of service, although many of them are preserved in museums or at railway stations for public viewing. Today only a few privately owned steam locomotives are still operating in South Africa, namely the ones being used by the 5-star luxury train Rovos Rail, and the tourist trains *Outeniqua Tjoe Choo*, *Apple Express* and (until 2008) *Banana Express*.

China

China continued to build mainline steam locomotives until late in the century, even building a few examples for American tourist operations. China was the last main-line user of steam locomotives, such use ending officially on the Ji-Tong line at the end of 2005. Some steam locomotives are still (2009) in use in industrial operations or in China. Some coal and other mineral operations maintain an active roster of JS, SY, or QJ steam locomotives bought secondhand from China Rail. The last steam locomotives built in China were of the SY 2-8-2 class, built until 1999. The last steam locomotive built in China was SY 1772, finished in 1999. As of 2008, at least five Chinese steam locomotives exist in the United States – 3 QJ's bought by RDC (2 for IAIS and 1 for R.J. Corman), a JS bought by the Boone Scenic Railway, and an SY bought by the NYSW for tourist operations, but re-painted and modified to represent a 1920s era US locomotive.

South Korea

The first steam locomotive in South Korea was the Moga (Mogul?) 2-6-0, followed by Sata, Pureo, Ame, Sig, Mika(USRA Heavy Mikado), Pasi(USRA Light Pacific), Hyeogi, Class 901, Mateo, Sori and Tou. Used until 1967, that locomotive is now in the Railroad Museum.

Other countries

In other countries, the conversion from steam was slower. By March 1973 in Australia, steam had vanished in all states. Diesel locomotives were more efficient and the demand for manual labour for service and repairs was less than steam. Cheap oil had cost advantages over coal.

Reading and Northern Railroad number 425 being readied in Pennsylvania, U.S.A., for the daily tourist train in 1993.

In Finland, the first diesels were introduced in the mid-1950s and they superseded the steam locomotives during the early '60s. The State Railways (VR) operated steam locomotives until 1975.

In Poland, on non-electrified tracks steam locomotives were superseded almost entirely by diesels by the early '90s. A few steam locomotives, however, operate still from Wolsztyn. Although they are maintained operational rather as a means of preserving railway heritage and as a tourist attraction, they do haul regular scheduled trains (mostly to Poznań). Apart from that, numerous railway museums and heritage railways (mostly narrow gauge) own steam locomotives in working condition.

In Germany steam locomotives continue to be used on a daily all-year-round basis on several narrow gauge passenger railways. The largest of these is the Harzer Schmalspur Bahnen network in the Harz Mountains, with dozens of daily trains on several routes.

In France steam locomotives have not been used for commercial services since 24 September 1975.[50]

In Bosnia some steam locomotives are still used for industrial purposes, for example at coal mineyard in Banovići [51] and ArcelorMittal factory in Zenica [52] .

In India steam locomotives were in use until 2000; they were replaced by a combination of diesel and electric locomotives. Steam locomotives from India were then sold to an undisclosed African country. A steam locomotive celebration run was organised between Thane and Mumbai to commemorate the 150th year of railways in India.

Indonesia also has experience with steam locomotives since 1876, and the last locomotives – manufactured by Krupp, Germany, D Series, in 1954 – operated until 1994. In 1994 they were replaced by diesel locomotives. In Sumatra Barat (West Sumatra) and Ambarawa we can find the rack railway track train (with maximum elevated 6% in mountainous area), now operated for tourism only. There are two museums, Taman Mini and Ambarawa (Ambarawa Railway Museum).[53]

Steam Locomotive B-5112 in Ambarawa Railway Museum - Indonesia

Pakistan still has a regular steam locomotive service; a line operates in the North-West Frontier Province and Sindh; It has been preserved as a "nostalgia" service for tourism in exotic locales,[54] indeed it is specifically advertised as being for "steam buffs".[54]

Hopes of revival

Er 774 38 0-10-0 on Steam Special Train in Moscow 11 July 2010

60163 *Tornado*, a new express locomotive built for the British main line, completed in 2008

Dramatic increases in the cost of diesel fuel prompted several initiatives to revive steam power.[55] [56] However none of these has progressed to the point of production, and in the early 21st century steam locomotives operate only in a few isolated regions of the world and in tourist operations. In Germany a small number of fireless steam locomotives are still working in industrial service, e.g. at power stations, where an on-site supply of steam is readily available.

