

Locomotive Components and Infrastructures



Paul Coronado

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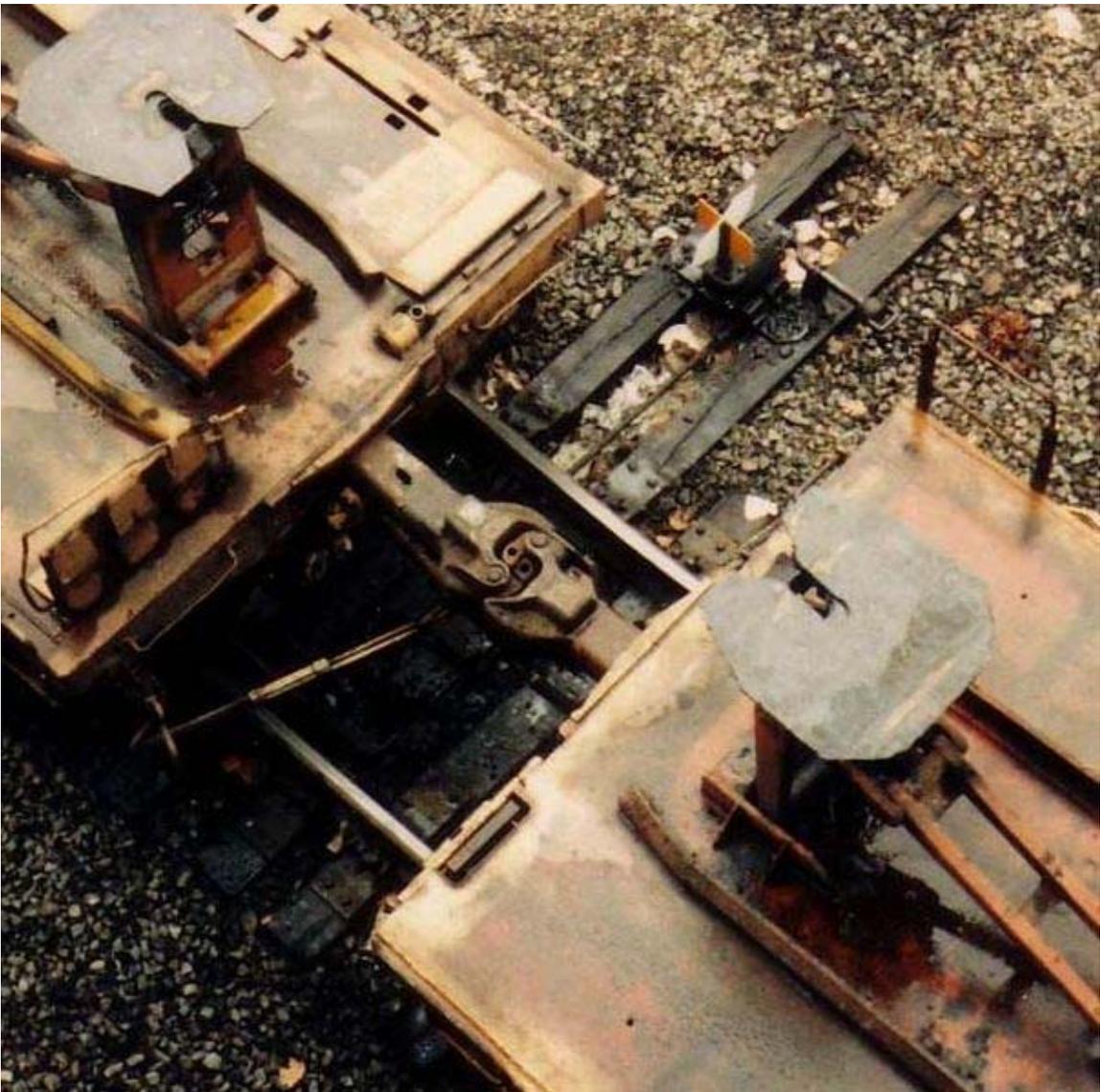
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Chapter 1

Coupling (Railway)



Knuckle (AAR Type "E") couplers in use



ICE coupler

A **coupling** (or a **coupler**) is a mechanism for connecting rolling stock in a train. The design of the coupler is standard, and is almost as important as the railway gauge, since flexibility and convenience are maximised if all rolling stock can be coupled together.

The equipment that connects the couplings to the rolling stock is known as the **draft gear**.

Nomenclature

The different types of coupling do not always have formal or official names, which makes descriptions of the couplings in use on any railway system problematic.

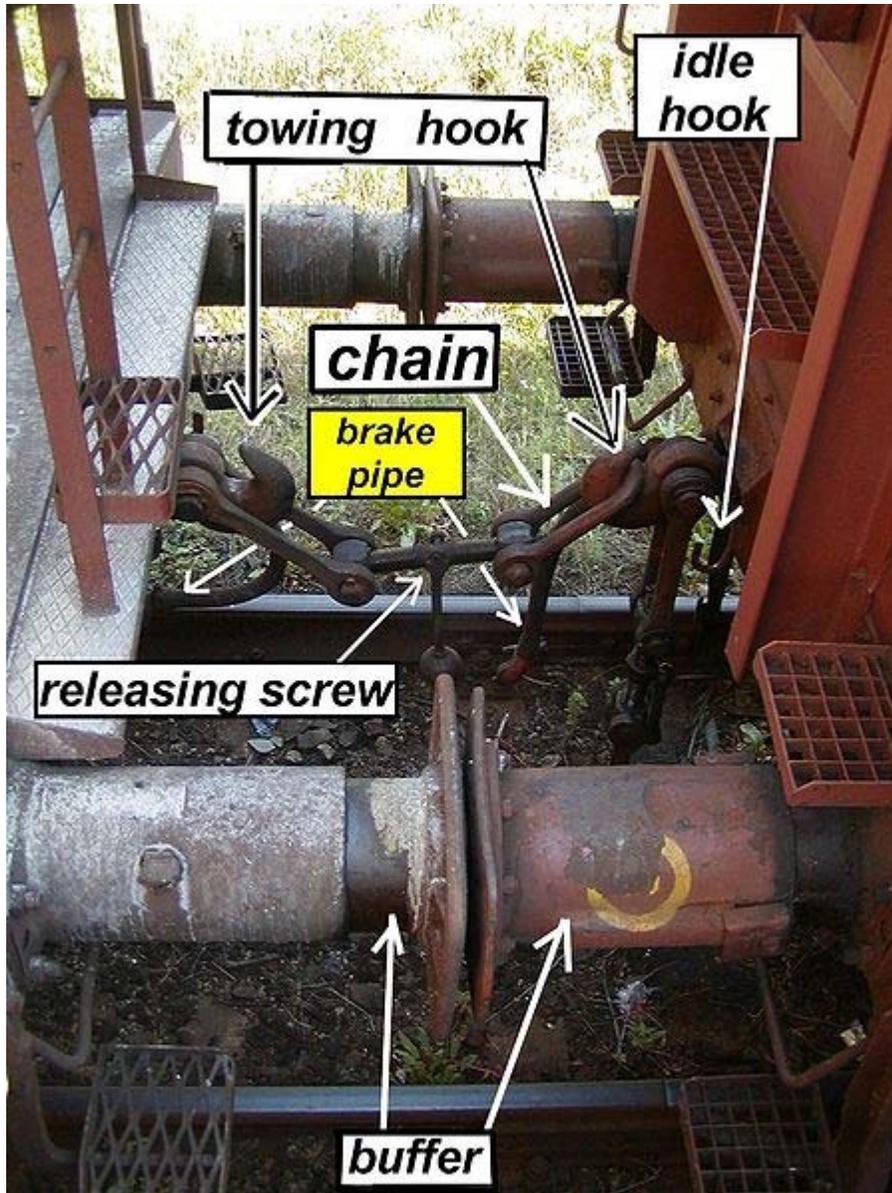
Buffers and chain



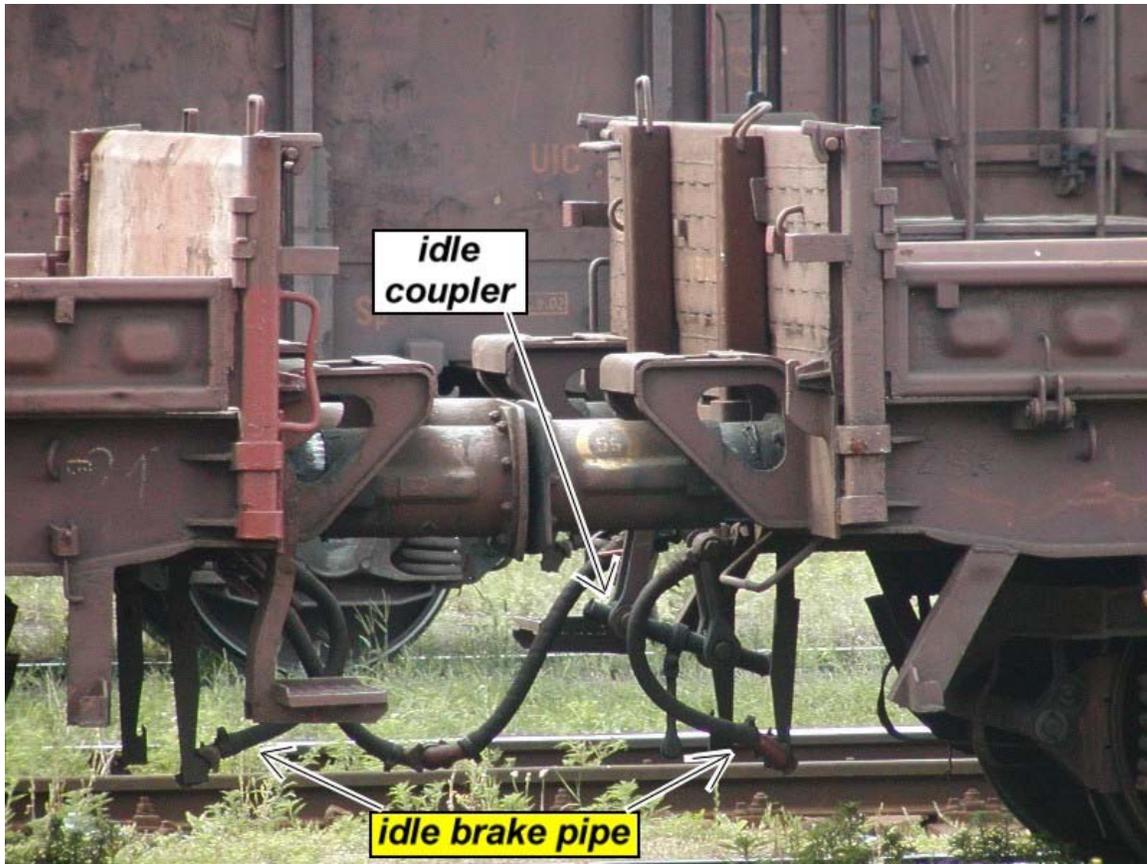
Traditional buffer-and-chain coupler



Two cars coupled



Chain coupler detail (train in shunting mode)



Cars coupled in ride mode

The standard type of coupling on railways following the British tradition is the buffer and chain coupling used on the pioneering Liverpool and Manchester Railway of 1830. These couplings followed earlier tramway practice but were made more regular. The vehicles are coupled by hand using a hook and links with a turnbuckle-like device that draws the vehicles together. In Britain, this is called a *screw coupling*. Vehicles have buffers, one at each corner on the ends, which are pulled together and compressed by the coupling device. This arrangement limits the slack in trains and lessens shocks. In contrast, Janney couplers encourage comparatively violent encounters in order to engage the coupling fully. The earliest buffers were fixed extensions of the wagon frames, but later spring buffers were introduced.

Inefficient and slow, the European system is relatively unsafe because it requires manual coupling between vehicles, exposing workers to the risk of being crushed. However, there is no need for the worker to go between vehicles while they are moving, which is an improvement over the link-and-pin types.

This coupling type is the standard in European countries (except the former Soviet Union, where the SA-3 automatic coupler is used). Coupling is done by a worker, who must climb between the cars. First he turns a releasing screw (an aid with two opposite windings, and it does not uncouple the train itself) to the loose position, and then he can

hang the chain on the hook. After hanging the chain on the towing hook the releasing screw must be turned to the tight position. When the coupler is uncoupled, it must be hung on the idle hook to prevent damage to itself or the brake pipes. Only shunting is permitted with a dangling chain. Disconnected brake pipes must be hung on hooks. (The picture shows two coupled cars, with a single brake pipe.)

The hooks and chain hold the carriages together, while the buffers keep the carriages from banging into each other so that no damage is caused. The buffers can be "dumb" or spring-loaded. That means there are no run-in forces on the coupler. The other benefit compared with automatic couplers is that its lesser slack causes smaller forces on curves; there is a lower probability of a broken coupler in a curve than with automatic couplers. The disadvantage is the smaller mass of the freight that can be hauled by that coupler (maximum 3,000 t/6,613,868 lb).

Early rolling stock was often fitted with a pair of auxiliary chains as a backup if the main coupling failed. This made sense before the fitting of continuous fail-safe braking systems.

On railways where rolling stock always pointed the same way, the chain might be mounted at one end only, as a small cost- and weight-saving method.

On German and Scandinavian railways, the left buffer is flatter than the right one, which is slightly more rounded. This provides better contact between the buffers than would be the case if both buffers were slightly rounded.

Three-link couplings

A peculiarly British institution was the "loose-coupled" freight train. This used three-link chain couplings with no means of drawing the wagons together: since such trains were not fitted with an automatic through-train braking system there were no pipes to connect between the vehicles. The couplings in the train were kept taut by the last vehicle of the train being a heavily ballasted guard's van with its brakes set slightly on. This helped prevent snapped couplings. Such trains travelled at low speeds and were phased out in the 1970s.

An improvement on this is the "Instanter" coupling, in which the middle link of a three link chain is specially shaped so that when lying "prone" it provides enough slack to make coupling possible, but when this middle link is rotated 90 degrees the length of the chain is effectively shortened, reducing the amount of slack without the need to wind a screw. The closeness of the coupling allows the use of inter-vehicle pipes for train brakes. It also has the advantage that it can be operated entirely from the side of the wagons using a shunter's pole and is therefore safer when shunting work is under way. These couplings are still prevalent in UK freight trains today.

Buffers-and-chain on the narrow gauge

Perhaps because of the buffer-locking problem occasioned by sharp curves – and Carl Pihl's successful promotion of the single-buffer Norwegian coupler that he designed to overcome this – conventional buffers-and-chain coupling is rarely employed on narrow-gauge systems: notable exceptions being the railway networks of Senegal/Mali and Côte d'Ivoire/Burkina Faso in Africa, and Queensland and Tasmania in Australia.

Problems with buffers and chain

Buffer-locking

The buffers and chain coupling system has a maximum load much less than that of the Janney coupling. Also, on sharp reverse curves, the buffers can get buffer-locked by slipping over – and onto the back of – an adjacent buffer. Although careful track design makes this occurrence rare, an accident at a Swiss station in the 1980s was caused by buffer-locked wagons. Buffer-lock could be caused on the very sharp turnouts by the older, rounded buffers. The newer buffers are rectangular and they are wider than they are tall. They are not so flat, so they rarely cause buffer-locking.

Variation with gauge



The narrow gauge "buffer-&-chain" coupler, called *Balancierhebelkupplung*

The width between the buffers tends to increase as the gauge increases, so that if wagons are changed from one gauge to another, the buffers will no longer match. This occurs because the buffers are originally extensions of the frames, which are spaced according to the gauge. Conversely, as gauge reduces, the distance between the buffers reduces also. The height of the buffers is usually lower on narrow gauge railways, corresponding to the generally lower height of the rolling stock.

On some narrow-gauge lines in Europe a simplified version is used, consisting of a single central buffer with a chain underneath. Sometimes there are two chains, one on each side of the coupler. The chain usually contains a screw-adjustable link to allow close coupling. On sharp curves, a single centre buffer is less likely to be subject to buffer-locking.

Link and pin



A link-and-pin coupler.

The link-and-pin coupling was the original style of coupling used on American railways, surviving on forestry railways after others converted to Janney couplings. While simple in principle, the link-and-pin coupling suffered from a lack of standardisation regarding size and height of the links.

The link-and-pin coupler consisted of a tubelike body that received an oblong link. During coupling, a railworker had to stand between the cars as they came together and guide the link into the coupler pocket. Once the cars were joined, the employee inserted a

pin into a hole a few inches from the end of the tube to hold the link in place. This procedure was exceptionally dangerous and many brakemen lost fingers or entire hands when they did not get their hands out of the way of the coupler pockets; many more were killed as a result of being crushed between cars or dragged under cars that were coupled too quickly. Brakemen were issued with heavy clubs that could be used to hold the link in position, but many brakemen would not use the club, and risk injury.

The link-and-pin coupler proved unsatisfactory because:

- It made a loose connection between the cars, with too much slack action.
- There was no standard design, and train crews often spent hours trying to match pins and links while coupling cars.
- The links and pins were often pilfered (due to their value as scrap metal), resulting in substantial replacement costs. John H. White suggests that the railroads considered this to be more important than the safety issue at the time.
- Crew members had to go between moving cars during coupling, and were frequently injured and sometimes killed.
- Eventually, railroads wished to operate trains that were heavier than the link-and-pin system could cope with.

An episode of the 1960s TV series *Casey Jones* was devoted to the problems of link-and-pin couplings.

The Miller Hook and Platform

The link and pin was replaced in U.S. passenger car usage during the latter part of the 19th century by the assemblage known as the Miller Platform, which included a new coupler called the Miller Hook. The Miller Platform (and hook coupler) was used for several decades before being replaced by the Janney coupler.

Norwegian



Norwegian coupling fitted to an ex-WDLR Alco from the Froissy Dompierre Light Railway



Norwegian coupling in Uganda

Norwegian (or meat chopper) couplings consist of a central buffer with a mechanical hook that drops into a slot in the central buffer. The Norwegian is found only on narrow gauge railways of 1,067 mm (3 ft 6 in) or less, such as Western Australian Government Railways, the Ffestiniog Railway and the Welsh Highland Railway, where low speeds and reduced train loads allow a simpler system. New Zealand Government Railways, during the 1970s, developed an extremely large and heavy-duty version of the chopper coupler. These were first applied to a fleet of GE locomotives (class Dx) that had arrived from the U.S. with auto couplers, however they were converted once it was decided that these locomotives would operate on other than just the North Island Main Trunk express freight trains. On railway lines where rolling stock always points the same way, the mechanical hook may be provided only on one end of each wagon. This was the situation on the Lynton & Barnstaple (L&B), a narrow gauge line in Devon, England, and still applies to railways in New Zealand. Similarly, the hand brake handles may also be on one side of the wagons only.

Norwegian couplings are not particularly strong, and may be supplemented by auxiliary chains. The L&B originally used side chains in conjunction with Norwegian couplers, but these were found to be unnecessary with the slow speeds employed (10–15 mph/16–24 km/h) and were removed within a year or so of the line opening in 1898.

The Pichi Richi Railway in South Australia uses Norwegian couplers as its standard, and converts Janney coupler to Norwegian as required. The slot in the "buffer beam" where the coupler protrudes appears to be about the same for both types of couplers. As a museum, it is appropriate to use the older type of coupling.

Not all Norwegian couplings are compatible with one another as they vary in height, width, and may or may not be limited to one hook at a time.

Bell

Automatic couplers

There are a number of automatic train couplings, most of which are mutually incompatible.

Janney (AAR) coupler

Later Master Car Builders Association coupler, now AAR (Association of American Railroads) coupler; also known as knuckle coupler and alliance coupler.

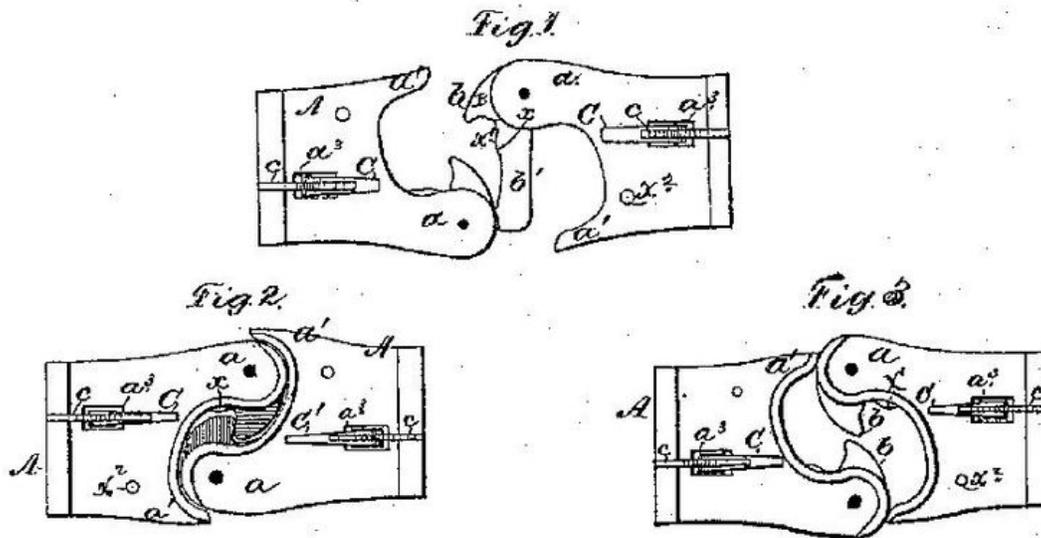


Diagram of the top view of Janney's coupler design as published in his patent application in 1873.

The knuckle coupler or Janney coupler was invented by Eli H. Janney, who received a patent in 1873 (U.S. Patent 138,405). It is also known as a "buckeye coupler", notably in the United Kingdom, where some rolling stock (mostly for passenger trains) is fitted with it. Janney was a dry goods clerk and former Confederate Army officer from Alexandria, Virginia, who used his lunch hours to whittle from wood an alternative to the link and pin coupler. The term Buckeye comes from the nickname of the US state of Ohio, the "Buckeye state" and the Ohio Brass Company which originally marketed the coupling.

In 1893, satisfied that an automatic coupler could meet the demands of commercial railroad operations and, at the same time, be manipulated safely, the United States Congress passed the Safety Appliance Act. Its success in promoting switchyard safety was stunning. Between 1877 and 1887, approximately 38% of all railworker accidents involved coupling. That percentage fell as the railroads began to replace link and pin couplers with automatic couplers. By 1902, only two years after the SAA's effective date, coupling accidents constituted only 4% of all employee accidents. Coupler-related accidents dropped from nearly 11,000 in 1892 to just over 2,000 in 1902, even though the number of railroad employees steadily increased during that decade.

When the Janney coupling was chosen to be the American standard, there were 8,000 patented alternatives to choose from. The only significant disadvantage of using the AAR (Janney) design is that sometimes the drawheads need to be manually aligned.



AAR Type "E" coupler serving as a tow hitch on a mobile crane. Pulling up on the link at the rear releases the knuckle allowing uncoupling.

The AAR coupler is used in Canada, the United States, Mexico, Japan, Australia, South Africa, Saudi Arabia, Cuba, Chile, Brazil, China and elsewhere. Among its features:

- Maximum tonnage as high as 32,000 metric tons (71,000,000 lb) such as on the Fortescue Railway.
- Minimum Ultimate Tensile Strength:
 - Grade E Knuckles: 650,000 pounds-force (2.9 MN)
 - Only Grade C or Grade E Knuckles are permissible in interchange service.
 - Grade E Coupler Bodies: 900,000 pounds-force (4.0 MN)

- Many AAR Coupler designs exist to accommodate requirements of various car designs, but all are required to have certain dimensions in common which allow for one design to couple to any other.
 - Lighter weight railways, especially those of narrow gauge or with no need for Interchange (freight rail) sometimes use smaller (three-quarter- or half-size) versions of the AAR coupling.
- AAR couplers are always right-handed.
- Required Coupler Heights
 - Empty Cars: 33.5 inches (85 cm) +/- 1-inch (2.5 cm)
 - Loaded Cars: 32.5 inches (83 cm) in +/- 1-inch (2.5 cm)
- AAR couplers are uncoupled by lifting the coupling pin with a lever at the corner of the car. This pin is locked when the coupler is under tension, so the usual uncoupling steps are to compress the coupling with a locomotive, lift and hold up the pin, then pull the cars apart. Side operated variants are called the "Sharon coupler" or "Buckeye coupler".
- Trains fitted with AAR couplers can accommodate heavier loads than any other type of coupler. Thus the heaviest coal trains in New Zealand have AAR couplings even though the remainder of the fleet has the "meat chopper" kind. Also, long-distance freight trains in North America are commonly more than 1-mile (1.6 km) long, whereas this is not seen in Europe, where most freight trains still use the buffers and chain system.

Changes since 1873

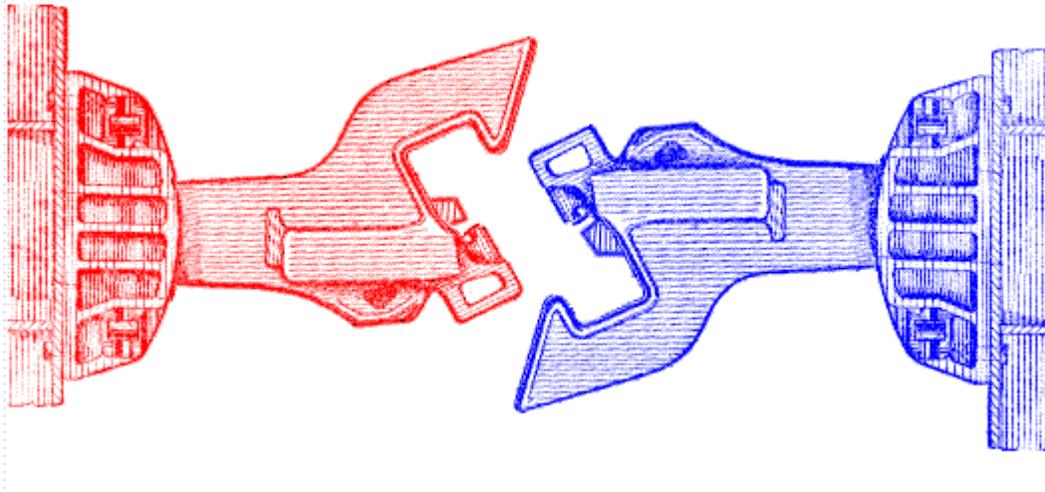


Standard AAR Type E couplers performing their function in a freight train.

The AAR coupler has withstood the test of time since its invention, and has seen only minor changes:

- The current AAR contour dates back to the Master Car Builders Association (MCBA) coupler.
- Buckeye coupler, a side operated version of the MCBA coupler
- Type "E" coupler, the original (plain) AAR coupler, derived from the Master Car Builders Association coupler.
- Type "F" coupler, a "tooth and socket" or "tightlock" variation to prevent accidents, derailments and wrecks from uncoupling the couplers. The "tooth" on a loose coupler could puncture any tank car or other car carrying hazardous materials. Variations on the AAR type "F" coupler have been devised to provide extra protection, in case of derailments and train wrecks, to cars routinely carrying sensitive or hazardous loads. These variations of type "F" couplers, generally involving "shelves", remain fully compatible with standard AAR couplers, but tend to keep derailments and collisions from uncoupling the cars (thereby preventing the "tooth" of the couplers from piercing the ends of the cars).
- The APTA (former AAR) standard type "H" coupler, a "tooth and socket" or "tightlock" variation used mostly, if not exclusively, on passenger cars. The Type "H" coupler is now under the supervision of the APTA (American Public Transportation Association)
- Types "F" and "H" couplers are also known as tightlock couplings.
- "pads" to reduce slack on passenger trains.
- improvement to castings, etc. to increase maximum trailing load.
- rotating-shaft couplers (type "F") introduced for use in rotary car dumpers such as on the Pilbara railways.
- narrow gauge railways such as the Victorian Puffing Billy Railway use a miniature version of the AAR coupler.

SA3 coupler



The simplified scheme of the SA-3 automatic couplers.

The Russian SA3 coupler works according to the same principles as the AAR coupler but is incompatible, it was introduced during the rebuilding of the railway network in Soviet Union after the Second World War and have since been used on the whole broad gauge network, including Finland and Mongolia. It is also used on the normal gauge networks of Iraq and on Malmbanan in Sweden for ore trains.

- Russian trains are rarely longer than about 750 m (2,460 ft) and rarely exceed a maximum tonnage about 6,000 t (13,000,000 lb), so it is not clear what potential load these couplings are capable of. The trains on Malmbanan are about 8,000 t (18,000,000 lb).
- The force to break the SA-3 coupler is about 300 tonnes-force (2.9 MN; 660,000 lbf).
- The maximum allowed tractive effort to the SA-3 is limited to 135 tonnes-force (1.32 MN; 298,000 lbf) by Russian white papers.
- The proposed European automatic coupler is compatible with the Russian coupler but with automatic air, control and power connections. Implementation is permanently delayed except for a few users.

Unicoupler/Intermat

Unicoupler has been developed by Knorr company from Germany in the 1970s and is widely used in Iran in freight cars. this type of coupler is compatible by SA-3 and willison couplers. The Unicoupler is also known as AK69e. The Unicoupler was the West-European development, it was developed in parallel with a compatible East-European counterpart, the Intermat coupler.

C-AKv

The C-AKv coupler is a newer compact willison coupler developed by Faiveley Transport. It is mechanical fully compatible to the SA-3 coupler and the Unicoupler and if additional buffers are mounted it can be coupled with the conventional European screw coupling too.

Other

- Scharfenberg coupler used on electric passenger trains - connects brake and controls.
 - Maximum tonnage under 1,000 t (2,200,000 lb).

Multi-Function Couplers

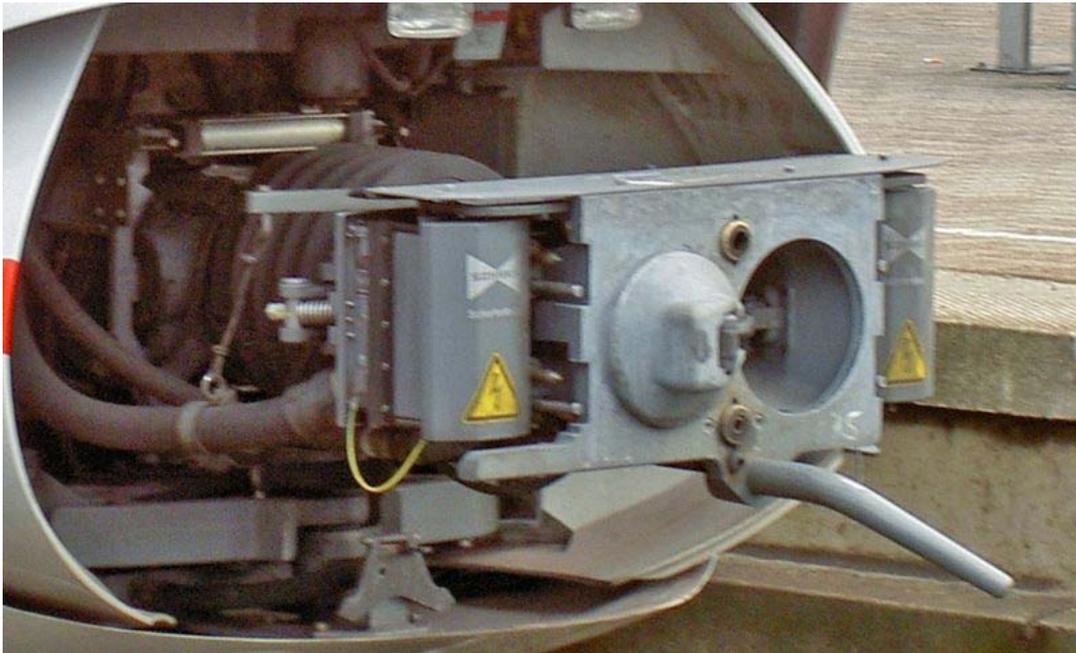
MFCs are 'fully automatic' couplers that make all connections between the rail vehicles (mechanical, air brake and electrical) without human intervention, in contrast to autocouplers which just handle the mechanical aspects. The majority of trains fitted with these types of couplers are multiple units, especially those used in mass transit operations.

There are a few designs of fully automatic couplers in use worldwide, including the Scharfenberg coupler, various knuckle hybrids (such as the Tightlock, used in the UK), the wedgelock coupling, Dellner couplings (similar to Scharfenberg couplers in appearance), BSI coupling and the Schaku-Tomlinson Tightlock coupling.

There are a number of other automatic train couplings similar to the Scharfenberg coupler, but not necessarily compatible with it. Older US transit operators continue to use these non-Janney electro-pneumatic coupler designs and have used them for decades.



Dellner manufactured Scharfenberg



Scharfenberg



BSI



APTA, Type "H", Tightlock coupling



Wedgelock



Budd Pin and cup coupler

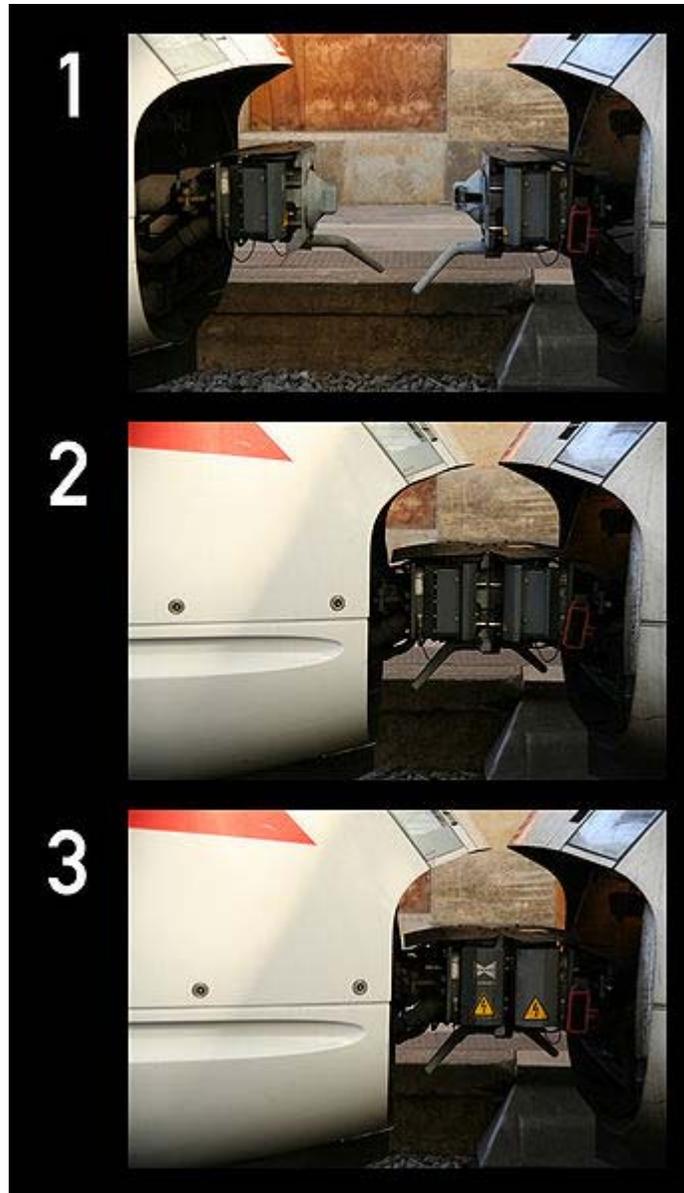
Westinghouse H-2 MU coupler

The Westinghouse coupler is used on the R62 and R62A train of the 7, 1, and 3 line, with a Scharfenberg with no power port at the front of the locomotive. The other cars use either a permanent drawbar, or a Westinghouse coupler, but all with Schaku.

Scharfenberg coupler



The MY locomotive, normally screw-coupled, has a Scharfenberg coupler mounted for transporting Lint 41 DMU's



Two ICE-T trains coupling. In picture #1 both trains are ready to be coupled, picture #2 shows the trains joined mechanically, picture #3 shows the trains coupled mechanically and electrically.

The Scharfenberg coupler (German: *Scharfenbergkupplung* or *Schaku*) is probably the most commonly used type of fully automatic coupling. Designed in 1903 by Karl Scharfenberg in Königsberg, Germany (today Kaliningrad, Russia), it has gradually spread from transit trains to regular passenger service trains, although outside Europe its use is generally restricted to mass transit systems. The Schaku coupler is superior in many ways to the AAR (Janney/Knuckle) coupler because it makes the electrical and also the pneumatic connections and disconnections automatic. However there is no standard for the placement of these electro-pneumatic connections. Some rail companies have them placed on the sides while others have them placed above the mechanical portion of

the Schaku coupler. The main disadvantage to the Scharfenberg coupler is its low maximum tonnage, which makes it unsuitable for freight operations.

Small air cylinders, acting on the rotating heads of the coupler, ensure the Schaku coupler engagement, making it unnecessary to use shock to get a good coupling. Joining portions of a passenger train can be done at very low speed (less than 2 mph/3.2 km/h in the final approach), so that the passengers are not jostled about. Rail equipment manufacturers such as Bombardier offer the Schaku coupler as an option on their mass transit systems and their passenger cars and locomotives. In North America all the trains of the Montreal Metro are equipped with it, as are new light rail systems in Denver, Baltimore and New Jersey. It is also used on light rail vehicles in Portland, Minneapolis, the Vancouver Skytrain, and the Scarborough RT in Toronto. It also equips all the dedicated rolling stock used for the shuttle services in the Channel Tunnel.

- Maximum tonnage under 1,000 t (2,200,000 lb).

United Kingdom

Due to the rush to dieselise and electrify, the United Kingdom ended up with a variety of incompatible couplings and electrical connections. The latter were categorised as yellow triangle, blue square, and so on.

Automatic Buffing Contact Coupler

- Automatic Buffing Contact Coupler

Other

Dellner

Dual couplings and match wagons



Coupling adapter for use between AAR couplers on locomotives and automatic couplers on commuter rail multiple units at New York's Pennsylvania Station. The adapter is seen from the bottom

If a wagon with one coupling system needs to be coupled to wagons with another coupling type there are two solutions. This may be needed when taking metro rolling stock from its manufacturer to the city where it is to be used:

- use a match wagon(s) which has different couplings at either end.
- use a coupling adaptor (such as illustrated).

Only some kinds of couplings coexist on the end of a wagon at the same time, because amongst other reasons they need to be at the same height. For example, in the Australian state of Victoria, engines had the AAR coupler, with buffers, and the chain mounted on a lug cast into the AAR coupler.

A match wagon or match truck (also known as a barrier vehicle / wagon in Britain and Transition Car in the United States) has different kinds of couplings at each end. If a pair of match wagons is used, a rake of wagons using coupling A can be inserted into a train otherwise using coupling B.

A coupling adaptor or compromise coupler might couple to an AAR coupling on a wagon, and present, for example, a meatchopper coupler or rapid transit coupler to the next wagon. Such an adaptor might weigh 100 kg (220 lb).

Dual coupling

It is possible to mount both buffers and chain and knuckle couplers on the same car, provided that one can swing out of the way. Alternatively, either a lug to hold the chain is cast in the body of the coupler or a chain is mounted on top of the coupler. This is also done with an SA3 coupler built by SAB WABCO.

Locomotives and some freight cars of the Indian Railways are fitted with a 'transition coupler' that incorporates a screw coupling within a knuckle coupler: the knuckle coupler remains in position and does not swing away when not in use. The screw coupling is mounted on a lug within the knuckle coupler. Most Indian freight cars use the knuckle coupler alone, without buffers, whereas passenger coaches almost exclusively use screw couplers and buffers. Exceptions are the new LHB coaches imported from Europe, and a few other makes of carriages converted to use knuckle couplers.



A Finnish locomotive with dual coupling

Some Russian locomotives and wagons have buffers together with the central coupler. When coupling to Finnish equipment, a short chain with a block that fits in the central coupler is placed on the Russian side, backing up and compressing the buffers so that the chain can be laid on the hook. (That is also the common way of coupling locomotives to or from wagons, faster than unscrewing the link.)



British-style dual buffer-and-chain/automatic coupler with knuckle swung out of the way

British locomotive-hauled passenger carriages adopted a dual coupling system in the 1950s. They have retractable buffers and a central Buckeye automatic knuckle coupler that lowers to reveal a hook for a screw-type chain coupling. When in use, a pin through the buckeye shank rests in the conventional hook. No chain is provided on dual-coupled vehicles, since the chain on the other vehicle can be used where knuckle couplers are not present. Inter-stock coupling was with the automatic coupler (with the buffers retracted), while connection to the locomotive was with the buffer-and-chain system with a screw coupler. Today this dual coupling system has been adopted for all loco-hauled passenger trains in Great Britain to allow faster shunting operations.

If worst comes to worst one might use a rope to join two wagons together, as might happen if one of the couplers breaks in service. This formed a plot point in the British comedy film *The Titfield Thunderbolt*, where a rope had to be used to connect a

commandeered antique locomotive to its train. The rope subsequently snapped, leaving the train stranded.

Sets of carriages

Automatic couplers like the Janney are safer in a collision because they help prevent the carriages telescoping. British Rail therefore decided to adopt a Janney variant for its passenger carriages, with the coupler able to swing out of the way for coupling to engines with the traditional buffer and chain system.

In New South Wales, sets of carriages were permanently coupled with a fixed bar, since the carriages were disconnected only at the workshops. Freight cars are sometimes coupled in pairs or triplets, using bar couplings in between.

Articulated sets of carriages or wagons share the intermediate bogies, and have no need for couplings in the intermediate positions.

Coupler conversion

From time to time, a railway decides that it needs to upgrade its coupling system from one that is proving unsatisfactory, to another that meets future requirements. This can be done gradually, which can create lots of problems with transitional incompatibilities, or overnight, which requires a lot of planning.

Japan

Japan converted its British-derived buffer and chain couplings to the American Janney coupling over a period of a few days in the early 1920s, after considerable preparation. Today, most (if not all) EMUs including high-speed Shinkansen trains, and some DMUs use the Shaku-Thomlinson type coupling system, while locomotive-hauled trains use the Janney coupling and Tightlock coupling system.

Australia

Australia, with its breaks of gauge, has always had different couplers on different systems, and has generally adopted gradual conversion. Conversion to the Janney coupling is now virtually complete. Commonwealth Railways started with Janney couplings on its standard gauge Trans-Australian line, and some railways, like the former Victorian Railways and the Queensland Railways, used dual couplers. Older couplers remain on Heritage railways.

Europe

The European network has traditionally been formed of many independent national railway networks with buffer and chain used near universally to allow the interchange of rolling stock. The European Union Technical Specifications for Interoperability (TSIs)

for high-speed passenger rolling stock mandate the use of Scharfenberg Type 10-compatible couplings. The Type 10 includes "horns" to aid coupling on curves and include a function to provide standardised automatic air-brake connections; the coupling horn is often visible poking out at the front of the nose of high-speed trains.

For European freight, the TSIs mandate buffer and chain couplings at specified heights. The European system links to the former Soviet Russian-gauge network, where SA3 automatic couplers are used. Some research has been undertaken to chose an automatic freight coupler compatible with the Soviet one, but owing to widescale replacement cost, no action has been taken to implement the conversion, except for some trial installations. In many heavy-haul applications, such as for coal and iron ore, either US AAR-type couplers or Soviet SA-3 couplers are used. Conversion is made harder to justify because the existing buffer and chain coupling is almost universal.

Meanwhile, drawgear of new rolling stock is being built at a height suitable for conversion. The proposed European freight coupling is compatible with the SA3 coupler but adds integrated air and electrical connections. This standard would need to be revised to allow for the unforeseen development of electronically controlled pneumatic brakes.

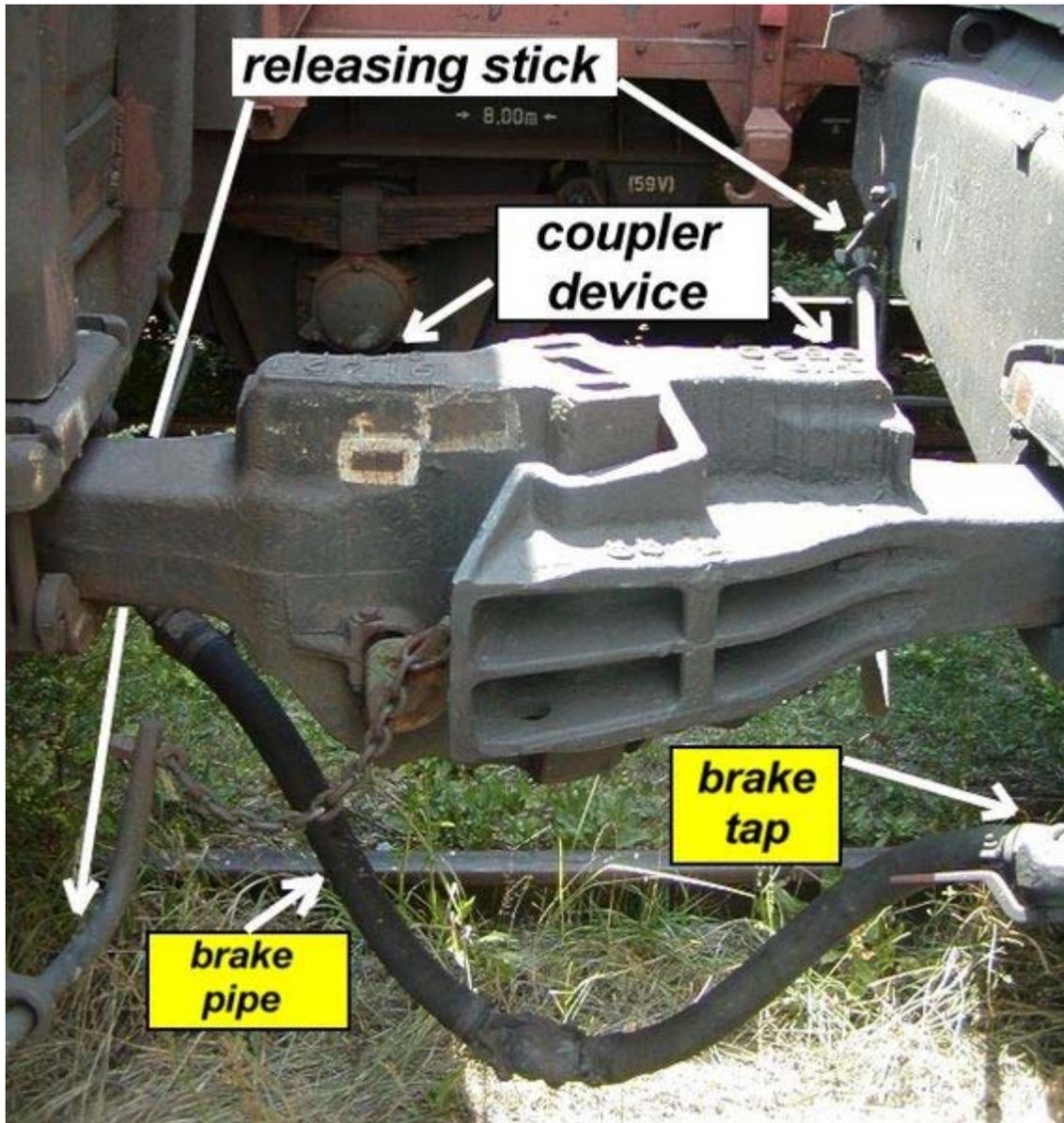
United States

Once Congress passed the Safety Appliance Act mandating conversion from the link and pin coupler to the Janney coupler, railroads in the United States had only a few years to implement the change. The railroads in North America, except for mass transit, form one unitary system, and uniformity of couplers is important for smooth interchange of rolling stock.

Latin America

Railways in Central and South America are fragmented by gauge, geography, and financial and technical heritage. While some systems have adopted the American Janney coupler, others retain the British buffer and hook (buffer and chain) coupler.

Soviet Union and successor states



Detail of the SA-3 coupler in coupled mode



SA-3 coupler, uncoupled

Russia and Central Asia used buffer and chain couplings, albeit with possibly wider centres for the buffers, until conversion to automatic SA3 couplers. The SA3 coupler was invented in 1932. Some wagons were equipped with SA-3 couplers in the 1930s (they could be coupled with chain coupling), but all cars received automatic couplers in 1957.