The Swiss company Dampflokomotiv- und Maschinenfabrik DLM AG delivered eight steam locomotives to rack railways in Switzerland and Austria between 1992 and 1996. Four of them are now the main means of traction on the Brienz Rothorn Bahn; the four others were for the Schafbergbahn in Austria, where they run 90% of the trains.

The same company rebuilt a German 2-10-0 locomotive to new standards with modifications such as roller bearings, light oil firing and boiler insulation.[57]

Several heritage railways in the UK have built new steam locomotives in the 1990s and early 2000s. These include the narrow gauge Ffestiniog and Corris railways in Wales. The Hunslet Engine Company was revived in 2005 and is now building steam locomotives on a commercial basis.[58] A standard gauge LNER Peppercorn Pacific "Tornado" was completed at Hopetown Works, Darlington, England and made its first run on 1 August 2008.[59] [60] It entered main line service later in 2008, to great public acclaim. Demonstration trips in France and Germany have been planned.[61] As of 2009 over half-a-dozen projects to build working replicas of extinct steam engines are going ahead, in many cases using existing parts from other types to build them. Examples include BR Class 6MT *Hengist* [62] , BR Class 3MT no. 82045, BR Class 2MT no. 84030,[63] Brighton Atlantic *Beachy Head* [64] , the LMS "Patriot" project, and the GWR "Saint", "County" and "Grange" projects.

In 1980 American financier Ross Rowland established American Coal Enterprises to develop a modernised coal-fired steam locomotive. His ACE 3000 concept attracted considerable attention, but never materialised.[65] [66]

In 1998, in his book "The Red Devil and Other Tales from the Age of Steam" [67][68] , David Wardale put forward the concept of a high speed, high efficiency "Super Class 5 4-6-0" locomotive for future steam haulage of tour trains on UK main lines. The idea was formalized in 2001 by the formation of 5AT Project [69] dedicated to developing and building the 5AT Advanced Technology Steam Locomotive, a project that was still active at the start of 2010.

Steam locomotives in popular culture

Over the years, steam locomotives have become a very popular image in representations of trains. Many toy trains based on steam locomotives are made, thereby making the image iconic with trains to children. Their popularity has lead to steam locomotives being portrayed in fictional works about trains, most notably *The Railway Series* by the Rev W. V. Awdry and *The Little Engine That Could* by Watty Piper. Steam locomotives have also been "stars" in many television shows about trains, such as *Thomas the Tank Engine and Friends*, based on characters from the books by Awdry.

Coins

The Biedermeier Period coin featuring a steam locomotive

The state quarter representing Utah, depicting the golden spike ceremony

Steam locomotives are a main topic for numerous collectors and bullion coins. The recent 20 euro Biedermeier Period coin, minted June 11, 2003, shows on the obverse an early model steam locomotive (the AJAX) on Austria's first railway line, the Kaiser Ferdinand's Nordbahn. The AJAX can still be seen today in the Austrian railway museum.

As part of the 50 State Quarters program, the quarter representing the U.S. state of Utah depicts the ceremony where the two halves of the First Transcontinental Railroad met at Promontory Summit in 1869. The coin recreates a popular image from the ceremony with steam locomotives from each company facing each other while the golden spike is being driven.

See also

General

- History of rail transport
- Timeline of railway history
- Live steam
- Steam locomotive production
- Steam turbine locomotive
- Steam railroad

Types of steam locomotives

- Beyer-Garratt
- Duplex
- Geared steam locomotive
- High pressure steam locomotive
- Mallet
- Steam dummy
- 5AT Advanced Technology Steam Locomotive

Historic locomotives

- Stephenson's Rocket
- Fairy Queen (locomotive)
- Catch me who can
- Invicta (locomotive)
- Tom Thumb (locomotive)
- John Bull (locomotive)
- LMR 57 Lion
- Locomotion No 1
- Novelty (locomotive)
- GKB 671
- City of Truro
- Flying Scotsman
- NYC Niagara
- Mallard (locomotive)
- Evening Star (locomotive)
- Union Pacific 844
- Union Pacific Big Boy
- Tornado (locomotive)

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External links

- TV and Radio programmes from the BBC archives celebrating steam trains [71]
- Database of surviving steam locomotives in North America [72]
- Information on North American steam railroads in operation [73]
- UK heritage railways and preserved locomotives database [74]
- National Preservation. Uk's leading forum on UK heritage railways [75]
- Pages for the British project to build a modern steam locomotive. The Advanced Steam Locomotive. (5AT) [76]
- International Steam Locomotives [77]
- Tracks of Time [78]
- Photos of Steam Locomotives [79] Photos of Steam Locomotives from all over the World

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