Middle East

While the Middle East is mostly standard gauge, three different couplings appear to be in use (not counting Scharfenberg couplings on EMU trains). These are buffer-and-chain, American, and Russian types.

Africa

South of the Sahara, Janney (AAR) and chopper couplings (not necessarily of compatible types) appear to account for most couplings. The preferred and proposed UAR standard is the American Janney (AAR) coupling.

- Rail transport in Ghana

Brake couplings

Couplings are needed for any continuous braking systems.

Electronically controlled brakes

Electronically controlled pneumatic brakes (ECP) need a method of connecting electrically adjacent wagons, both for power and for command signals, and this can be done by plugs and sockets, or by very short range radio signals.

Model trains

On model railroads couplers vary according to scale, and have evolved over many years. Early model trains were coupled using various hook-and-loop arrangements, which were frequently asymmetrical, requiring all cars to be pointing in the same direction. In the larger scales, working scale or near-scale models of Janney couplers were quite common, but proved impractical in HO and smaller scales.

For many years, the "X2F" or "Horn-Hook" coupler was quite common in HO scale, as it could be produced as a single piece of moulded plastic. Similarly, for many years, a "lift-hook" coupler known as the *Rapido* and developed by Arnold, a German manufacturer of N-scale model trains, was commonly used in that scale.

The chief competitor of both these couplers, more popular among serious modellers, was the Magne-Matic, a magnetically-released knuckle coupler developed by Keith and Dale Edwards, and manufactured by Kadee, a company they started. While they closely resemble miniature Janney couplers, they are somewhat different mechanically, with the knuckle pivoting from the center of the coupler head, rather than from the side. A steel pin, designed to resemble an air brake hose, allows the couplers to be released magnetically; the design of the coupler head prevents this from happening unless the train is stopped or reversed with a mated pair of couplers directly over an uncoupling magnet. An earlier, mechanically-tripped version of the design had a straight pin extending down from the knuckle itself, which engaged a diamond-shaped mechanical "ramp" between the rails, which had to be raised above rail height when uncoupling was desired.

Once the Kadee patents ran out, a number of other manufacturers began to manufacture similar (and compatible) magnetic knuckle couplers.

Recently, an exact-scale HO model of the AAR coupler has been designed and manufactured by Frank Sergent, of Sergent Engineering. This design uses a tiny stainless steel ball to lock the knuckle closed. Uncoupling is achieved by holding a magnetic wand over the coupler pair to draw the balls out of the locking pockets.

In O scale, an exact-scale working miniature version of the "Alliance" coupler was manufactured from the 1980s by GAGO models in Australia. Since 2002 it has been

marketed by the Waratah Model Railway Company European modellers tend to use scale hook and chain couplings.

In British 00 scale (similar to H0 scale) models the 'tension lock' coupler developed by Tri-ang is standard. This is similar in operation to the meatchopper type of coupling. Remote uncoupling is possible by using a sprung ramp between the rails. By halting the train over the ramp, it is split at this point. While it works well, it is often seen as ugly and obtrusive (although smaller designs are available, these are not always fully compatible with other models) and many British modellers prefer to retrofit either Kadee types or working hook and chain couplings.

A recent development is an interchangeable coupling which plugs into a standardised socket, known as NEM 362 and which can be easily unplugged as required. This allows the modeller to easily standardise on whatever coupling is desired, without individual manufacturers needing to change their coupling type.

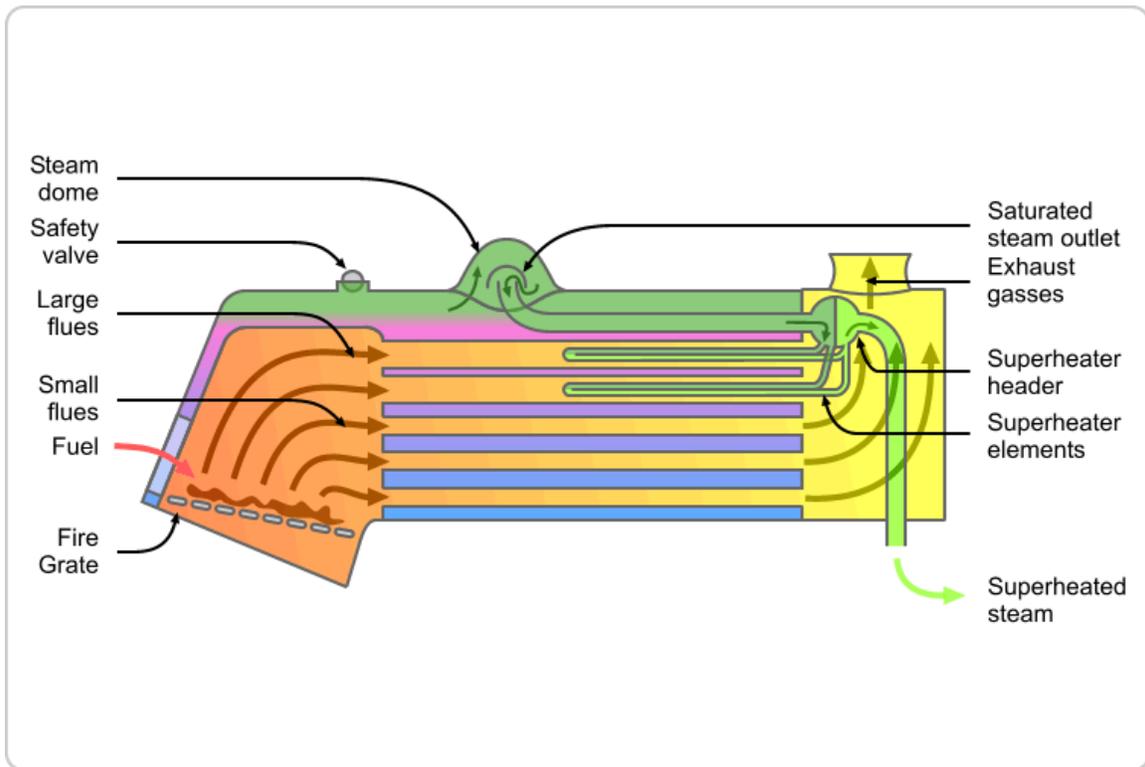
Accidents

Different kinds of coupling have different accident rates.

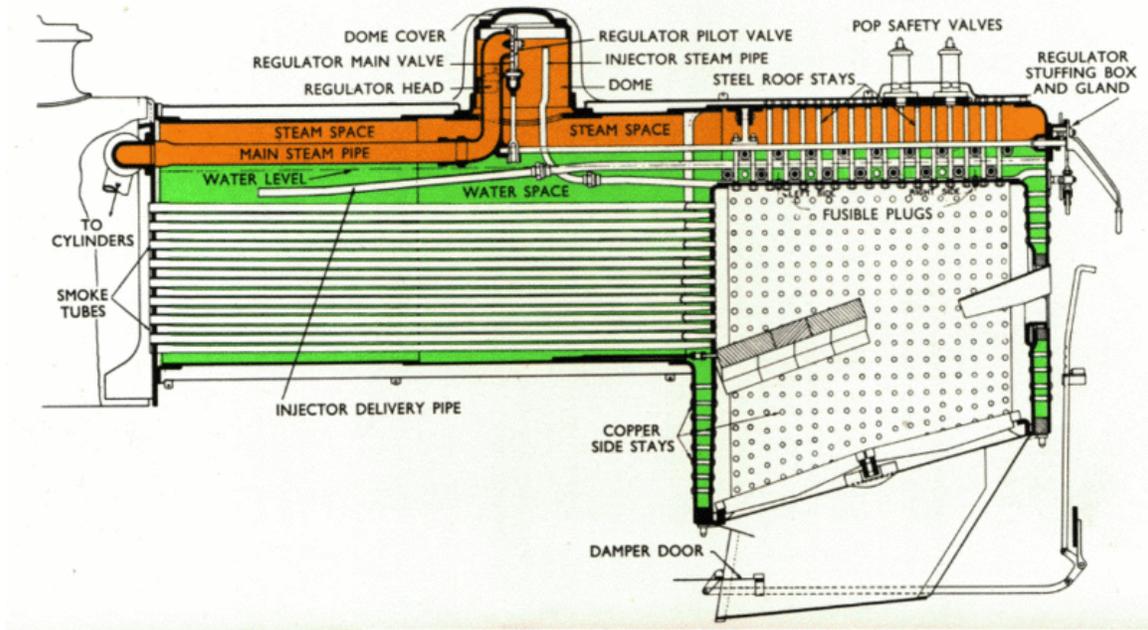
- UK 1906 - twelve fatal and 523 non-fatal accidents
- The Murulla rail accident of 1926 involved the breakage of a "drawhook" leading to a runaway and then a collision. Drawhooks imply "buffers and screw" couplings.

Chapter 2

Firebox (Steam Engine)



Components of a locomotive boiler, firebox at the left



Section of typical boiler and firebox

In a steam engine, the **firebox** is the area where the fuel is burned, producing heat to boil the water in the boiler. Most are somewhat box-shaped, hence the name.

Railway locomotive firebox



The firedoor into the firebox of a steam locomotive

In the standard steam locomotive firetube type boiler, the firebox is surrounded by water space on five sides. The underside is not so surrounded. If the engine burns solid fuel, there is a grate covering most of the bottom of the firebox to hold the fuel. An ashpan collects the solid combustion waste below. Combustion air generally enters at the base, and the airflow is usually controlled by damper doors.

Brick arch

There is a large brick arch (made from fire brick) at the front of the box which directs heat and flames back towards the firedoor at the rear. Without the arch, flames would be sucked straight into the firetubes, and only the front of the box would receive heat. The brick arch and the bars of the grate require periodic replacement due to the extreme heat they endure.

Firetubes

Firetubes are attached to one wall of the firebox (the front wall for a longitudinal boiler, the top for a vertical boiler) and carry the hot gaseous products of combustion through the boiler water, heating it, before they escape to the atmosphere.

Sheets and stays



Cutaway of locomotive firebox and boiler. Note the stays to support the "sheets" (plates) against pressure, the fusible plugs and the "mudhole" to allow access for scraping away scale

The metal walls of the firebox are normally called *sheets*, which are separated by *stays*. Since any corrosion is hidden, the stays may have longitudinal holes, called *tell-tales*, drilled in them which leak before they become unsafe. The *crown sheet* is the top of the firebox.

Belpaire firebox

Normally the top of the firebox is semicircular to match the contour of the boiler, however the Belpaire firebox has more of a square shape and is usually made as large as

possible within the loading gauge, to offer the greatest heating surface where the fire is hottest.

Wootten firebox

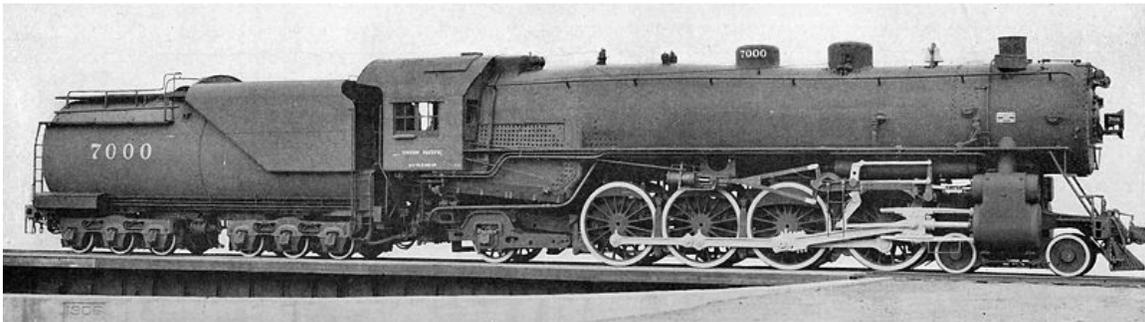
The Wootten firebox was very tall and wide to allow combustion of anthracite coal waste. Its size necessitated unusual placement of the crew, examples being camelback locomotives.

Combustion chamber

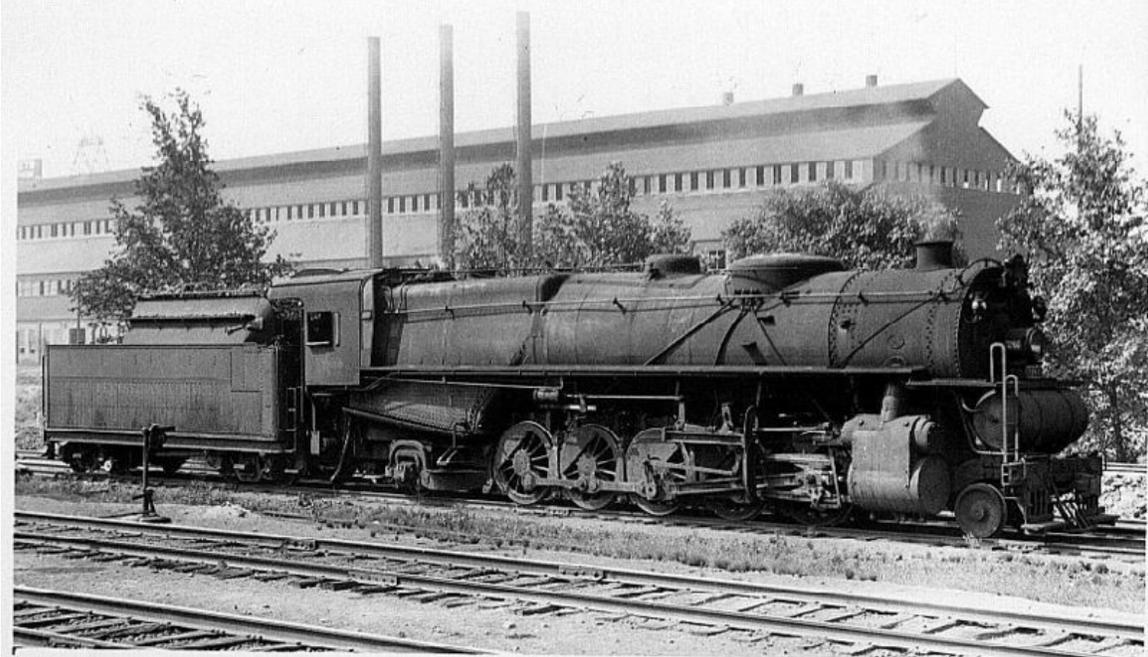
Some fireboxes were equipped with a so-called combustion chamber which placed additional space between the fire and the boiler. This allowed more complete combustion and thus greater heat.

Fireman's duties

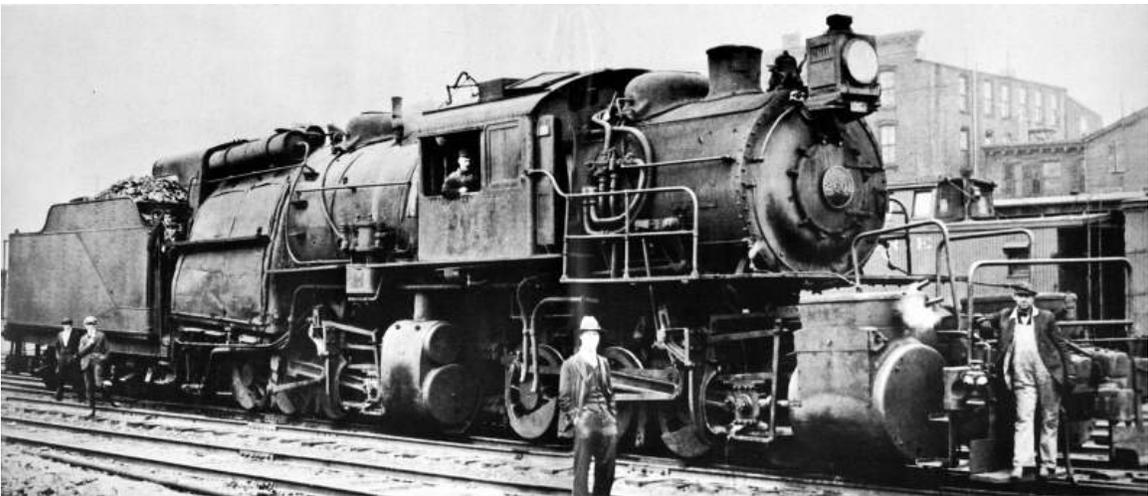
The fireman's role on a steam locomotive is to ensure the driver (engineer) has an adequate supply of steam at his disposal at all times. This is achieved by maintaining a supply of fuel to the fire, and by maintaining the boiler water level so that it covers the firebox crown sheet at all times – otherwise, the latter will overheat and weaken, and a boiler explosion may result. In addition, the fireman also serves as a backup for the driver, keeping a lookout ahead.



Locomotive with a normal firebox. The round top of the firebox makes attaching the boiler easier



The flat sides and square corners show the shape of the Belpaire firebox. This offers a greater heating surface, increasing the efficiency of the engine



The Wootten firebox can be seen as the large construction just in front of the tender. Note the unusual position of the drivers cab. The fireman was left exposed between firebox and tender

Road locomotive firebox

Road locomotives, such as traction engines, usually had fireboxes similar to those on railway locomotives but there were exceptions, e.g. the Sentinel steam waggon which had a vertical water tube boiler.

Stationary boiler firebox

There were, and are, many different designs of firebox for stationary boilers. In flue-type boilers (e.g. the Lancashire boiler) the flues themselves form the firebox. In water-tube boilers, the firebox is usually a firebrick-lined compartment below the water tubes.

Marine boiler firebox

In marine boilers there are also various different types of firebox. The main distinction is, again, between fire-tube types (e.g. the Scotch boiler, with internal firebox) and water-tube types (e.g. the Yarrow boiler, with external firebox).

Chapter 3

Adams Axle and Blastpipe

Adams axle

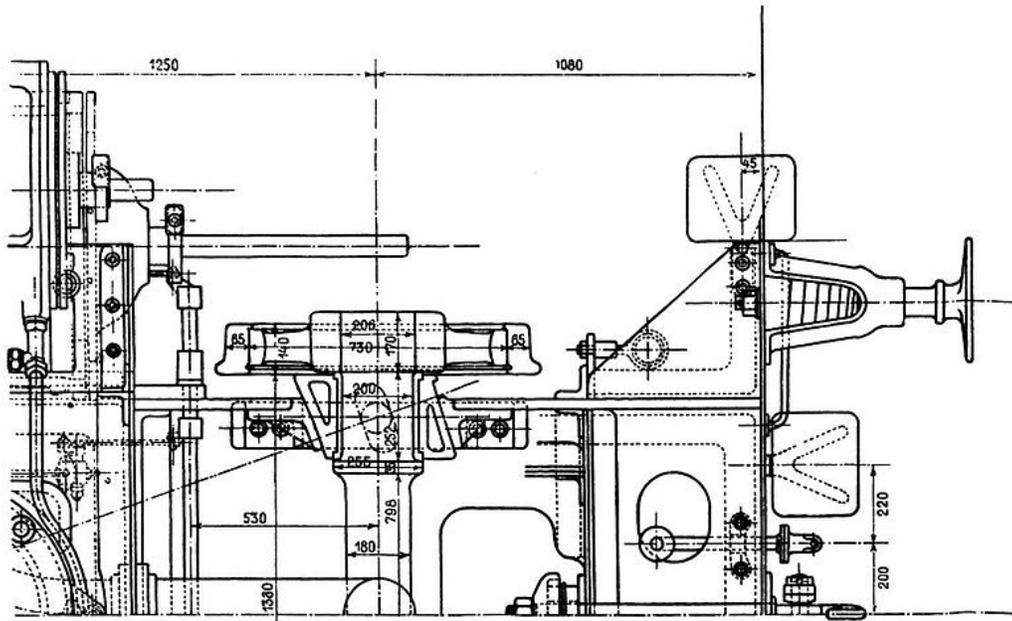


Abb. 122.

Construction drawing of a Adams axle

The **Adams axle** is a form of radial axle for rail locomotives that enable them to negotiate curves more easily. It was invented by William Bridges Adams and patented in 1865. The invention uses axle boxes that slide on an arc in shaped horn blocks, so

allowing the axle to slide out to either side. This is similar to the movement of a Bissell truck, but with the notional centre point of the curve being where the pivot of the truck would be. This design, using slide bearings, is more expensive than one employing a shaft, but takes up less space.

Trials

In 1865 the Society of Engineers, London, made direct comparison between the radial axle, invented by William Bridges Adams, and a bogie design with an india-rubber central bearing invented by William Adams: during trials on the North London Railway the laterally sprung bogie was thought superior to the radial axle, but when William Adams moved from the NLR to the London and South Western Railway he adopted the design of his rival William Bridges Adams. The locomotives now known as Adams Radials are named after the LSWR Locomotive Superintendent, but are famous for the axle invented by William Bridges Adams.

Inventor

Notwithstanding the 1865 comparative trials of the two inventors' products, there is some confusion over the inventor of the axle. *Lexicon der Eisenbahn* cites William Adams (1823-1904) as the inventor indicates that William Bridges Adams (1797-1872) patented the invention.

Blastpipe

The **blastpipe** is part of the exhaust system of a steam locomotive that discharges exhaust steam from the cylinders into the smokebox beneath the chimney in order to increase the draught through the fire.

History

The primacy of discovery of the effect of directing the exhaust steam up the chimney as a means of providing draft through the fire is the matter of some controversy, Ahrons (1927) devoting significant attention to this matter. The exhaust from the cylinders on the first steam locomotive – built by Richard Trevithick – was directed up the chimney, and he noted its effect on increasing the draft through the fire at the time. At Wylam Timothy Hackworth also employed a blastpipe on his earliest locomotives, but it is not clear whether this was an independent discovery or a copy of Trevithick's design. Shortly after Hackworth George Stephenson also employed the same method, and again it is not clear whether that was an independent discovery or a copy of one of the other engineers.

The locomotives at the time employed either a single flue boiler or a single return flue, with the fire grate at one end of the flue. For boilers of this design the blast of a contracted orifice blastpipe was too strong, and would lift the fire. It was not until the development of the multitubular boiler that the centrally positioned, contracted orifice

blastpipe became standard. The combination of multi-tube boiler and steam blast are often cited as the principal reasons for the high performance of *Rocket* of 1829 at the Rainhill Trials.

Description

Soon after the power of the steam blast was discovered it became apparent that a smokebox was needed beneath the chimney, to provide a space in which the exhaust gases emerging from the boiler tubes can mix with the steam. This had the added advantage of allowing access to collect the ash drawn through the fire tubes by the draught. The blastpipe, from which steam is emitted, was mounted directly beneath the chimney at the bottom of the smokebox.

The steam blast is largely self-regulating: an increase in the rate of steam consumption by the cylinders increases the blast, which increases the draught and hence the temperature of the fire. Modern locomotives are also fitted with a *blower*, which is a device that releases steam directly into the smokebox for use when a greater draught is needed without a greater volume of steam passing through the cylinders. An example of such situation is when the regulator is closed suddenly, or the train passes through a tunnel. If a single line tunnel is poorly ventilated, a locomotive entering at high speed can cause a rapid compression of the air within the tunnel. This compressed air may enter the chimney with substantial force. This can be extremely dangerous if the firebox door is open at the time. For this reason the blower is often turned on in these situations, to counteract the compression effect.

Later development

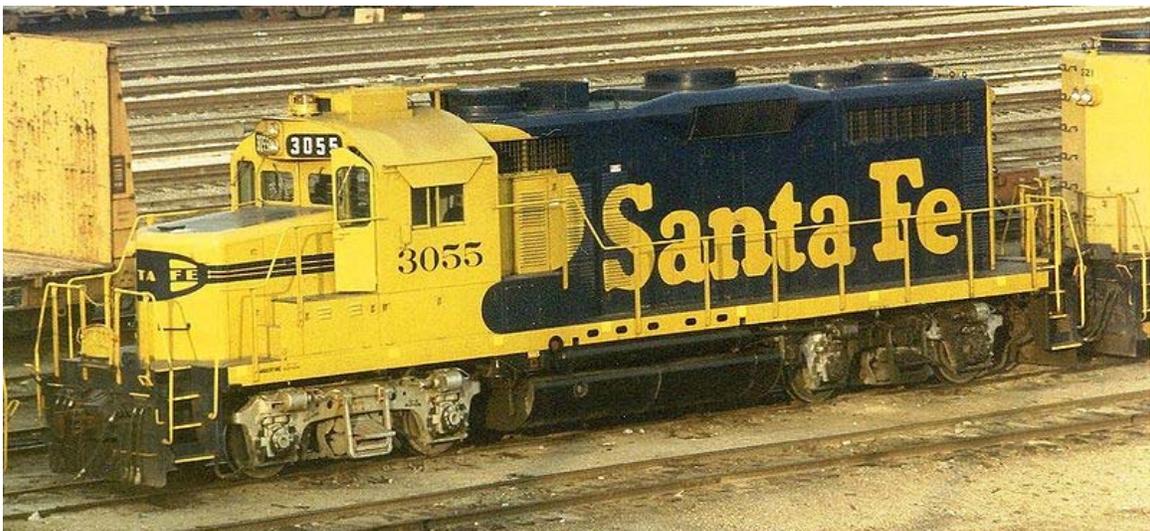
Little development of the basic principles of smokebox design took place until 1908, when the first comprehensive examination of steam-raising performance was carried out by W.F.M. Goss of Purdue University. These principles were adopted on the Great Western Railway by Churchward. A later development was the so-called *jumper-top* blastpipe which controlled the area of the blastpipe at different steaming rates to maximise efficiency.

The aim of blastpipe modification is to obtain maximum smokebox vacuum with minimum back pressure on the pistons. The simplest modification is a double chimney with twin blastpipes, but many other arrangements have been tried. Towards the end of the steam era the Kylchap exhaust was popular and used on the Nigel Gresley's Mallard. Other designs include Giesl, Lemaître and Lempor blastpipes.

Chapter 4

Blomberg B and Booster Engine

Blomberg B



ATSF #3055, an EMD GP20, rides on Blomberg B trucks.



Blomberg B detail



Blomberg M truck of a GP40-2

The **Blomberg B** was a "B" diesel locomotive truck. These trucks were the standard EMD four wheel truck from the FT up until the GP60. EMD introduced the truck in 1936. Unofficially it is named after Martin Blomberg, who joined the company the year before. The truck was derived from an earlier six wheel truck (*described in U.S. Patent 2,189,125, filed January 29, 1938, and approved February 6, 1940*), and was used starting with the FT.

Identification

Blomberg trucks can be identified by their prominent outside swing hangers, which afford a better ride during side-to-side movement. The outside placement has the advantage of widening its spring base from 56 to 96 inches (1,422 to 2,438 mm).

A popular modification by railroads in later years was reducing the number of brake shoes from 8 to 4 by reconfiguring the double-clasp brake rigging, removing one brake

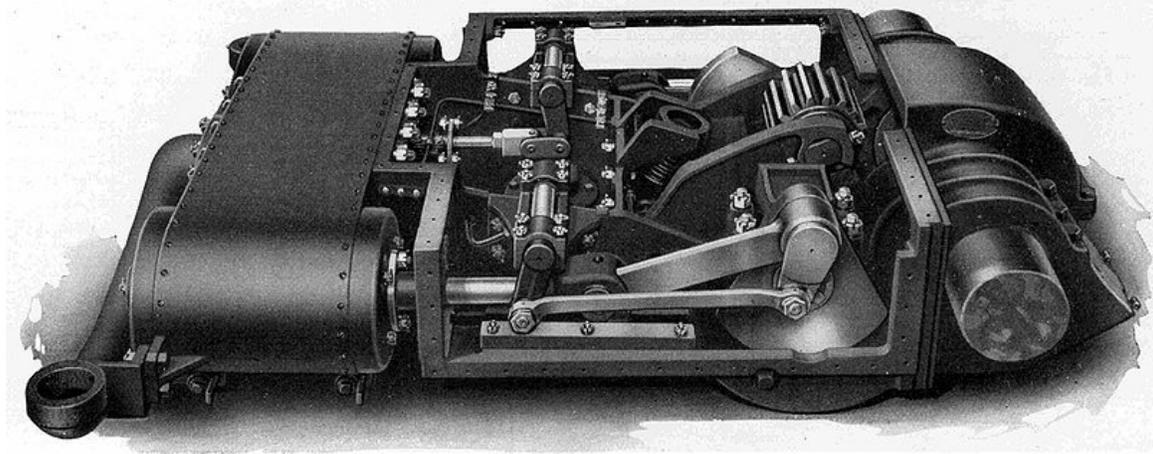
shoe per wheel. This can give the Blomberg B the appearance of later Blomberg M trucks.

***M* version**

A modified (M) version of the truck called the **Blomberg M** was used starting with the four-axle Dash 2 series locomotives. Hydraulic snubbers (shocks) were used on diagonally opposite (*front right and rear left*) journals, and the leaf spring suspension was replaced with rubber pads. This version had only one brake actuating cylinder per side and revised brake rigging using threaded adjusters, reducing the number of brake shoes to 4 versus 8 on the earlier B model.

There is also a later variation of the Blomberg M found on the GP60 and F59PH models. The main spotting features of this version are leaf spring suspension (as opposed to rubber pads) and exposed roller bearing ends, along with damper shocks between the trucks and locomotive carbody to reduce sway. Similar looking trucks can be found under modern MPI MPXpress locomotives.

Booster engine



Booster engine with the cover removed to show the mechanism. The driven axle is on the right; the booster normally hung behind it.

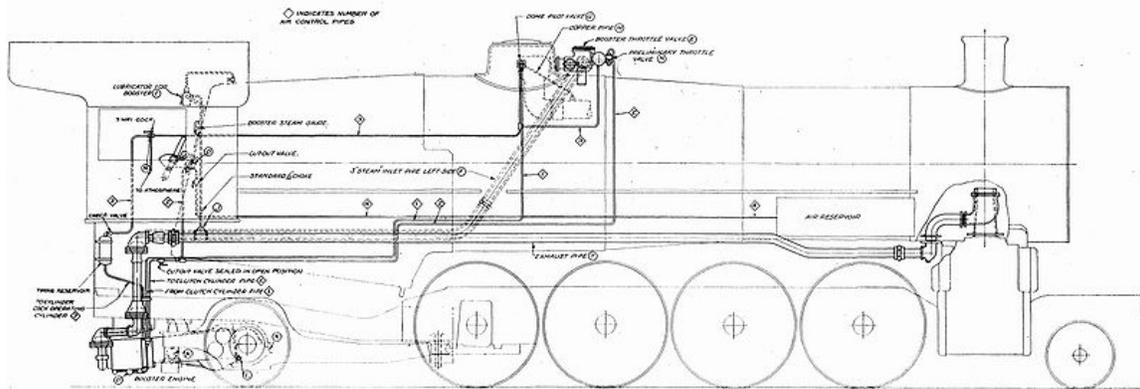


Diagram showing how a booster is installed and connected.

A **booster engine** for steam locomotives is a small two-cylinder steam engine back-gear-connected to the trailing truck axle on the locomotive or, if none, the lead truck on the tender. A rocking idler gear permits it to be put into operation by the engineer. It would drive one axle only and could be non-reversible with one idler gear or reversible with two idler gears.

They were used to start a heavy train or maintain low speed under demanding conditions. It could be cut in while moving at speeds under 15 mph (24 km/h). Rated at about 300 hp (224 kW) at speeds of from 10 to 30 miles per hour (16 to 48 km/h). It would automatically cut out at 30 mph (48 km/h). Tractive effort of 10-12,000 lbf (44 to 53 kN) was common.

Tender boosters were equipped with side-rods connecting axles on the lead truck. Such small side-rods restricted speed and thus confined to switching locomotives, often used in transfer service between yards. Such boosters were far rarer than engine boosters.

Reasons for booster use

The booster is intended to address fundamental flaws of the standard steam locomotive. First, most steam locomotives do not provide power to all wheels. The amount of force that can be applied to the rail depends on the weight on driven wheels and the factor of adhesion of the wheels against the track. Unpowered wheels effectively 'waste' weight which could be used for traction. Unpowered wheels are generally needed to provide stability at speed, but at low speed this is not necessary.

Second, the "gearing" of a steam locomotive is constant, since the pistons are linked directly to the wheels via rods and cranks. Since this is fixed, a compromise must be struck between ability to haul at low speed and the ability to run fast without inducing excessive piston speeds (which would cause failure) or the exhaustion of steam. This compromise means that the steam locomotive at low speeds is not able to use all the power the boiler is capable of producing; it simply cannot use steam that quickly, and

there is a big gap between the amount of steam the boiler could produce and the amount that can be used. The booster enables that wasted potential to be put to use.

Disadvantages

Boosters were costly to maintain with their flexible steam and exhaust pipes, idler gear etc.

Usage

The booster saw most use in North America. Railway systems elsewhere often considered the expense and complexity unjustified.

Even in the North American region, booster engines were applied to only a fraction of all locomotives built. Some railroads used boosters extensively while others did not. The New York Central was a fan of the booster and applied it to all of its 4-6-4 Hudson locomotives. The rival Pennsylvania Railroad, however, used few booster-equipped locomotives.

Canadian Pacific Railway rostered a grand total of 3257 steam locomotives acquired between 1881 and 1949, yet only 55 were equipped with boosters. 17 H1 class 4-6-4s, 2 K1 class 4-8-4s and all 36 T1 class 2-10-4s.

In Australia, Victorian Railways equipped all but one of its X class 2-8-2 locomotives (built between 1929 and 1947) with a 'Franklin' two cylinder booster engine after the successful trial of the device on a smaller N class 2-8-2 in 1927. The South Australian Railways 500 class 4-8-2 heavy passenger locomotives were rebuilt into 4-8-4s with the addition of a booster truck from 1929 onwards.

NZR's Kb class of 1939 were built with booster trucks to enable the locomotives to handle the steeper grades of the South Island lines.

Chapter 5

Combustion Chamber and Connecting Rod

Combustion chamber

A **combustion chamber** is the part of an engine in which fuel is burned.

Internal combustion engine

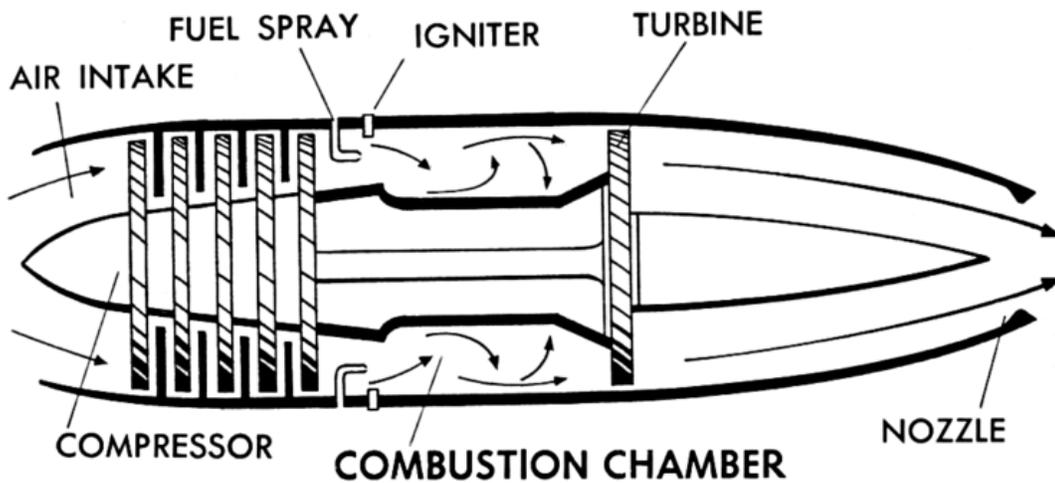


Diagram of jet engine showing the combustion chamber.

The hot gases produced by the combustion occupy a far greater volume than the original fuel, thus creating an increase in pressure within the limited volume of the chamber. This

pressure can be used to do work, for example, to move a piston on a crankshaft or a turbine disc in a gas turbine. The energy can also be used to produce thrust when directed out of a nozzle as in a rocket engine.

Petrol or gasoline engine

A reciprocating engine is often designed so that the moving pistons are flush with the top of the cylinder block at top dead centre. The combustion chamber is recessed in the cylinder head and commonly contains a single intake valve and a single exhaust valve. Some engines use a dished piston and in this case the combustion chamber can be considered as partly within the cylinder. Various shapes of combustion chamber have been used, such as L-head (or flathead) for side-valve engines; "bathtub", "hemispherical" and "wedge" for overhead valve engines; and "pent-roof" for engines having 3, 4 or 5 valves per cylinder. The shape of the chamber has a marked effect on power output, efficiency and harmful emissions; the designer's objectives are to burn all of the mixture as completely as possible while avoiding excessive temperatures (which create NO_x). This is best achieved with a compact rather than elongated chamber. The intake valve/port is usually placed to give the mixture a pronounced "swirl" (the term is preferred to turbulence which implies movement without overall pattern) above the rising piston, improving mixing and combustion. The shape of the piston top also affects the amount of swirl. Note that swirl rotates about a horizontal axis, not (symmetrically) about a vertical axis. Finally, the spark plug must be situated in a position from which the flame front can reach all parts of the chamber at the desired point, usually around 15 degrees after top dead centre. It is strongly desirable to avoid narrow crevices where stagnant "end gas" can become trapped, as this tends to detonate violently after the main charge, adding little useful work and potentially damaging the engine. Also, the residual gases displace room for fresh air/fuel mixture and will thus reduce the power potential of each firing stroke.

Diesel engine

Diesel engines fall into two broad classes:

- Direct injection, where the combustion chamber consists of a dished piston
- Indirect injection, where the combustion chamber is in the cylinder head

Direct injection engines usually give better fuel economy but indirect injection engines can use a lower grade of fuel.

Harry Ricardo was prominent in developing combustion chambers for diesel engines, the best known being the Ricardo Comet.

Gas turbine

The combustion chamber in gas turbines and jet engines (including ramjets and scramjets) is called the combustor.

The combustor is fed high pressure air by the compression system, adds fuel and burns the mix and feeds the hot, high pressure exhaust into the turbine components of the engine or out the exhaust nozzle.

Different types of combustors exist, mainly:

- Can type: Can combustors are self contained cylindrical combustion chambers. Each "can" has its own fuel injector, igniter, liner, and casing.
- Cannular type: Like the can type combustor, can annular combustors have discrete combustion zones contained in separate liners with their own fuel injectors. Unlike the can combustor, all the combustion zones share a common ring (annulus) casing.
- Annular type: Annular combustors do away with the separate combustion zones and simply have a continuous liner and casing in a ring (the annulus).

Steam engine

The term **combustion chamber** is also used to refer to an additional space between the firebox and boiler in a steam locomotive. This space is used to allow further combustion of the fuel, providing greater heat to the boiler.

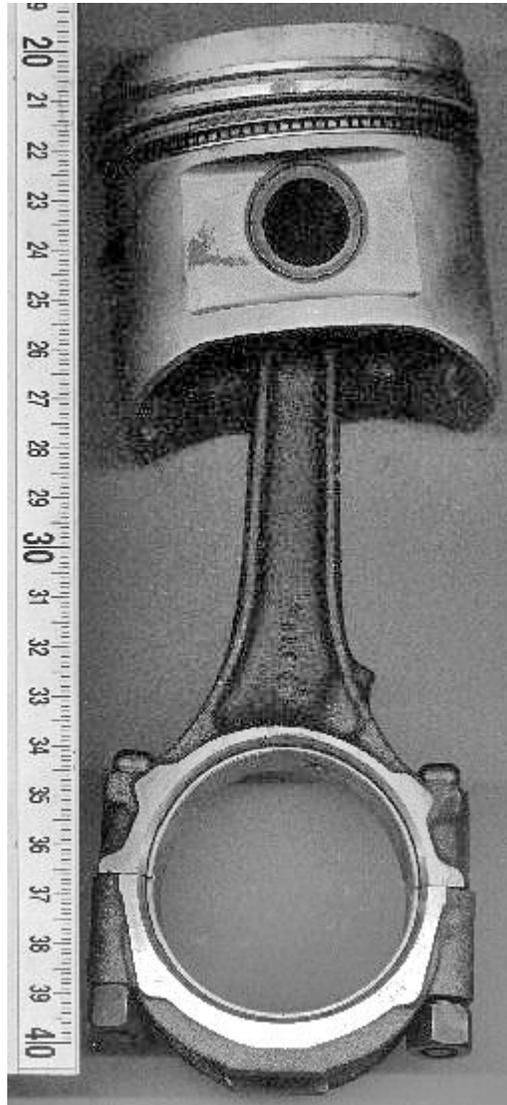
Large steam locomotives usually have a combustion chamber in the boiler to allow the use of shorter firetubes. This is because:

- Long firetubes have a theoretical advantage in providing a large heating surface but, beyond a certain length, this is subject to diminishing returns.
- Very long firetubes are prone to sagging in the middle.

Micro Combustion Chambers

Micro combustion chambers are the devices in which combustion happens at a very small volume, due to which surface to volume ratio increases which plays a vital role in stabilizing the flame.

Connecting rod



piston (top) and connecting rod from typical automotive engine (scale is in centimetres)

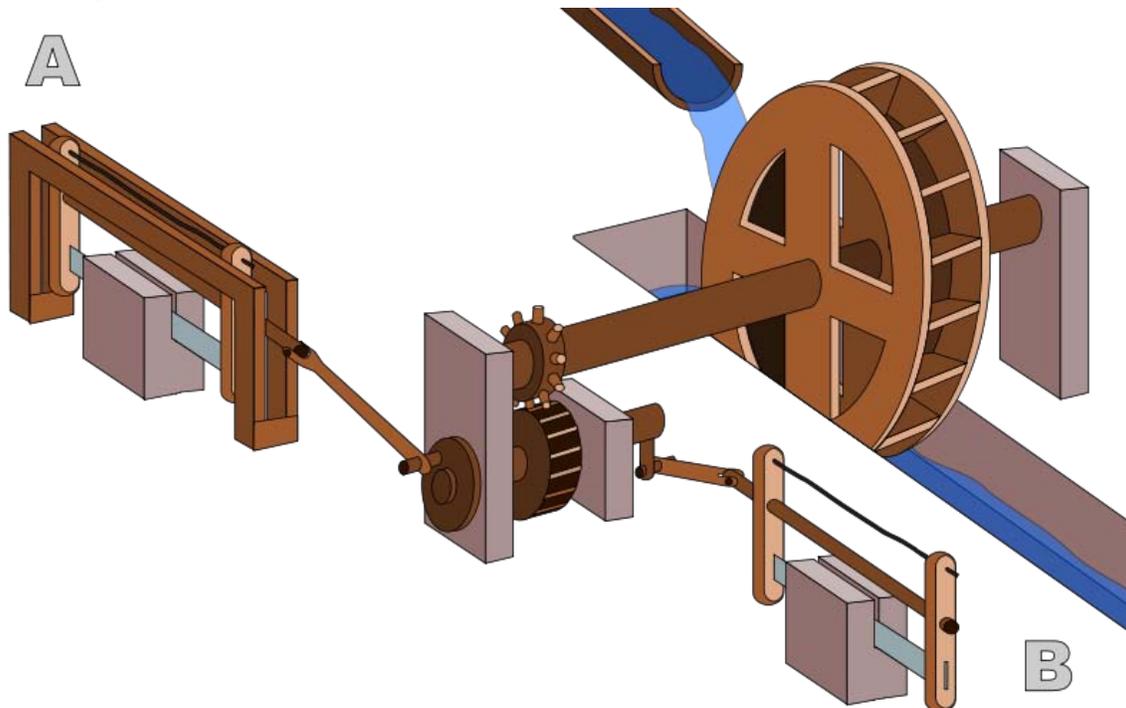
In a reciprocating piston engine, the **connecting rod** or **conrod** connects the piston to the crank or crankshaft. Together with the crank, they form a simple mechanism that converts linear motion into rotating motion.

Connecting rods may also convert rotating motion into linear motion. Historically, before the development of engines, they were first used in this way.

As a connecting rod is rigid, it may transmit either a push or a pull and so the rod may rotate the crank through both halves of a revolution, i.e. piston pushing and piston pulling. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push.

Today, connecting rods are best known through their use in internal combustion piston engines, such as car engines. These are of a distinctly different design from earlier forms of connecting rods, used in steam engines and steam locomotives.

History



Scheme of the Roman Hierapolis sawmill, the earliest known machine to combine a connecting rod with a crank.

The earliest evidence for a connecting rod appears in the late 3rd century AD Roman Hierapolis sawmill. It also appears in two 6th century Eastern Roman saw mills excavated at Ephesus respectively Gerasa. The crank and connecting rod mechanism of these Roman watermills converted the rotary motion of the waterwheel into the linear movement of the saw blades.

Sometime between 1174 and 1206, the Arab inventor and engineer Al-Jazari described a machine which incorporated the connecting rod with a crankshaft to pump water as part of a water-raising machine, but the device was unnecessarily complex indicating that he still did not fully understand the concept of power conversion.

In Renaissance Italy, the earliest evidence of a – albeit mechanically misunderstood – compound crank and connecting-rod is found in the sketch books of Taccola. A sound understanding of the motion involved displays the painter Pisanello (d. 1455) who showed a piston-pump driven by a water-wheel and operated by two simple cranks and two connecting-rods.

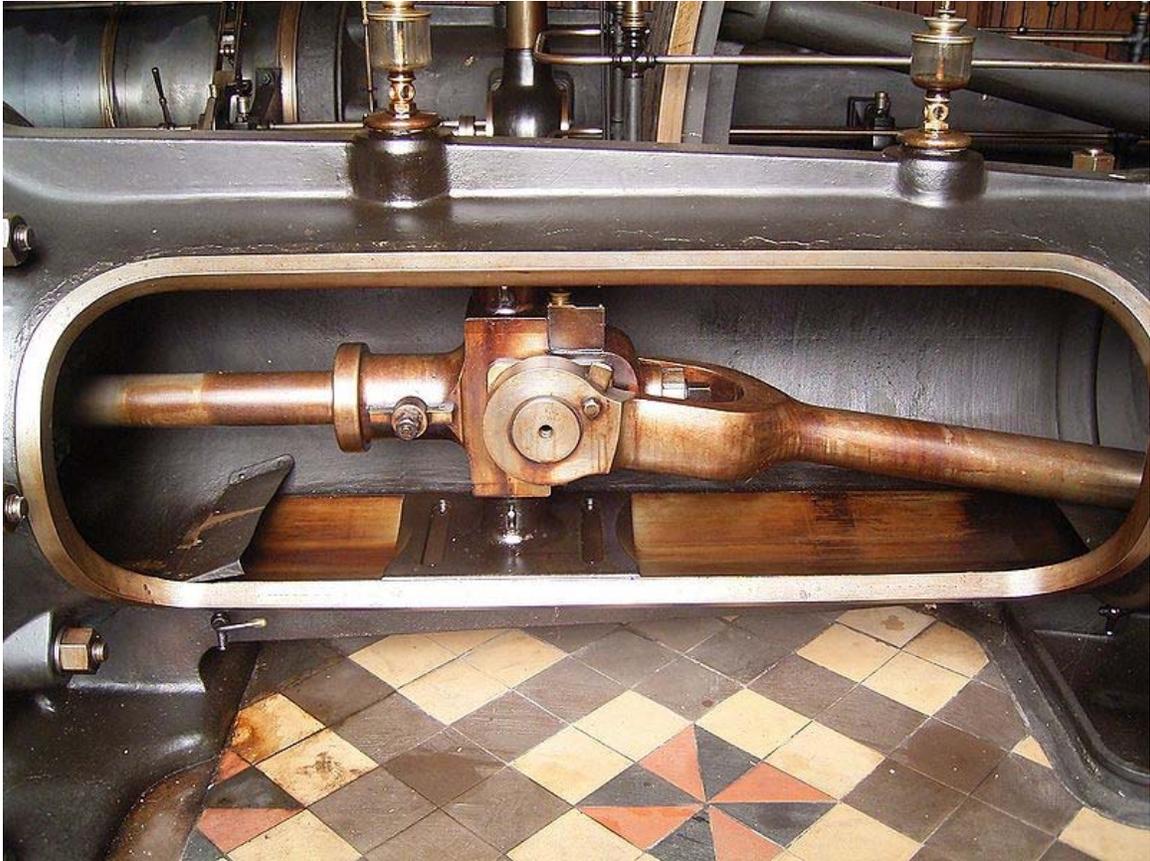
By the 16th century, evidence of cranks and connecting rods in the technological treatises and artwork of Renaissance Europe becomes abundant; Agostino Ramelli's *The Diverse and Artifactitious Machines* of 1588 alone depicts eighteen examples, a number which rises in the *Theatrum Machinarum Novum* by Georg Andreas Böckler to 45 different machines.

Steam engines



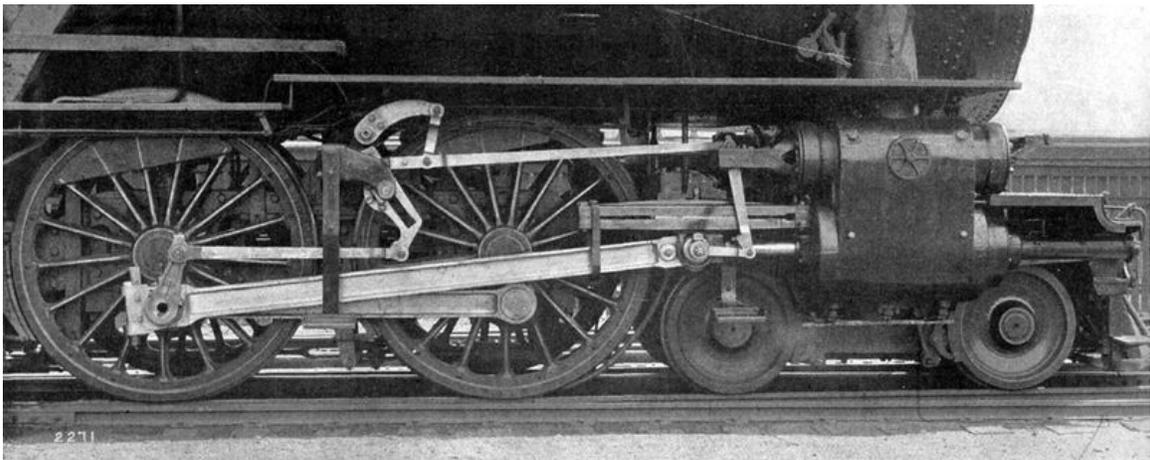
Beam engine, with twin connecting rods (almost vertical) between the horizontal beam and the flywheel cranks

The first steam engines, Newcomen's atmospheric engine, was single-acting: its piston only did work in one direction, and so these used a chain rather than a connecting rod. Their output rocked back and forth, rather than rotating continuously.



Crosshead of a stationary steam engine: piston rod to the left, connecting rod to the right

Steam engines after this are usually double-acting: their internal pressure works on each side of the piston in turn. This requires a seal around the piston rod and so the hinge between the piston and connecting rod is placed outside the cylinder, in a large sliding bearing block called a crosshead.



Steam locomotive rods, the large angled rod being the connecting rod

In a steam locomotive, the crank pins are usually mounted directly on one or more pairs of driving wheels, and the axle of these wheels serves as the crankshaft. The connecting rods, also called the **main rods** (*in US practice*), run between the crank pins and crossheads, where they connect to the piston rods. Crossheads or trunk guides are also used on large diesel engines manufactured for marine service. The similar rods between driving wheels are called **coupling rods** (*in British practice*).

The connecting rods of smaller steam locomotives are usually of rectangular cross-section but, on small locomotives, marine-type rods of circular cross-section have occasionally been used. Stephen Lewin, who built both locomotive and marine engines, was a frequent user of round rods. Gresley's A4 Pacifics, such as *Mallard*, had an alloy steel connecting rod with a web that was only 3/8" thick.

On Western Rivers steamboats, the connecting rods are properly called **pitmans**, and are sometimes incorrectly referred to as pitman arms.

Internal combustion engines



Failure of a connecting rod is one of the most common causes of catastrophic engine failure.

In modern automotive internal combustion engines, the connecting rods are most usually made of steel for production engines, but can be made of T6-2024 and T651-7075

aluminum alloys (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for a combination of lightness with strength, at higher cost) for high performance engines, or of cast iron for applications such as motor scooters. They are not rigidly fixed at either end, so that the angle between the connecting rod and the piston can change as the rod moves up and down and rotates around the crankshaft. Connecting rods, especially in racing engines, may be called "billet" rods, if they are machined out of a solid billet of metal, rather than being cast.

The **small end** attaches to the piston pin, gudgeon pin or wrist pin, which is currently most often press fit into the connecting rod but can swivel in the piston, a "floating wrist pin" design. The **big end** connects to the bearing journal on the crank throw, in most engines running on replaceable bearing shells accessible via the *connecting rod bolts* which hold the bearing "cap" onto the big end. Typically there is a pinhole bored through the bearing and the big end of the connecting rod so that pressurized lubricating motor oil squirts out onto the thrust side of the cylinder wall to lubricate the travel of the pistons and piston rings. Most small two-stroke engines and some single cylinder four-stroke engines avoid the need for a pumped lubrication system by using a rolling-element bearing instead, however this requires the crankshaft to be pressed apart and then back together in order to replace a connecting rod.

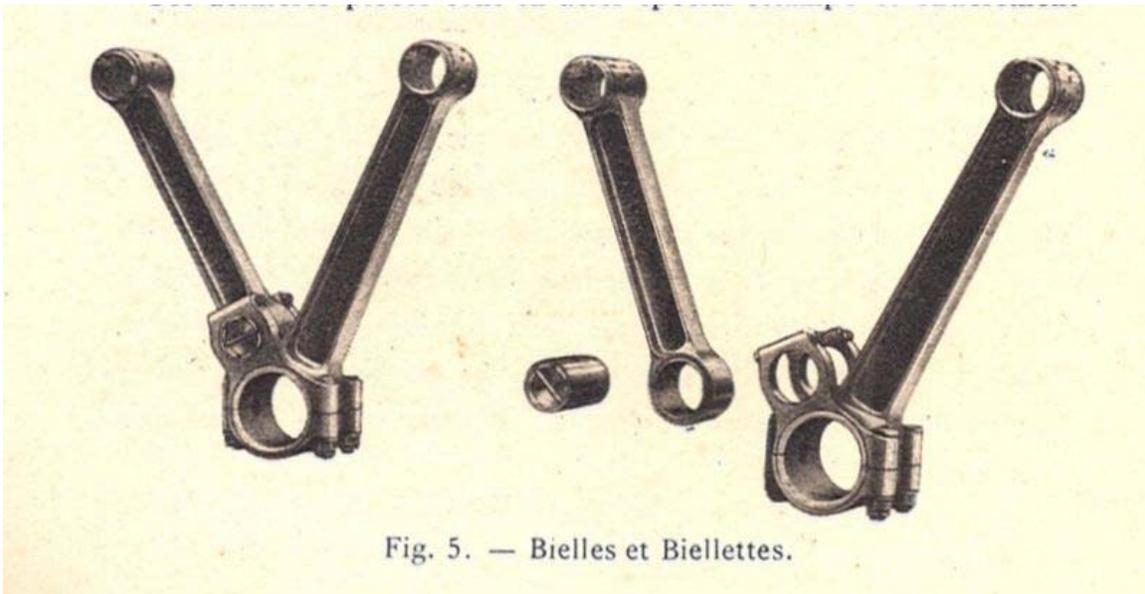
The connecting rod is under tremendous stress from the reciprocating load represented by the piston, actually stretching and being compressed with every rotation, and the load increases to the square of the engine speed increase. Failure of a connecting rod, usually called "throwing a rod" is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; it can result from fatigue near a physical defect in the rod, lubrication failure in a bearing due to faulty maintenance, or from failure of the rod bolts from a defect, improper tightening. Re-use of rod bolts is a common practice as long as the bolts meet manufacturer specifications. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety, and often more systematic quality control.

When building a high performance engine, great attention is paid to the connecting rods, eliminating stress risers by such techniques as grinding the edges of the rod to a smooth radius, shot peening to induce compressive surface stresses (to prevent crack initiation), balancing all connecting rod/piston assemblies to the same weight and Magnafluxing to reveal otherwise invisible small cracks which would cause the rod to fail under stress. In addition, great care is taken to torque the connecting rod bolts to the exact value specified; often these bolts must be replaced rather than reused. The big end of the rod is fabricated as a unit and cut or cracked in two to establish precision fit around the big end bearing shell. Therefore, the big end "caps" are not interchangeable between connecting rods, and when rebuilding an engine, care must be taken to ensure that the caps of the different connecting rods are not mixed up. Both the connecting rod and its bearing cap are usually embossed with the corresponding position number in the engine block.

Recent engines such as the Ford 4.6 liter engine and the Chrysler 2.0 liter engine, have connecting rods made using powder metallurgy, which allows more precise control of size and weight with less machining and less excess mass to be machined off for balancing. The cap is then separated from the rod by a fracturing process, which results in an uneven mating surface due to the grain of the powdered metal. This ensures that upon reassembly, the cap will be perfectly positioned with respect to the rod, compared to the minor misalignments which can occur if the mating surfaces are both flat.

A major source of engine wear is the sideways force exerted on the piston through the connecting rod by the crankshaft, which typically wears the cylinder into an oval cross-section rather than circular, making it impossible for piston rings to correctly seal against the cylinder walls. Geometrically, it can be seen that longer connecting rods will reduce the amount of this sideways force, and therefore lead to longer engine life. However, for a given engine block, the sum of the length of the connecting rod plus the piston stroke is a fixed number, determined by the fixed distance between the crankshaft axis and the top of the cylinder block where the cylinder head fastens; thus, for a given cylinder block longer stroke, giving greater engine displacement and power, requires a shorter connecting rod (or a piston with smaller compression height), resulting in accelerated cylinder wear.

Compound rods



Articulated connecting rods

Many-cylinder multi-bank engines such as a V12 layout have little space available for many connecting rod journals on a limited length of crankshaft. This is a difficult compromise to solve and its consequence has often led to engines being regarded as failures (Sunbeam Arab, Rolls-Royce Vulture).

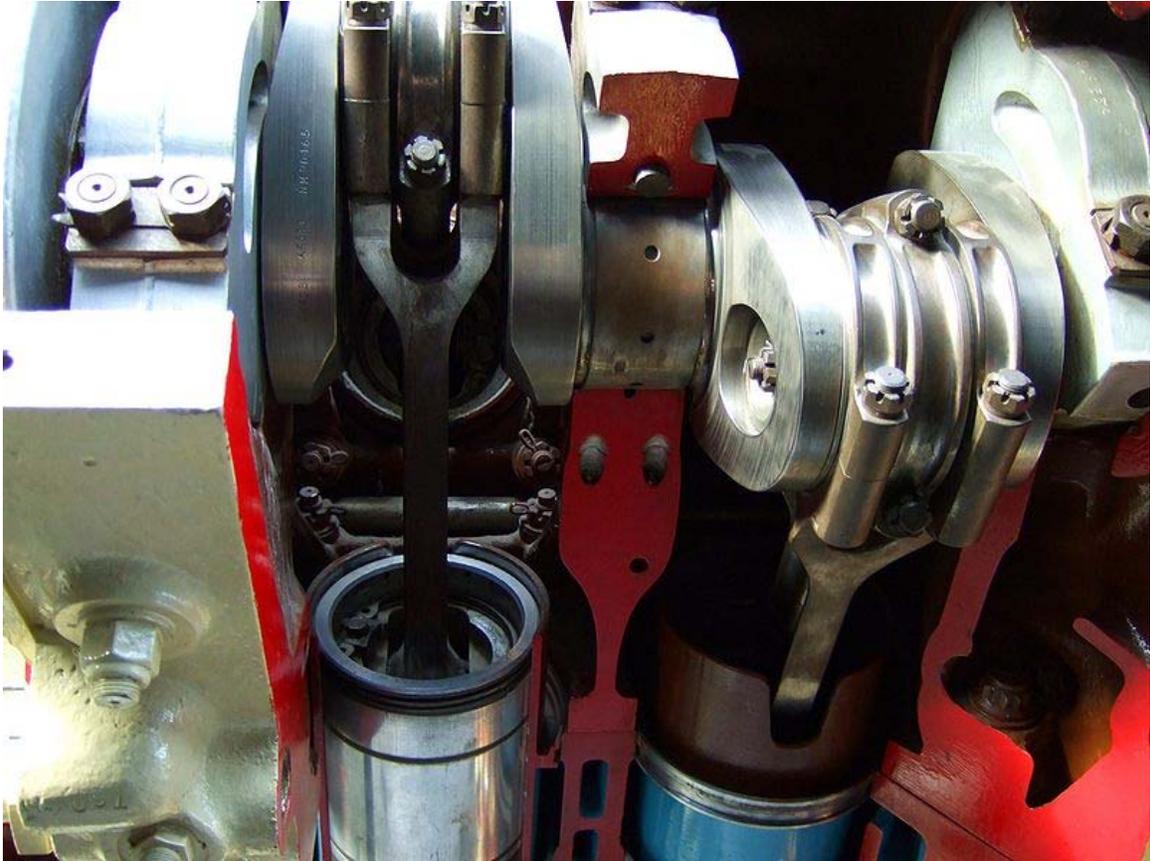
The simplest solution, almost universal in road car engines, is to use simple rods where cylinders from both banks share a journal. This requires the rod bearings to be *narrower*, increasing bearing load and the risk of failure in a high-performance engine. This also means the opposing cylinders are not exactly in line with each other.

In certain engine types, master/slave rods are used rather than the simple type shown in the picture above. The master rod carries one or more ring pins to which are bolted the much smaller big ends of slave rods on other cylinders. Certain designs of V engines use a master/slave rod for each pair of opposite cylinders. A drawback of this is that the stroke of the subsidiary rod is slightly shorter than the master, which increases vibration in a vee engine, catastrophically so for the Sunbeam Arab.



BMW 132 radial aero engine rods

Radial engines typically have a master rod for one cylinder and multiple slave rods for all the other cylinders in the same bank.



Fork and blade rods of a Napier Deltic

The usual solution for high-performance aero-engines is a "forked" connecting rod. One rod is split in two at the big end and the other is thinned to fit into this fork. The journal is still shared between cylinders. The Rolls-Royce Merlin used this "fork-and-blade" style.

Chapter 6

Countersteam Brake and Coupling Rod

Countersteam brake

A **countersteam brake** is a brake on a steam locomotive that uses the engine (specifically the cylinders) to help brake the locomotive.

It uses the working principle of steam cylinders fitted with piston valves such that, by changing the configuration of the valve gear, the motion of the valves is also altered such that they work in opposition to the movement of the pistons.

Because of the inertia of a steam locomotive in its initial direction of travel, changing the direction in which the steam cylinders have to work acts first to brake the movement of the connecting rod, which in turn slows the transmission of power to the drive of the locomotive until it stops.

The countersteam brake is often confused with the counterpressure brake, which works with air, not steam, and acts as a dynamic brake. Unlike the countersteam brake, the counterpressure brake is permitted to be used as an independent braking system in its own right.

Operation

The countersteam brake is actually not a brake in the true sense; but simply a way of using the working principle of a steam engine to produce a braking effect. It is therefore not a separate component of a steam locomotive. Countersteam braking is however only achievable with piston valves. On simple slide valves, no opposing steam admission is possible due to the way they are constructed.

Using the countersteam brake, experienced locomotive drivers can reverse the running direction of a steam locomotive almost as if it hasn't been brought to a stop, because the actual changeover point occurs whilst the locomotive is still moving in the initial direction of travel. This technique requires detailed knowledge and experience because if it is not carried out correctly, damage to the locomotive engine may result.

On steam locomotives without a second independent brake system (like e.g. a compressed-air brake, vacuum brake or steam brake) for the engine, in addition to the usual counterweight or fixed brake, the countersteam brake was used as a braking system. Today, steam locomotives generally have to have two independent brake systems in order to be licensed, so that the countersteam brake is not viewed as a braking system, but is nevertheless still used.

Coupling rod



connecting rod and coupling rods attached to a small locomotive driving wheel

A **coupling rod** or **side rod** connects the driving wheels of a locomotive. Steam locomotives in particular usually have them, but some diesel and electric locomotives, especially older ones and shunters, also have them. The coupling rods transfer the power to all the wheels.

Development

Locomotion No 1 was the first locomotive to employ coupling rods rather than chains. In the 1930s reliable roller bearing coupling rods were developed.

Balancing

The coupling rod's off-center attachment to the outside of the driving wheel inevitably creates an eccentric movement and vibration when in motion. To compensate for this, the driving wheels always had built-in counterweights that somewhat offset the angular momentum of the coupling rods. This vibration reduction was more effective when the rods move horizontally and less so when they are moving vertically. A counterweight is clearly visible at the top of the wheel in the image.

Coupling rods move in vertical motion as well as horizontally as the wheels rotate, but the engine's piston and its immediate attachments only move horizontally. Because the momentum of the connecting rods alone in up and down motion is considerably less than that resulting from the combined horizontal movement of the connecting rods, piston and driving rod, a wheel counterweight cannot be made to balance the entire assembly perfectly during its complete rotation. The counterweights have to be fixed in one position on their driving wheel to avoid a design complexity that would be both unreliable and unmaintainable.

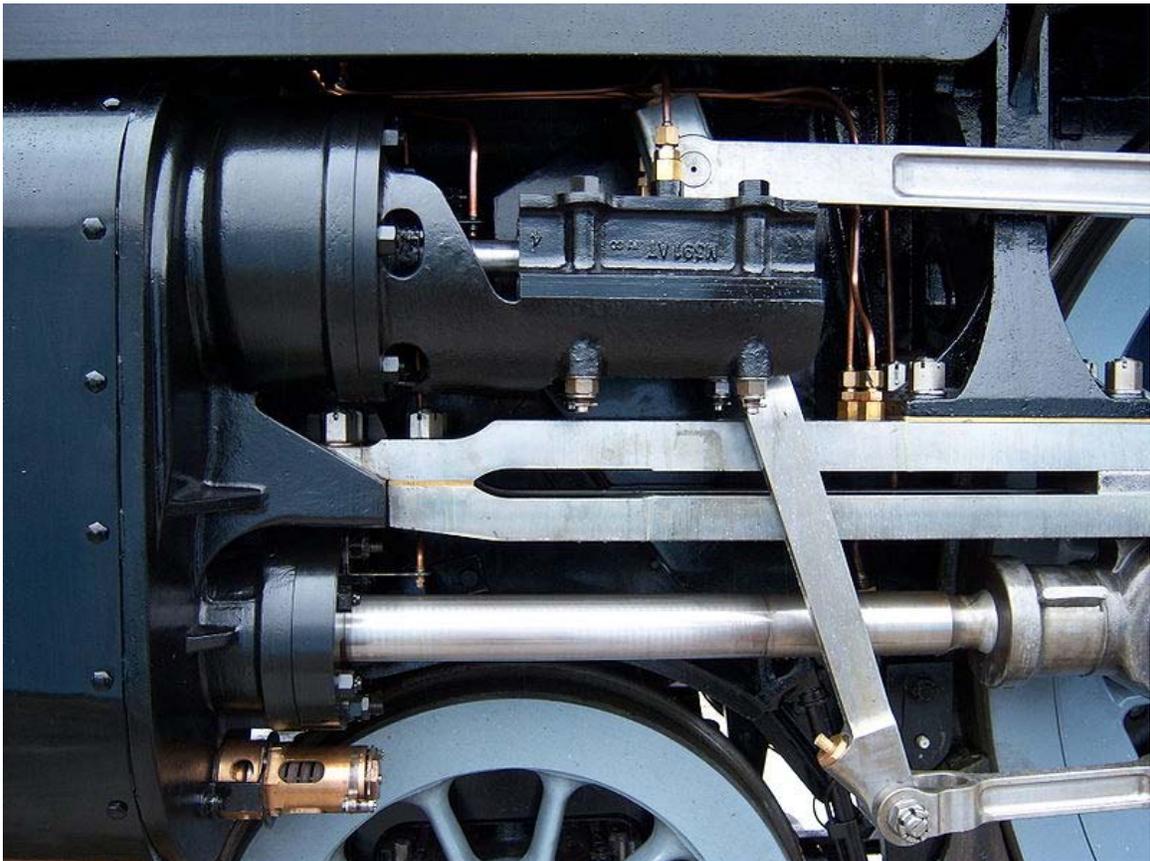
An inevitable vibration that results during the complete circular movement of the driving wheels and rods is called hammering and it is destructive to both the locomotive and the roadbed. In some locomotives, this hammering is so intense that at speed, the drivers alternately jump from the rail head, then slam down hard on the rails as the wheels complete their rotation. Unfortunately, hammering is inherent to conventional two-cylinder piston-driven steam locomotives and that is one of the several reasons they have been retired from service.

Materials

Initially, coupling rods were made of steel. As technology progressed and better materials became available, the connecting rods were manufactured of lighter and stronger alloys, which in turn permitted smaller counterweights and also reduced hammering.

Chapter 7

Cylinder (Locomotive)



The 'motion' on the left-hand side of 60163 *Tornado*. The black casting to the left houses the cylinder, in which slides the piston; the piston rod is immediately above the wheel.

The **cylinders** of a **steam locomotive** are the components that convert the power stored in the steam into motion.

Cylinders may be arranged in several different ways.

Early locomotives

On early locomotives (e.g. Puffing Billy) the cylinders were often set vertical and the motion was transmitted through beams, as in a beam engine.

Direct drive

The next stage (e.g. Stephenson's Rocket) was to drive the wheels directly from steeply inclined cylinders placed at the back of the locomotive. Direct drive became the standard arrangement but the cylinders were moved to the front and placed either horizontal or nearly horizontal.

Inside or outside cylinders

The front-mounted cylinders could be placed either inside (between the frames) or outside. Examples:

- Inside cylinders, Planet locomotive
- Outside cylinders, GNR Stirling 4-2-2

In the 19th and early 20th centuries, inside cylinders were widely used in the UK but outside cylinders were more common in Continental Europe and the USA. The reason for this difference is unclear. From about 1920, outside cylinders became more common in the UK but many inside-cylinder engines continued to be built.

Three or four cylinders

The demand for more power led to the development of engines with three cylinders (two outside and one inside) or four cylinders (two outside and two inside). Examples:

- Three cylinders, SR Class V
- Four Cylinders, LMS Princess Royal Class

Crank angles

On a two-cylinder engine the cranks, whether inside or outside, are set at 90 degrees. As the cylinders are double-acting (i.e. fed with steam alternately at each end) this gives four impulses per revolution and ensures that there are no dead centres.

On a three-cylinder engine, two arrangements are possible:

- cranks set to give six equally-spaced impulses per revolution – the usual arrangement. If the three cylinder axes are parallel the cranks will be 120 degrees

apart, but if the centre cylinder does not drive the leading driving axle it will probably be inclined (as on most US three-cylinder locomotives and on some of Gresley's three-cylinder locomotives in Great Britain) and the inside crank will be correspondingly shifted from 120 degrees.

- outside cranks set at 90 degrees, inside crank set at 135 degrees, giving six unequally spaced impulses per revolution. This arrangement was sometimes used on three-cylinder compound locomotives which used the outside (low pressure) cylinders for starting. This will give evenly-spaced exhausts when the engine is working compound.

Two arrangements are also possible on a four-cylinder engine:

- all four cranks set at 90 degrees. With this arrangement the cylinders act in pairs so there are four impulses per revolution, as with a two-cylinder engine.
- pairs of cranks set at 90 degrees with the inside pair set at 45 degrees to the outside pair. This gives eight impulses per revolution. It increases weight and complexity, by requiring four sets of valve gear, but gives smoother torque and reduces the risk of slipping.

Valves

The **valve chests** or **steam chests** which contain the slide valves or piston valves may be located in various positions.

Inside cylinders

If the cylinders are small, the valve chests may be located between the cylinders. For larger cylinders the valve chests are usually on top of the cylinders but, in early locomotives, they were sometimes underneath the cylinders.

Outside cylinders

The valve chests are usually on top of the cylinders but, in older locomotives, the valve chests were sometimes located alongside the cylinders and inserted through slots in the frames. This meant that, while the cylinders were outside, the valves were inside and could be driven by inside valve gear.

Valve gear

There are many variations in the location of the valve gear. In British practice, inside valve gear is usually of the Stephenson type while outside valve gear is usually of the Walschaerts type. However, this is not a rigid rule and most types of valve gear are capable of being used either inside or outside. Joy valve gear was once popular, e.g. on the LNWR G Class.

Inside cylinders

On inside cylinder engines the valve gear is nearly always inside (between the frames), e.g. LMS Fowler Class 3F.

Outside cylinders

On engines with outside cylinders there are three possible variations:

- Inside valve gear driving inside valves, e.g. NER Class T2
- Inside valve gear driving outside valves through rocking shafts, e.g. GWR 4900 Class
- Outside valve gear driving outside valves, e.g. LSWR N15 Class

Three cylinders

There are three common variations:

- Three sets of valve gear (two outside, one inside), e.g. LNER Peppercorn Class A2
- Outside valve gear driving the outside valves. Inside valve driven by Gresley conjugated valve gear, e.g. LNER Class A1/A3
- Three sets of inside valve gear (all valves inside), e.g. NER Class T3

Four cylinders

There are three common variations:

- Four sets of valve gear (two outside, two inside), e.g. SR Lord Nelson Class
- Inside valve gear driving the inside valves directly and the outside valves via rocking shafts, e.g. GWR 4073 Class
- Outside valve gear driving the outside valves directly and the inside valves via rocking shafts, e.g. LMS Princess Coronation Class

Other variations



The cylinders on a Shay locomotive.

There are many other variations, e.g. geared steam locomotives which may have only one cylinder. The only conventional steam locomotive with one cylinder that is known is the Nielson One-Cylinder Locomotive.

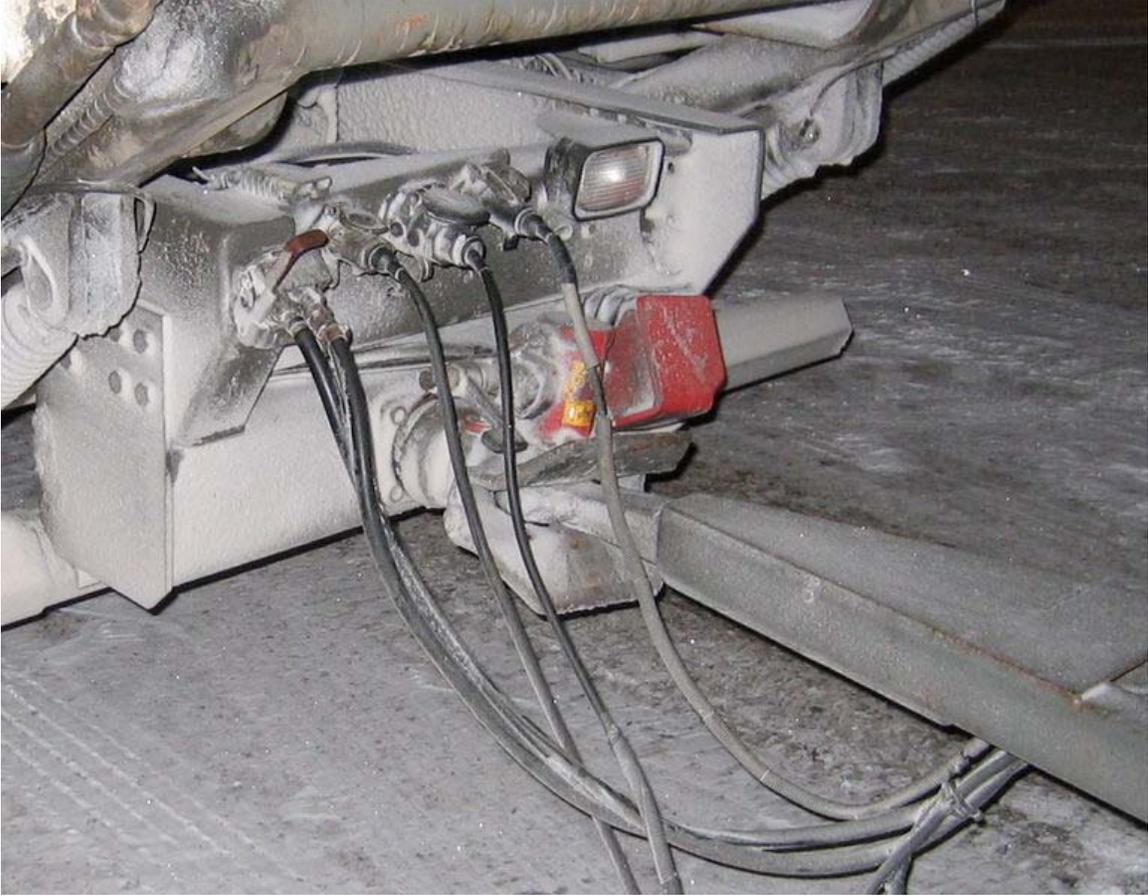
Chapter 8

Drawbar (Haulage) and Driving Wheel

Drawbar (haulage)



Pickfords ballast tractor with exceptional load on specialist trailer. The tractor is a Scammell, and is connected to the trailer via a drawbar.



Heavy duty drawbar system on a truck

A **drawbar** is a solid coupling between a hauling vehicle and its hauled load. Drawbars are in common use with rail transport, road trailers, both large and small, industrial and recreational, and with agricultural equipment.

Agriculture

Agricultural equipment is hauled from a tractor mounted drawbar. Specialist agricultural tools such as ploughs are attached to specialist drawbars which have functions in addition to transmitting tractive force.

Road

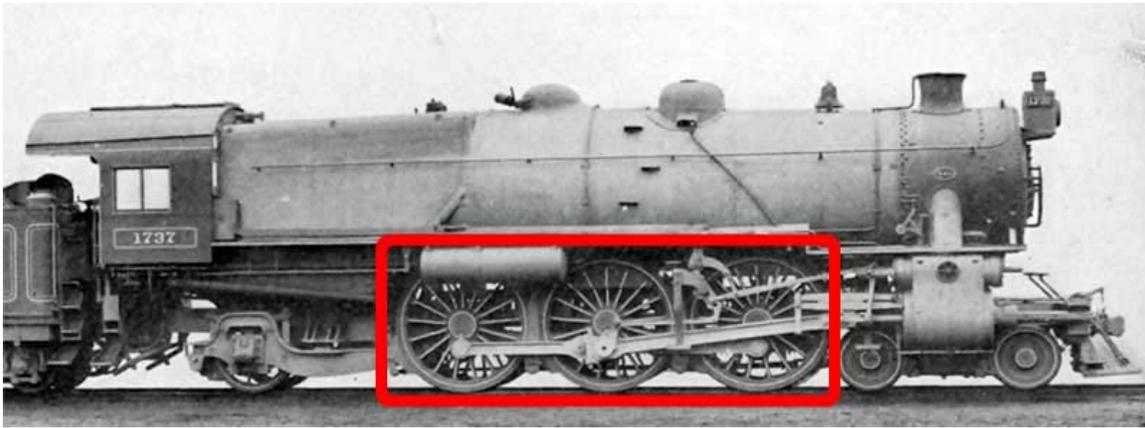
The drawbar should not be confused with the fifth wheel coupling. The drawbar requires a trailer which either loads the drawbar lightly (for example a small boat trailer, or caravan, where a load of up to ~50 kg is part of correct trailer loading practice), or the load is the weight of the coupling components only (larger trailers, usually but not always with a steerable hauled axle, front or rear). By contrast, the fifth wheel is designed to transmit a major proportion of the load's weight to the hauling vehicle.

A drawbar is mounted or located on the tractive vehicle and is used to accept the coupling of the load. The direction of haulage may be push or pull, though pushing tends to be for a pair of ballast tractors working one pulling and the other pushing an exceptional load on a specialist trailer.

Rail

A rail locomotive hauls its load through a drawbar and hauling force is transmitted between rolling stock via drawbars between units. With rail transport the tractive effort is "cascaded" through the train of wagons. Each wagon, even though unpowered, may be considered the tractive vehicle for the wagon(s) further away in the chain.

Driving wheel



The driving wheels (boxed) on a 4-6-2 locomotive.



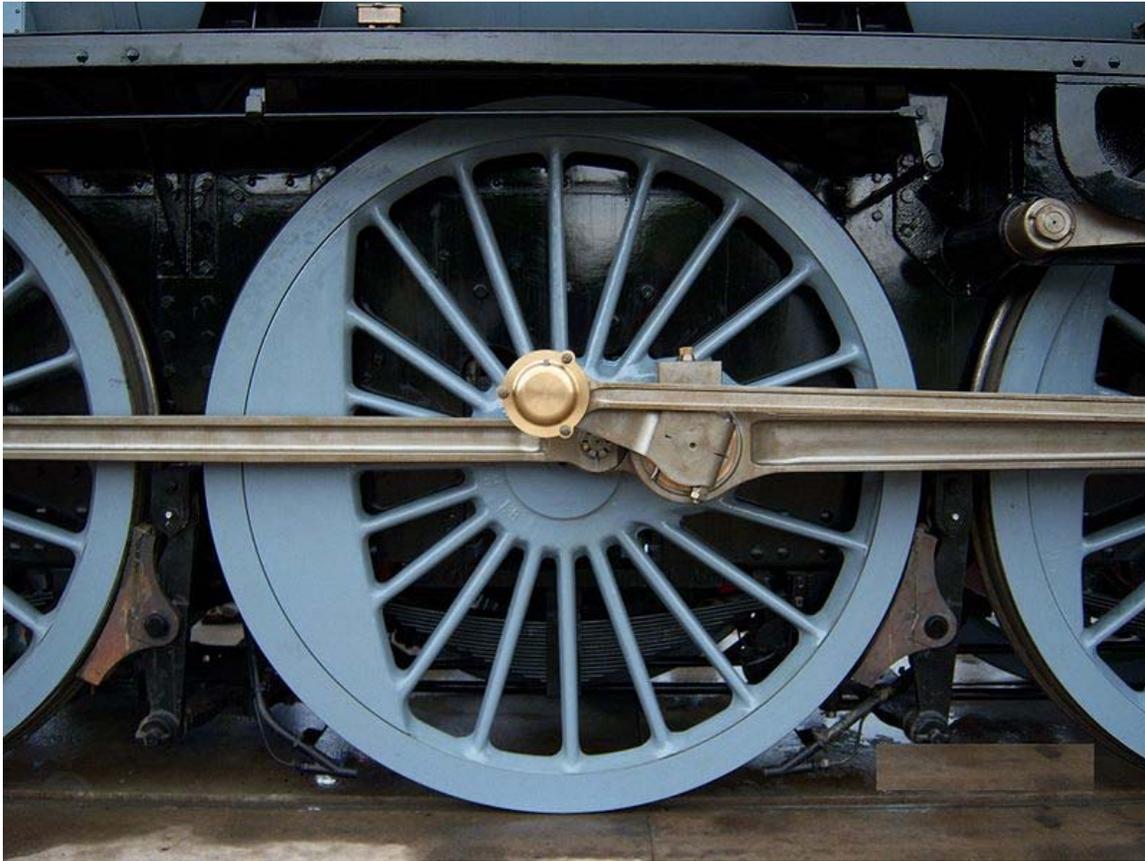
The four driving wheels on one side of a 4-8-4 locomotive.

On a steam locomotive, a **driving wheel** is a powered wheel which is driven by the locomotive's pistons (or turbine, in the case of a steam turbine locomotive). On a conventional, non-articulated locomotive, the driving wheels are all coupled together with side rods (also known as coupling rods); normally one pair is directly driven by the main rod (or connecting rod) which is connected to the end of the piston rod; power is transmitted to the others through the side rods.

On Diesel and Electric locomotives the driving wheels may be directly driven by the traction motors. Coupling rods are not usually used, and it is quite common for each axle to have its own motor. Jackshaft drive and coupling rods were used in the past (e.g. in the Swiss Crocodile locomotive) but their use is now confined to shunting locomotives.

On an articulated locomotive or a duplex locomotive driving wheels are grouped into sets which are linked together within the set.

Diameter

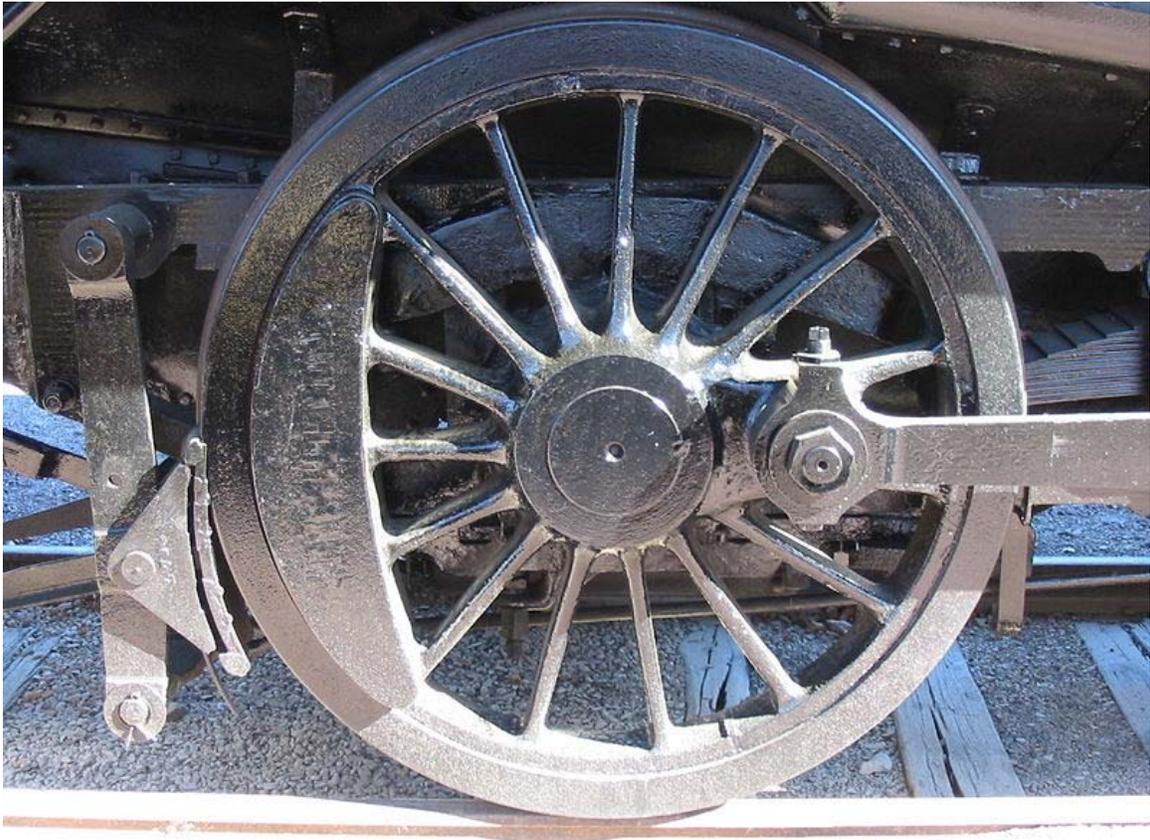


One of six 6 ft 8 in (2.03 m) driving wheels belonging to 60163 *Tornado*

Driving wheels are generally larger than leading or trailing wheels. Since a conventional steam locomotive is directly driven, one of the few ways to 'gear' a locomotive for a particular performance goal is to size the driving wheels appropriately. Freight locomotives generally had driving wheels between 40 and 60 inches (1,016 and 1,524 mm) in diameter; dual-purpose locomotives generally between 60 and 70 inches (1,524 and 1,778 mm), and passenger locomotives between 70 and 100 inches (1,778 and 2,540 mm) or so. Some long wheelbase locomotives (four or more coupled axles) were equipped with **blind drivers**. These were driving wheels without the usual flanges, which allowed them to negotiate tighter curves without binding.

The driving wheels on express passenger locomotives have come down in diameter over the years, e.g. from 8 ft 1 in (2,464 mm) on the GNR Stirling 4-2-2 of 1870 to 6 ft 2 in (1,880 mm) on the SR Merchant Navy Class of 1941. This is because improvements in valve design allowed for higher piston speeds.

Balancing



A driving wheel on a steam locomotive.

On steam locomotives the driving wheels have balance weights to balance the weight of the coupling and connecting rods. The crescent-shaped balance weight is clearly visible in the picture on the right.

Whyte notation

In the Whyte notation, driving wheels are designated by the middle number or numbers in the set. The UIC classification system counts the number of axles rather than the number of wheels and driving wheels are designated by letters rather than numbers. The suffix 'o' is used to indicate independently powered axles.

The number of driving wheels on locomotives varied quite a bit. Some early locomotives had as few as two driving wheels (one axle). The largest number of total driving wheels was 24 (twelve axles) on the 2-8-8-8-2 and 2-8-8-8-4 locomotives. The largest number of coupled driving wheels was 14 (seven axles) on the ill-fated AA20 4-14-4 locomotive.

Other uses of the term driving wheel

The term **driving wheel** is sometimes used to denote the **drive sprocket** which moves the track on tracked vehicles such as tanks and bulldozers.

Chapter 9

Dynamic Braking



NS #5348 sporting a Dynamic brake.

Dynamic braking is the use of the electric traction motors of a railroad vehicle as generators when slowing the vehicle. It is termed *rheostatic* if the generated electrical power is dissipated as heat in brake grid resistors, and *regenerative* if the power is

returned to the supply line. Dynamic braking lowers the wear of friction-based braking components, and additionally regeneration can also lower energy consumption.

Principle of operation

During braking, the motor fields are connected across either the main traction generator (diesel-electric loco) or the supply (electric locomotive) and the motor armatures are connected across either the brake grids or supply line. The rolling locomotive wheels turn the motor armatures, and if the motor fields are now excited, the motors will act as generators.

For a given direction of travel, current flow through the motor armatures during braking will be opposite to that during motoring. Therefore, the motor exerts torque in a direction that is opposite from the rolling direction. Braking effort is proportional to the product of the magnetic strength of the field windings, times that of the armature windings.

For permanent magnet motors, dynamic braking is easily achieved by shorting the motor terminals, thus bringing the motor to a fast abrupt stop. This method, however, dissipates all the energy as heat in the motor itself, and so cannot be used in anything other than low-power intermittent applications due to cooling limitations. It is not suitable for traction applications.

Rheostatic braking

The electrical energy produced by the motors is dissipated as heat by a bank of onboard resistors. Large cooling fans are necessary to protect the resistors from damage. Modern systems have thermal monitoring, so if the temperature of the bank becomes excessive, it will be switched off, and the braking will revert to air only.

Regenerative braking

In electrified systems the similar process of **regenerative braking** is employed whereby the current produced during braking is fed back into the power supply system for use by other traction units, instead of being wasted as heat. It is normal practice to incorporate both regenerative and rheostatic braking in electrified systems. If the power supply system is not "*receptive*", i.e. incapable of absorbing the current, the system will default to rheostatic mode in order to provide the braking effect.

Yard locomotives with onboard energy storage systems which allow the recovery of some of this energy which would otherwise be wasted as heat are now available. The Green Goat model, for example, is being used by Canadian Pacific Railway, BNSF Railway, Kansas City Southern Railway and Union Pacific Railroad.

Blended braking



A picture of an ex-Connex Class 466 EMU at Blackfriars station in the year 2006. The popular Class 466 EMUs use Dynamic blended braking.

Dynamic braking alone is insufficient to stop a locomotive, as its braking effect rapidly diminishes below about 10 to 12 miles per hour (16 to 19 km/h). Therefore it is always used in conjunction with the regular air brake. This combined system is called **blended braking**. Li-ion batteries have also been used to store energy for use in bringing trains to a complete halt.

Although blended braking combines both dynamic and air braking, the resulting braking force is designed to be the same as what the air brakes on their own provide. This is achieved by maximizing the dynamic brake portion, and automatically regulating the air brake portion, as the main purpose of dynamic braking is to reduce the amount of air braking required. This conserves air, and minimizes the risks of over-heated wheels. One locomotive manufacturer, Electro-Motive Diesel (EMD), estimates that dynamic braking provides between 50% to 70% of the braking force during blended braking.

Self-load test

It is possible to use the brake grids as a form of dynamometer or load bank to perform a "self load" test of locomotive engine horsepower. With the locomotive stationary, the main generator (MG) output is connected to the grids instead of the traction motors. The

grids are normally large enough to absorb the full engine output power, which is calculated from MG voltage and current output.

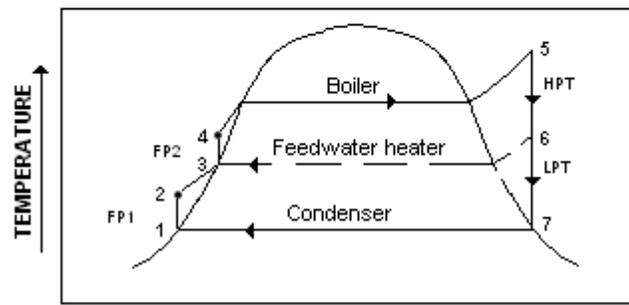
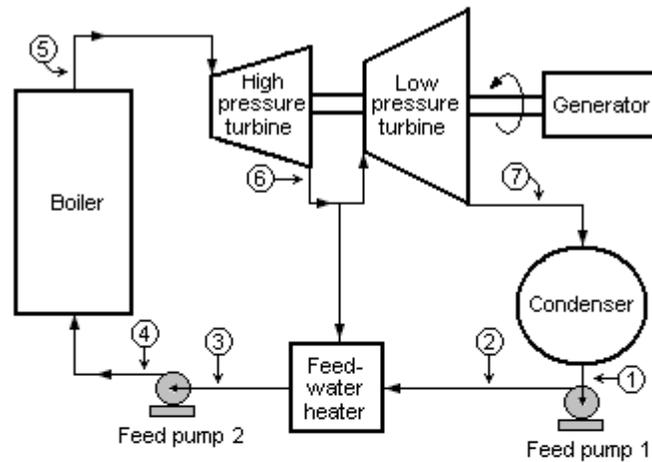
Hydrodynamic braking

Diesel engined locomotives with hydraulic transmission may be equipped for hydrodynamic braking. In this case, the torque converter or fluid coupling acts as a retarder in the same way as a water brake. Braking energy heats the hydraulic fluid, and the heat is dissipated (via a heat exchanger) by the engine cooling radiator. The engine will be idling (and producing little heat) during braking, so the radiator is not overloaded.

Chapter 10

Feedwater Heater and Giesl Ejector

Feedwater heater



FP1 = Feed pump 1
FP2 = Feed pump 2
HPT = High pressure turbine
LPT = Low pressure turbine

A Rankine cycle with two steam turbines and a single open feedwater heater.

A **feedwater heater** is a power plant component used to pre-heat water delivered to a steam generating boiler. Preheating the feedwater reduces the irreversibilities involved in steam generation and therefore improves the thermodynamic efficiency of the system. This reduces plant operating costs and also helps to avoid thermal shock to the boiler metal when the feedwater is introduced back into the steam cycle. Many of the locomotive systems are **ACFI** type.

In a steam power plant (usually modeled as a modified Rankine cycle), feedwater heaters allow the feedwater to be brought up to the saturation temperature very gradually. This minimizes the inevitable irreversibilities associated with heat transfer to the working fluid (water).

Cycle discussion and explanation

The energy used to heat the feedwater is usually derived from steam extracted between the stages of the steam turbine. Therefore, the steam that *would be used* to perform expansion work in the turbine (and therefore generate power) is not utilized for that purpose. The percentage of the total cycle steam mass flow used for the feedwater heater is termed the extraction fraction and must be carefully optimized for maximum power plant thermal efficiency since increasing this fraction causes a decrease in turbine power output.

Feedwater heaters can also be *open* and *closed* heat exchangers. An open feedwater heater is merely a direct-contact heat exchanger in which extracted steam is allowed to mix with the feedwater. This kind of heater will normally require a feed pump at both the feed inlet and outlet since the pressure in the heater is between the boiler pressure and the condenser pressure. A deaerator is a special case of the open feedwater heater which is specifically designed to remove non-condensable gases from the feedwater.

Closed feedwater heaters are typically shell and tube heat exchangers where the feedwater passes throughout the tubes and is heated by turbine extraction steam. These do not require separate pumps before and after the heater to boost the feedwater to the pressure of the extracted steam as with an open heater. However, the extracted steam (which is most likely almost fully condensed after heating the feedwater) must then be throttled to the condenser pressure, an isenthalpic process that results in some entropy gain with a slight penalty on overall cycle efficiency.

Many power plants incorporate a number of feedwater heaters and may use both open and closed components.

Feedwater heaters are used in both fossil- and nuclear-fueled power plants. Smaller versions have also been installed on steam locomotives, portable engines and stationary engines. An economiser serves a similar purpose to a feedwater heater, but is technically different. Instead of using actual cycle steam for heating, it uses the lowest-temperature flue gas from the furnace (and therefore does not apply to nuclear plants) to heat the water before it enters the boiler proper. This allows for the heat transfer between the

furnace and the feedwater to occur across a smaller average temperature gradient (for the steam generator as a whole). System efficiency is therefore further increased when viewed with respect to actual energy content of the fuel.

Giesl ejector



Steam locomotive with Giesl flat ejector



Austrian 0-12-0T and 0-6-2T fitted with Giesl ejectors, Eisenerz depot, August 1971

A **Giesl ejector** is a suction draught system for steam locomotives that works on the same principle as a feedwater pump.

This ejector (German: *Ejektor*, *Flachschorstein* or *Quetschesse*) was invented in 1951 by the Austrian engineer, Dr. Adolph Giesl-Gieslingen. The Giesl ejector ensures improved suction draught and a correspondingly better use of energy. The existing blastpipe in a locomotive is replaced by several, small, fan-shaped, diverging blast pipes, from which the diffuser gets its flat, long, drawn-out shape.

Giesl claimed that his ejector enabled a saving in coal of between 6 and 12 % – although in practice the maximum saving was more like 8 % – and an increase in power of up to 20 %. Many railway administrations converted their steam engines to Giesl ejectors, including the ÖBB, ČSD and Deutsche Reichsbahn (DR) in East Germany, as well as railway companies in Africa, China and Japan. The licence fees were not paid in every case, it being said that often they almost cancelled out the saving in coal. In the DR it was assessed that the Giesl ejectors would pay for themselves within a year, as a result of which they converted over 500 locomotives; primarily the Classes 38.10, 50, 52 and 65.10.

Use in the United Kingdom



Ejector from *Edward Thomas*, on display in the Narrow Gauge Railway Museum

In 1958, Dr Giesl-Gieslingen approached British Railways to offer a free trial of the ejector. When this offer was turned down, the inventor made the same offer to the preserved Talyllyn Railway in Wales, and locomotive No. 4, *Edward Thomas* was fitted with one. Although a coal saving of 40% was officially announced at the time, this has since been disputed by the railway's chief engineer. The ejector was removed in 1969, and no difference in coal consumption was found. The ejector is now on display in the Narrow Gauge Railway Museum at Tywyn.

In 1962, Bulleid Battle of Britain class 4-6-2 34064 *Fighter Command* was fitted with a Giesl ejector on the grounds that a desired spark arrestor would "suffocate" an ordinary blastpipe. It quickly became apparent, following some adjustment, that the ejector improved the locomotive design, and it was held in high regard by the crews. As a consequence of this experience and for the same reasons, during the 1980s the preserved Bulleid West Country class 4-6-2 34092 *City of Wells* was similarly fitted at the Keighley and Worth Valley Railway.

A BR Standard Class 9F 2-10-0 92250 was also fitted with a Giesl ejector, but with "indifferent" results.

Chapter 11

Long Hood and Leading Wheel

Long hood

The **long hood** of a hood unit-style diesel locomotive is, as the name implies, the longer of the two hoods (narrower sections of the locomotive body in front and behind of the cab) on a locomotive.

Equipment

The long hood normally contains the diesel engine (prime mover), the main generator or alternator, the locomotive's cooling radiators, the dynamic brake resistor grids if fitted, and most of the locomotive's auxiliary equipment. Head-end power equipment, if fitted, is normally in the long hood; steam generators for heating older passenger cars may be either in the long or short hoods.

Operating direction

Normally, the long hood is the rear of the locomotive. For early hood unit models, this was not the case; railroads preferred to have the long hood at the front and the cab at the rear, as in a steam locomotive; this followed crew preference for greater protection in a collision. Later, preferences changed to having the short hood at the front and the long hood at the rear, for better visibility, especially when more powerful engines required larger, visibility-obscuring radiator units.

United States



A Norfolk Southern GP38-2 operating long hood forward through Ridgewood, New Jersey.

The railroads that held out the longest for long-hood leading were the Norfolk and Western Railway and the Southern Railway (later merged into the Norfolk Southern). When Southern Railway received their first EMD GP7s, they were delivered with a high, short hood, and Southern Railway pointed the locomotive LHF for crew safety. After the first GP7s hit the Southern Railway System, subsequent locomotives were ordered with the high, short hood and the long hood designated (starting after the SD45 order) as the front. Here is a list of each locomotive Southern ordered with a high, short hood, and operated LHF.

General Motors Electro-Motive Division

- GP7,
- GP9,
- GP18,
- GP38,
- GP38-2,
- GP40X (SOU 7000-7002),
- GP49 (SOU 4600-4605),

- GP50 (SOU 7003-7092),
- SD7,
- SD9,
- SD35,
- SD40,
- SD40-2,
- SD45

(note: the SD50 and the GP59 are the first units ordered with the low, short hood, and pointed LHF)

General Electric Transportation Systems

- B30-7,
- U23B,
- B23-7,
- U30C,
- U30B,
- U33C,

The Norfolk and Western Railway (NW) operated as Southern Railway did, with the long hood toward the front; the only difference between NW locomotives and the Southern Railway locomotives was the position of the bell. NW had the bell on the short hood while Southern had the bell on the long hood.

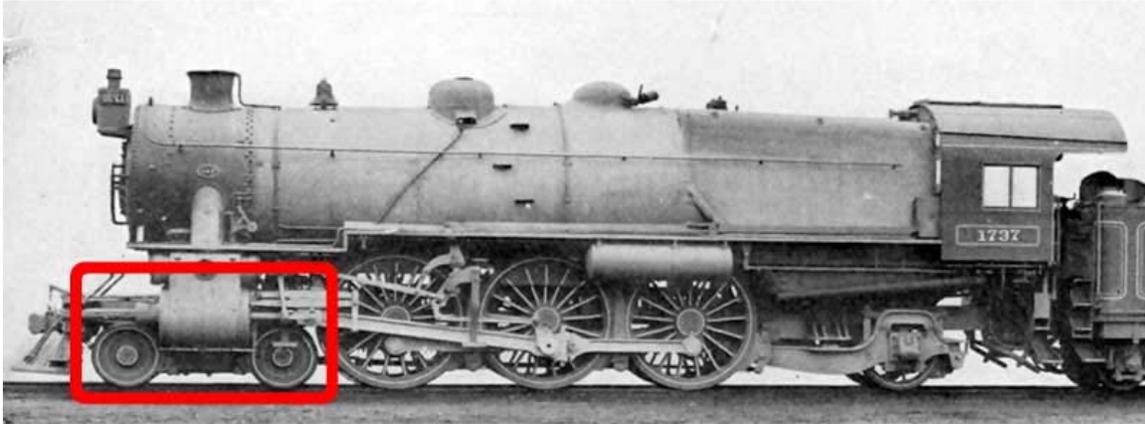
It should also be noted that many early diesel locomotive builders designated the long hood end of their road switchers as the front. Examples include models manufactured by the American Locomotive Company and Baldwin Locomotive Works.

Long hood forward is a fading practice. Most modern production of locomotives in the USA feature wide cabs, which bar the ability to run the unit LHF because most modern production locomotives have desktop style controls. The desktop style prevents the engineer from turning in his or her chair to face the other end of the locomotive.

Great Britain

The term Long hood forward is not used in Britain and the hood would be described as a "bonnet" or "engine compartment". Most British diesel locomotives have a cab at each end so the term does not apply. Where a single-cab design was used it was designed to be operated long hood forward but, in practice, it might operate in either direction, like a steam tank locomotive. Apart from shunters, the only single-cab class still in service in Britain is the British Rail Class 20. These are now usually operated cab forward (often in pairs) to give the driver a better view of the road ahead and some have been fitted with nose-mounted video cameras for use when working long hood forward.

Leading wheel



The leading wheels (boxed) on a 4-6-2 locomotive

The **leading wheel** or **leading axle** of a steam locomotive is an unpowered wheel or axle located in front of the driving wheels. The axle or axles of the leading wheels are normally located in a truck (or "bogie"). Leading wheels are used to help the locomotive negotiate curves and to support the front portion of the boiler.

Importantly, the leading bogie does not have simple rotational motion about a vertical pivot, as might first be thought. It must also be free to slip sideways to a small extent (otherwise the locomotive is unable to follow curves accurately – a point lost on the 19th century railway pioneers), and some kind of springing mechanism is normally included to control this movement and give a tendency to return to centre. The sliding bogie of this type was patented by William Adams in 1865. The first use of leading wheels is commonly attributed to John B. Jervis who employed them in his 1832 design for a locomotive with four leading wheels and two driving wheels (a type that became known as the *Jervis*). In the Whyte system of describing locomotive wheel arrangements, his locomotive would be classified as a 4-2-0: that is to say, it had four leading wheels, two driving wheels, and no trailing wheels. In the UIC classification system, which counts axles rather than wheels and uses letters to denote powered axles, the *Jervis* would be classified 2-A.

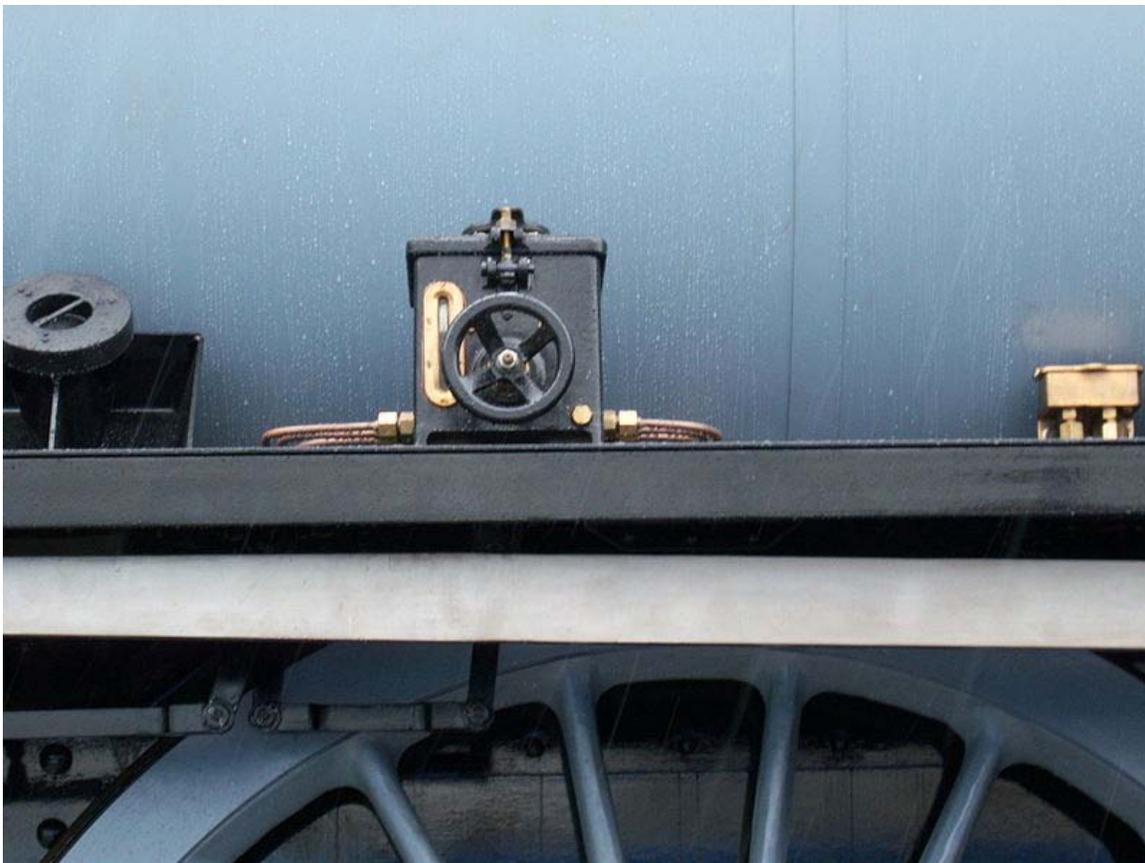
Locomotives without leading trucks are generally regarded as unsuitable for high speed use. The British Railway Inspectorate condemned the practice in 1895, following an accident involving two 0-4-4s at Doublebois, Cornwall, on the Great Western Railway. Other designers, however, persisted with the practice and the famous 0-4-2 Gladstone class passenger expresses of the London, Brighton and South Coast Railway remained in trouble-free service until 1933. A single leading axle (known as a pony truck) increases stability somewhat, while a four-wheel leading truck is almost essential for high-speed operation.

The highest number of leading wheels on a single locomotive is six as seen on the 6-2-0 Crampton type and the Pennsylvania Railroad's 6-4-4-6 S1 duplex locomotive and 6-8-6 S2 steam turbine. Six-wheel leading trucks were not very popular. The Cramptons were built in the 1840s, but it wasn't until 1939 that the PRR used one on the S1.

Chapter 12

Mechanical Lubricator and Pantograph (Rail)

Mechanical lubricator



Modern locomotive lubricators. The centre item is a mechanical lubricator for the cylinders, operated by the connecting lever seen below it (or by the hand wheel, for priming). The smaller one to the right is a drip-feed lubricator.

A **Mechanical lubricator**, or automatic lubricator, is a device fitted to a steam engine to supply lubricating oil to the cylinders and, sometimes, the bearings and axle box mountings as well. There are various types of mechanical lubricator.

Displacement lubricator

The displacement lubricator was introduced in the United Kingdom in 1860 by John Ramsbottom. It operates by allowing steam to enter a closed vessel containing oil. After condensing, the water sinks to the bottom of the vessel, causing the oil to rise and overflow into delivery pipes. The oil from the delivery pipes is introduced into the steam pipe, where it is atomised and carried to the valves and cylinders.

In early applications in steam locomotives, either two displacement lubricators (one for each cylinder) would be positioned at the front of the boiler near the valves, often on either side of the smokebox or one lubricator would be placed behind the smokebox. The behind smokebox configuration has the advantage that a good connection can be made to the steam pipe and was used by the Great Western Railway. It has the disadvantage that the lubricator's accessibility is reduced and additional drain pipes are required to be connected to the waste to avoid it dripping onto the boiler.

Later types of lubricator (from around 1887), referred to as the "sight-feed" type, allowed a sight glass to be positioned in the cab where the rate of oil feed could be observed.

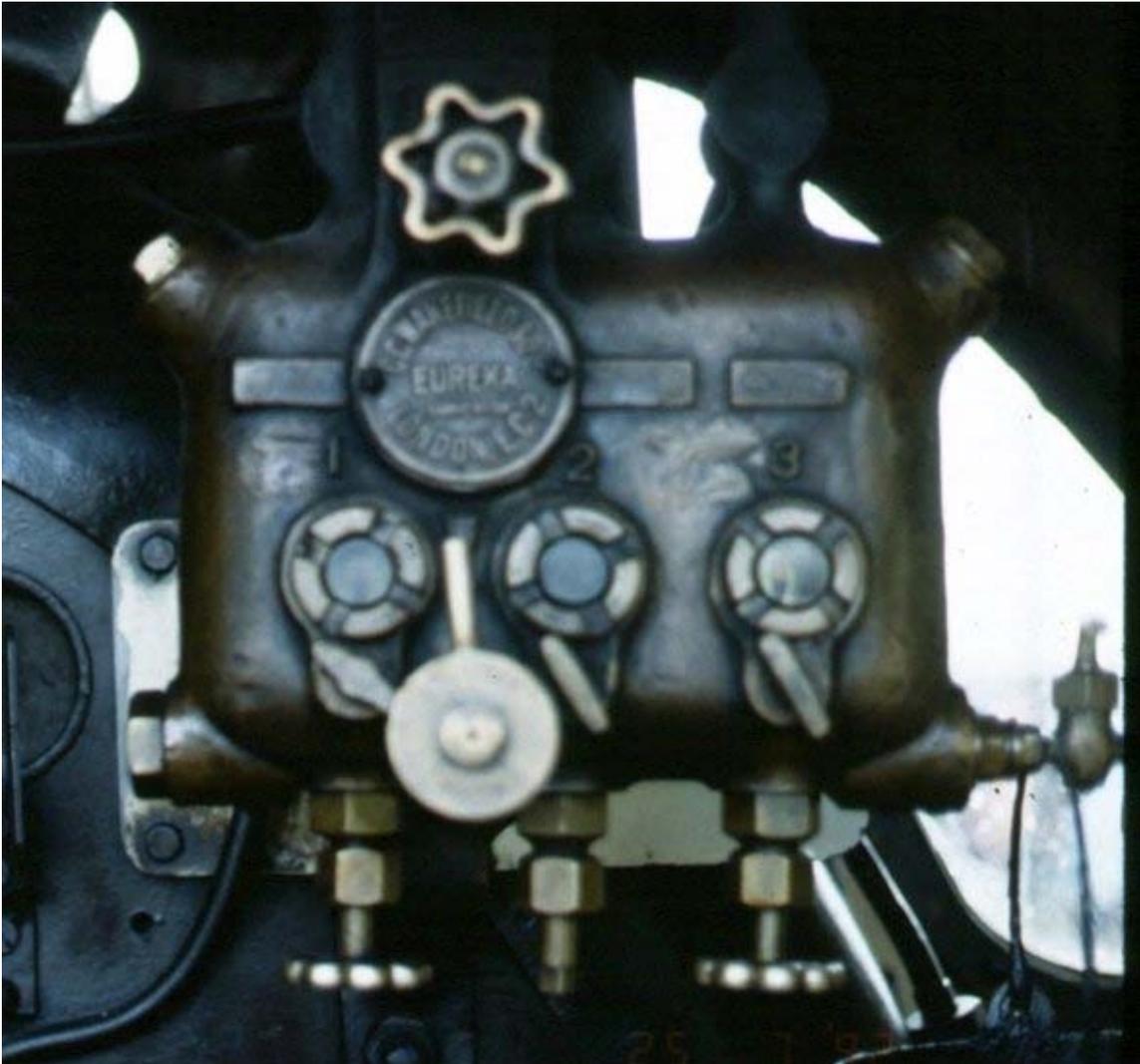
The displacement lubricator was a useful stop-gap but had the disadvantage that it was difficult to accurately control over the rate of oil feed and lubrication was only supplied when the engine was doing work (when a locomotive is coasting with the regulator closed, no steam is present to operate the lubricator).

In the Ramsbottom type the flow of lubricant depended mainly on the weather. In cold weather the rate of feed would increase because steam would condense more rapidly. The Roscoe type lubricator, improved the situation by providing a valve with which to regulate the flow of steam and hence lubricant. Setting the valve correctly required experience and depended on the speed of the train.

The Roscoe lubricator was invented by James Roscoe in 1862 and patented in British Patent 1337. It incorporated two improvements over the original Ramsbottom type, the ability to control the quantity of steam which entered the lubricator, via a control valve, and the addition of an air filled chamber within the oil reservoir. The chamber expanded when steam was cut off, the aim of which was to supply oil even when the locomotive was coasting. However, this proved ineffective in practice, particularly if the locomotive was coasting for a long time (e.g. down a hill).

When more sophisticated lubricators, such as the Wakefield and Detroit types, were developed, displacement lubricators fell out of use but they are still used on model steam engines .

Wakefield lubricator



Wakefield displacement lubricator mounted on a locomotive boiler backplate

This was patented by Charles Wakefield in the 1890s .

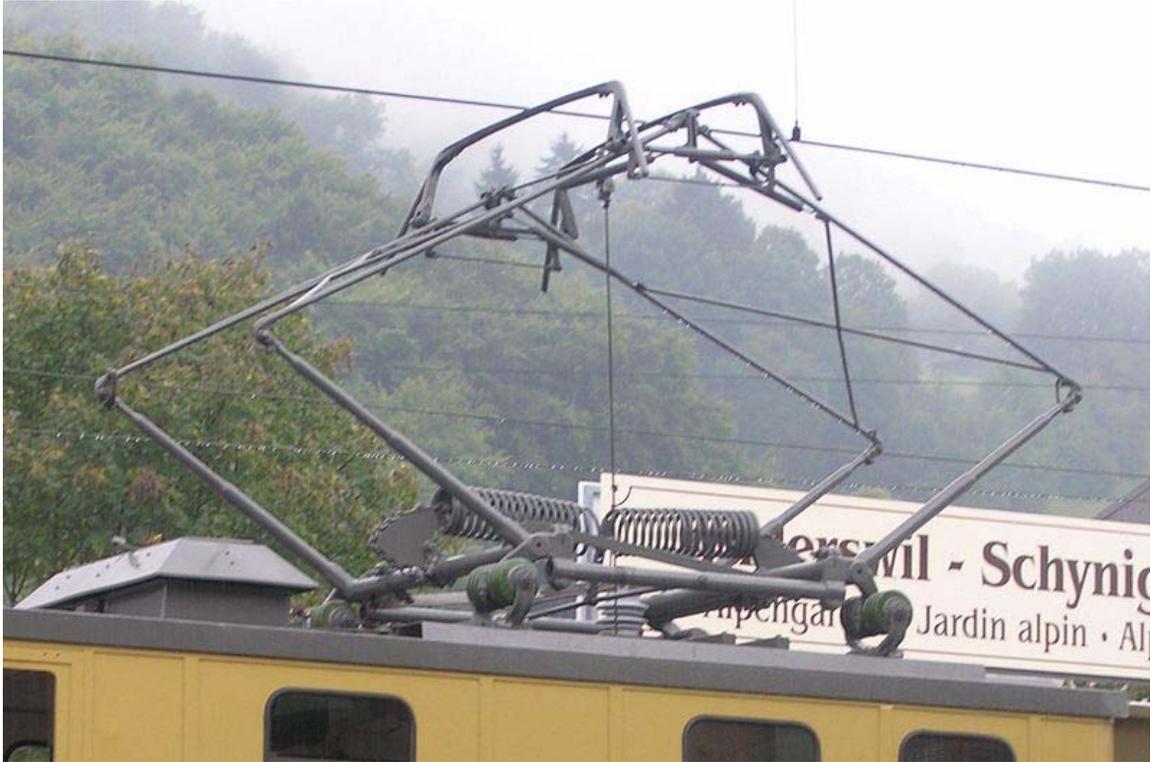
Detroit lubricator

This was made by the Detroit Lubricator Company.

Silvertown lubricator

Developed by the Midland Railway and made by Gresham and Craven .

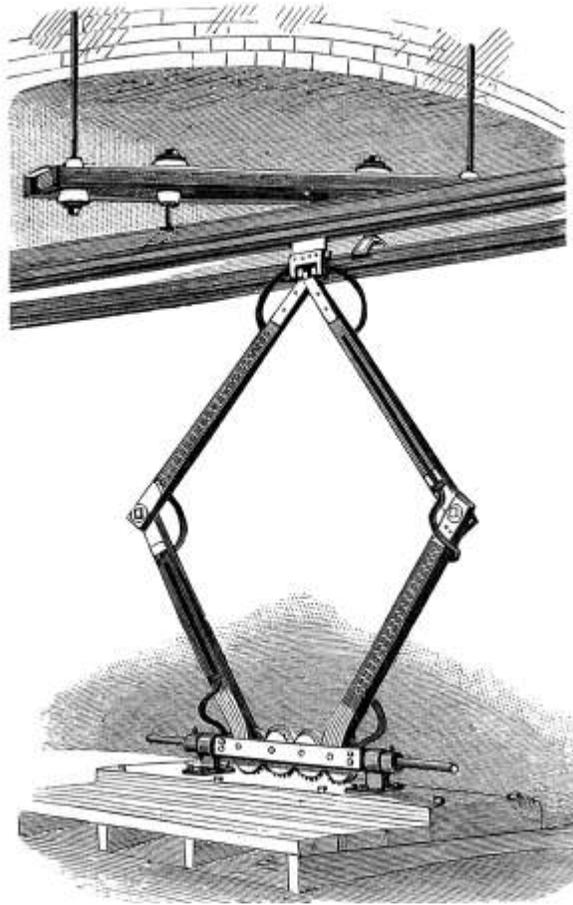
Pantograph (rail)



The diamond-shaped pantograph of the Swiss cogwheel loco in Schynige Platte, built in 1911.

A **pantograph** is a device that collects electric current from overhead lines for electric trains or trams. The term stems from the resemblance to pantograph devices for copying writing and drawings.

Invention



Early (1895) flat pantograph on a Baltimore & Ohio Railroad electric locomotive. The contact ran inside the \cap section bar, so both lateral and vertical flexibility was necessary

A flat side-pantograph was invented in 1895 at the Baltimore & Ohio Railroad and in Germany in 1900 by Siemens & Halske. The familiar diamond-shaped roller pantograph was invented by John Q. Brown of the Key System shops for their commuter trains which ran between San Francisco and the East Bay section of the San Francisco Bay Area in California. They appear in photographs of the first day of service 26 October 1903. For many decades thereafter, the same diamond shape was used by electric rail systems around the world and remains in use by some today.

The pantograph was an improvement on the simple trolley pole which prevailed up to that time primarily because it allowed an electric rail vehicle to travel at higher speeds without losing contact with the catenary.

Modern use



The (asymmetrical) 'Z'-shaped pantograph of the electrical pickup on the Berlin Straßenbahn. This pantograph uses a single-arm design.



The (asymmetrical) 'Z'-shaped pantograph of the Desiro Class 360/2 EMU on the Suvarnabhumi Airport Rail Link

The most common type of pantograph today is the so called half-pantograph (sometimes 'Z'-shaped), which has evolved to provide a more compact and responsive single-arm design at high speeds as trains get faster. The half-pantograph can be seen in use on everything from very fast trains (such as the TGV) to low-speed urban tram systems. The design operates with equal efficiency in either direction of motion, as demonstrated by the Swiss and Austrian railways whose newest high performance locomotives, the Re 460 and Taurus respectively, operate with them set in opposite directions.

Technical details



Pantographs easily adapt to various heights of the overhead wires by partly folding. The tram line pictured here runs in Vienna.

The electric transmission system for modern electric rail systems consists of an upper weight carrying wire (known as a catenary) from which is suspended a contact wire. The pantograph is spring loaded and pushes a contact shoe up against the contact wire to draw the electricity needed to run the train. The steel rails on the tracks act as the electrical return. As the train moves, the contact shoe slides along the wire and can set up acoustical standing waves in the wires which break the contact and degrade current collection. This means that on some systems adjacent pantographs are not permitted.

Pantographs are the successor technology to trolley poles, which were widely used on early streetcar systems. Trolley poles are still used by trolleybuses, whose freedom of movement and need for a two-wire circuit makes pantographs impractical, and some streetcar networks, such as the Toronto Streetcar System, which have frequent turns sharp enough to require additional freedom of movement in their current collection to ensure unbroken contact.

Pantographs with overhead wires are now the dominant form of current collection for modern electric trains because, although more expensive and fragile than a third-rail system, they allow the use of higher voltages.

Pantographs are typically operated by compressed air from the vehicle's braking system, either to raise the unit and hold it against the conductor or, when springs are used to effect the extension, to lower it. As a precaution against loss of pressure in the second case, the arm is held in the down position by a catch. For high-voltage systems, the same air supply is used to "blow out" the electric arc when roof-mounted circuit breakers are used.

Single- and double-arm pantographs



High-performance pantograph for measurements on the ICE S

Pantographs may have either a single or a double arm. Double arm pantographs are usually heavier, requiring more power to raise and lower, but may also be more fault tolerant. For example, "... [New Jersey Transit] encountered numerous wire downings on

the Northeast Corridor Branch (New York City - Trenton, NJ) before they decided to replace the pantographs on Arrow-III trains with a more forgiving dual arm design, possibly in 1991..."

On railways of the former USSR, the most widely used pantographs are those with a double arm ("made of two rhombs"), but since the late 1990s there have been some single-arm pantographs on Russian railways. Some streetcars use double-arm pantographs, among them the Russian KTM-5, KTM-8, LVS-86 and many other Russian-made trams, as well as some Euro-PCC trams in Belgium. American streetcars use either trolley poles or single-arm pantographs.

Metro systems and overhead lines



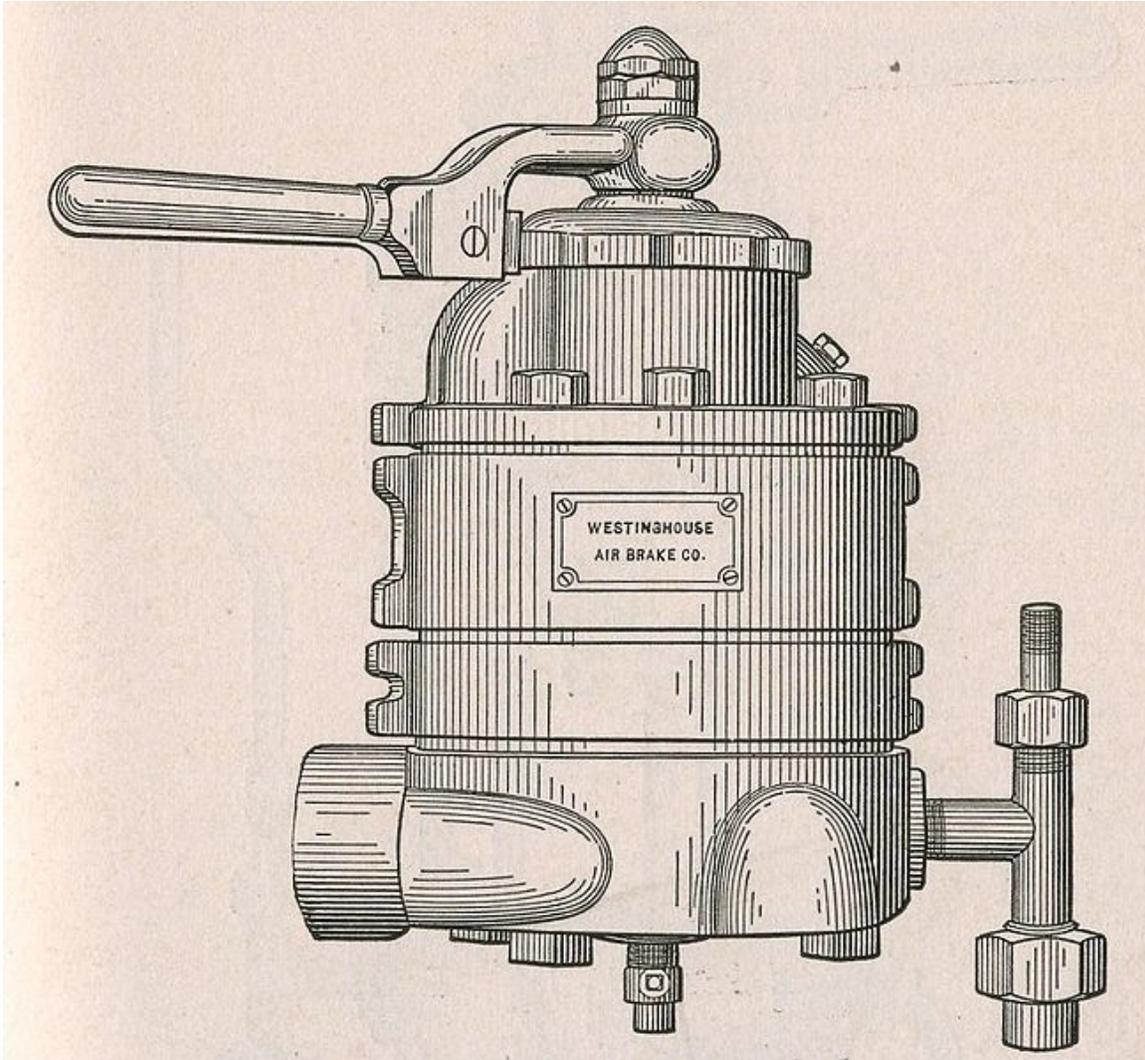
Symmetrical, diamond shaped pantographs on trams in Prague.

Most rapid transit systems are powered by a third rail, but some use pantographs, particularly ones that involve extensive above-ground running. Hybrid metro-tram or 'pre-metro' lines whose routes include tracks on city streets or in other publicly-accessible areas, such as the MBTA Green Line, must of course use overhead wire, since a third rail would normally present too great a risk of electrocution.

The only current exception to this is the new Bordeaux tram system that uses an underground system called alimentation par sol, which only applies power to segments of track that are completely covered by the tram. This system is used in the historic centre of Bordeaux where an overhead wire system would cause a visual intrusion.

Overhead pantographs are sometimes used as alternatives to third rails because third rails can ice over in certain winter weather conditions. The MBTA Blue Line or the Wonderland Line uses pantograph power for all of its surface route. The entire Metro system of Barcelona, Spain, uses overhead wiring and pantographs.

Until 2010 the Oslo metro line 1 changed from third rail to overhead line power at Frøen station. Due to the many level crossings, it was deemed difficult to install a third rail on the rest of the older line 1 tracks.



Control handle and valve for a Westinghouse Air Brake.

On railcars, an **air brake** is a conveyance braking system actuated by compressed air. Modern trains rely upon a fail-safe air brake system that is based upon a design patented by George Westinghouse on March 5, 1872. The Westinghouse Air Brake Company (WABCO) was subsequently organized to manufacture and sell Westinghouse's invention. In various forms, it has been nearly universally adopted.

The Westinghouse system uses air pressure to charge air reservoirs (tanks) on each car. Full air pressure signals each car to release the brakes. A reduction or loss of air pressure signals each car to apply its brakes, using the compressed air in its reservoirs.

Background

Prior to the introduction of air brakes, stopping a train was a difficult business. In the early days when trains consisted of one or two cars and speeds were low, the engine

driver could stop the train by reversing the steam flow to the cylinders, causing the locomotive to act as a brake. However, as trains got longer, heavier and faster, and started to operate in mountainous regions, it became necessary to fit each car with brakes, as the locomotive was no longer capable of bringing the train to a halt in a reasonable distance.

The introduction of brakes to railcars necessitated the employment of additional crew members called brakemen, whose job it was to move from car to car and apply or release the brakes when signaled to do so by the engineer with a series of whistle blasts. Occasionally, whistle signals were not heard, incorrectly given or incorrectly interpreted, and derailments or collisions would occur because trains were not stopped in time.

Brakes were manually applied and released by turning a large brake wheel located at one end of each car. The brake wheel pulled on the car's brake rigging and clamped the brake shoes against the wheels. As considerable force was required to overcome the friction in the brake rigging, the brakeman used a stout piece of wood called a "club" to assist him in turning the brake wheel.

The job of a passenger train brakeman wasn't too difficult, as he was not exposed to the weather and could conveniently move from car to car through the vestibules, which is where the brake wheel was (and still is, in many cases) located. Also, passenger trains were not as heavy or lengthy as their freight counterparts, which eased the task of operating the brakes.

A brakeman's job on a freight train was far more difficult, as he was exposed to the elements and was responsible for many more cars. To set the brakes on a boxcar (UIC: covered wagon) the brakeman had to climb to the roof ("coon the buggy" in railroad slang) and walk a narrow catwalk to reach the brake wheel while the car was swaying and pitching beneath his feet. There was nothing to grasp other than the brake wheel itself, and getting to the next car often required jumping. Needless to say, a freight brakeman's job was extremely dangerous, and many were maimed or killed in falls from moving trains.

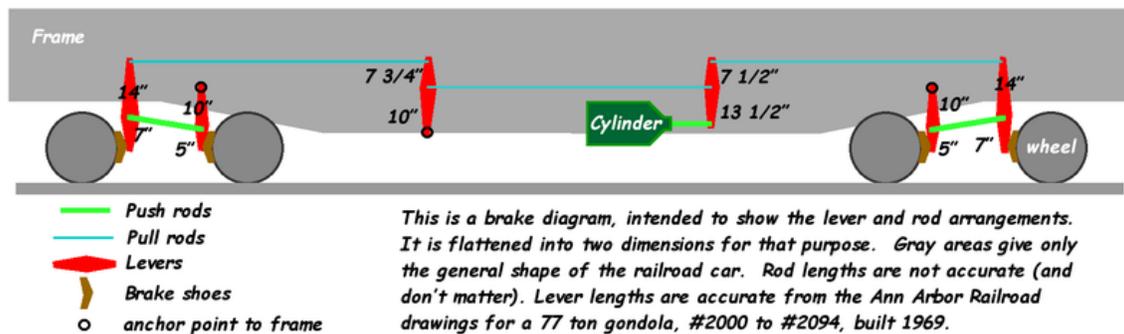
Complicating matters, the manually operated brakes had limited effectiveness and controlling a train's speed in mountainous terrain was a dicey affair. Occasionally, the brakemen simply could not set enough brakes to a degree where they were able to reduce speed while descending a grade, which usually resulted in a runaway—followed by a disastrous wreck.

When adopted, the Westinghouse system had a major effect on railroad safety. Reliable braking was assured, reducing the frequent accidents that plagued the industry. Brakemen were no longer required to risk life and limb to stop a train, and with the engineer now in control of the brakes, misunderstood whistle signals were eliminated. As a result, longer and heavier trains could be safely run at higher speeds.

During his lifetime, Westinghouse made many improvements to his invention. The United States Congress passed the Safety Appliance Act in 1893 making the use of some

automatic brake system mandatory. By 1905, over 2,000,000 freight, passenger, mail, baggage and express railroad cars and 89,000 locomotives in the United States were equipped with the Westinghouse Automatic Brake.

Overview



A comparatively simple brake linkage

In the air brake's simplest form, called the *straight air system*, compressed air pushes on a piston in a cylinder. The piston is connected through mechanical linkage to brake shoes that can rub on the train wheels, using the resulting friction to slow the train. The mechanical linkage can become quite elaborate, as it evenly distributes force from one pressurized air cylinder to 8 or 12 wheels.

The pressurized air comes from an air compressor in the locomotive and is sent from car to car by a *train line* made up of pipes beneath each car and hoses between cars. The principal problem with the straight air braking system is that any separation between hoses and pipes causes loss of air pressure and hence the loss of the force applying the brakes. This deficiency could easily cause a runaway train. Straight air brakes are still used on locomotives, although as a dual circuit system, usually with each bogie (truck) having its own circuit.

In order to design a system without the shortcomings of the straight air system, Westinghouse invented a system wherein each piece of railroad rolling stock was equipped with an air reservoir and a *triple valve*, also known as a *control valve*.



Rotair Valve Westinghouse Air brake Company

The triple valve is described as being so named as it performs three functions: Charging air into a air tank ready to be used, applying the brakes, and releasing them. In so doing, it supports certain other actions (i.e. it 'holds' or maintains the application and it permits the exhaust of brake cylinder pressure and the recharging of the reservoir during the release). In his patent application, Westinghouse refers to his 'triple-valve device' because of the three component valvular parts comprising it: the diaphragm-operated poppet valve feeding reservoir air to the brake cylinder, the reservoir charging valve, and the brake cylinder release valve. When he soon improved the device by removing the poppet valve action, these three components became the piston valve, the slide valve, and the graduating valve.

- If the pressure in the train line is lower than that of the reservoir, the brake cylinder exhaust portal is closed and air from the car's reservoir is fed into the brake cylinder to apply the brakes. This action continues until equilibrium between the brake pipe pressure and reservoir pressure is achieved. At that point, the airflow from the reservoir to the brake cylinder is lapped off and the cylinder is maintained at a constant pressure.
- If the pressure in the train line is higher than that of the reservoir, the triple valve connects the train line to the reservoir feed, causing the air pressure in the reservoir to increase. The triple valve also causes the brake cylinder to be exhausted to atmosphere, releasing the brakes.
- As the pressure in the train line and that of the reservoir equalize, the triple valve closes, causing the air pressure in the reservoir and brake cylinder to be maintained at the current level.

Unlike the straight air system, the Westinghouse system uses a *reduction* in air pressure in the train line to apply the brakes. When the engineer (driver) applies the brake by operating the locomotive brake valve, the train line vents to atmosphere at a controlled rate, reducing the train line pressure and in turn triggering the triple valve on each car to feed air into its brake cylinder. When the engineer releases the brake, the locomotive brake valve portal to atmosphere is closed, allowing the train line to be recharged by the compressor of the locomotive. The subsequent increase of train line pressure causes the triple valves on each car to discharge the contents of the brake cylinder to atmosphere, releasing the brakes and recharging the reservoirs.

Under the Westinghouse system, therefore, brakes are applied by reducing train line pressure and released by increasing train line pressure. The Westinghouse system is thus fail safe—any failure in the train line, including a separation ("break-in-two") of the train, will cause a loss of train line pressure, causing the brakes to be applied and bringing the train to a stop.

Modern air brake systems are in effect two braking systems combined:

- The **service brake** system, which applies and releases the brakes during normal operations, and
- The **emergency brake** system, which applies the brakes rapidly in the event of a brake pipe failure or an emergency application by the engineer.

When the train brakes are applied during normal operations, the engineer makes a "service application" or a "service rate reduction", which means that the train line pressure reduces at a controlled rate. It takes several seconds for the train line pressure to reduce and consequently takes several seconds for the brakes to apply throughout the train. In the event the train needs to make an emergency stop, the engineer can make an "emergency application," which immediately and rapidly vents all of the train line pressure to atmosphere, resulting in a rapid application of the train's brakes. An

emergency application also results when the train line comes apart or otherwise fails, as all air will also be immediately vented to atmosphere.

In addition, an emergency application brings in an additional component of each car's air brake system: the emergency portion. The triple valve is divided into two portions: the service portion, which contains the mechanism used during brake applications made during service reductions, and the emergency portion, which senses the immediate, rapid release of train line pressure. In addition, each car's air brake reservoir is divided into two portions—the service portion and the emergency portion—and is known as the "dual-compartment reservoir". Normal service applications transfer air pressure from the service portion to the brake cylinder, while emergency applications cause the triple valve to direct all air in both the service portion and the emergency portion of the dual-compartment reservoir to the brake cylinder, resulting in a 20–30% stronger application.

The emergency portion of each triple valve is activated by the extremely rapid rate of reduction of train line pressure. Due to the length of trains and the small diameter of the train line, the rate of reduction is high near the front of the train (in the case of an engineer-initiated emergency application) or near the break in the train line (in the case of the train line coming apart). Farther away from the source of the emergency application, the rate of reduction can be reduced to the point where triple valves will not detect the application as an emergency reduction. To prevent this, each triple valve's emergency portion contains an auxiliary vent port, which, when activated by an emergency application, also locally vents the train line's pressure directly to atmosphere. This serves to propagate the emergency application rapidly along the entire length of the train.

Enhancements

Electro-pneumatic or EP brakes are a type of air brake that allows for immediate application of brakes throughout the train instead of the sequential application. EP brakes have been in use in German high-speed trains (most notably the ICE) since the late 1980s, and in British practice since 1949, fully described in Electro-pneumatic brake system on British railway trains. Electro-pneumatic brakes are currently in testing in North America and South Africa in captive service ore and coal trains.

Passenger trains have had for a long time a 3-wire version of the Electro-pneumatic brake, which gives seven levels of braking force. In most cases the system is not fail-safe, with the wires being energized in sequence to apply the brakes, but the conventional automatic air brake is also provided to act as a fail safe, and in most cases can be used independently in the event of a failure of the EP brakes.

In North America, WABCO supplied HSC (High Speed Control) brake equipment for several post-World War II streamlined passenger trains. This was an electrically controlled overlay on conventional D-22 passenger and 24-RL locomotive brake equipment. On the conventional side, the control valve set a reference pressure in a volume, which set brake cylinder pressure via a relay valve. On the electric side, pressure from a second straight-air trainline controlled the relay valve via a two-way check valve.

This "straight air" trainline was charged (*from reservoirs on each car*) and released by magnet valves on each car, controlled electrically by a 3 wire trainline, in turn controlled by an "electro-pneumatic master controller" in the controlling locomotive. This controller compared the pressure in the straight air trainline with that supplied by a self lapping portion of the engineers valve, signaling all of the "apply" or "release" magnets valves in the train to open simultaneously, changing the pressure in the "straight air" trainline much more rapidly and evenly than possible by simply supplying air directly from the locomotive. The relay valve was equipped with four diaphragms, magnet valves, electric control equipment, and an axle-mounted speed sensor, so that at speeds over 60 mph full braking force was applied, and reduced in steps at 60, 40 and 20 mph, bringing the train to a gentle stop. Each axle was also equipped with anti-lock brake equipment. The combination minimized braking distances, allowing more full-speed running between stops. The "straight air" (*electro-pneumatic trainline*), anti-lock, and speed graduating portions of the system were not dependent on each other in any way, and any or all of these options could be supplied separately.

Later systems replace the automatic air brake with an electrical wire (in the UK, at least, known as a "round the train wire") that has to be kept energized to keep the brakes off.

More recent innovations are electronically controlled pneumatic brakes where the brakes of all the wagons (cars) and locomotives are connected by a kind of **local area network**, which allows individual control of the brakes on each wagon, and the reporting back of performance of each wagon's brakes.

Limitations

The Westinghouse air brake system is very trustworthy, but not infallible. Recall that the car reservoirs recharge only when the brake pipe pressure is higher than the reservoir pressure, and that the car reservoir pressure will rise only to the point of equilibrium. Fully recharging the reservoirs on a long train can require considerable time (8 to 10 minutes in some cases), during which the brake pipe pressure will be lower than locomotive reservoir pressure.

If the brakes must be applied before recharging has been completed, a larger brake pipe reduction will be required in order to achieve the desired amount of braking effort, as the system is starting out at a lower point of equilibrium (lower overall pressure). If many brake pipe reductions are made in short succession ("fanning the brake" in railroad slang), a point may be reached where car reservoir pressure will be severely depleted, resulting in substantially reduced brake cylinder piston force, causing the brakes to fail. On a descending grade, the unfortunate result will be a runaway.

In the event of a loss of braking due to reservoir depletion, the engineer (driver) may be able to regain control with an emergency brake application, as the emergency portion of each car's dual-compartment reservoir should be fully charged—it is not affected by normal service reductions. The triple valves detect an emergency reduction based on the *rate* of brake pipe pressure reduction. Therefore, as long as a sufficient volume of air can

be rapidly vented from the brake pipe, each car's triple valve will cause an emergency brake application. However, if the brake pipe pressure is too low due to an excessive number of brake applications, an emergency application will not produce a large enough volume of air flow to trip the triple valves, leaving the engineer with no means to stop the train.

To prevent a runaway due to loss of brake pressure, dynamic (rheostatic) braking can be utilized so the locomotive(s) will assist in retarding the train. Often, blended braking, the simultaneous application of dynamic and train brakes, will be used to maintain a safe speed and keep the slack stretched as the train crests a grade.

Another solution to loss of brake pressure is the two-pipe system, fitted on most modern passenger stock and many freight wagons. In addition to the traditional brake pipe, this enhancement adds the main reservoir pipe, which is continuously charged with air directly from the locomotive's main reservoir. The main reservoir is where the locomotive's air compressor output is stored, and is ultimately the source of compressed air for all systems that use it.

Since the main reservoir pipe is kept constantly pressurized by the locomotive, the car reservoirs can be charged independently of the brake pipe, this being accomplished via a check valve to prevent backfeeding into the pipe. This arrangement helps to reduce the above described pressure loss problems, and also reduces the time required for the brakes to release, since the brake pipe only has to recharge itself.

Main reservoir pipe pressure can also be used to supply air for auxiliary systems such as pneumatic door operators or air suspension. Nearly all passenger trains (all in the UK and USA), and many freights, now have the two-pipe system.

Accidents

The air brake can fail if one of the cocks where the pipes of each carriage are joined together is accidentally closed. In this case, the brakes on the wagons behind the closed cock will fail to respond to the driver's command. This happened in 1953 to the *Federal Express*, a Pennsylvania Railroad train pulling in to Washington DC's Union Station, causing the train to crash into the passenger concourse and fall through the floor. Similarly, in the Gare de Lyon train accident a valve was accidentally closed by the crew, reducing braking power.

There are a number of safeguards that are usually taken to prevent this sort of accident happening. Railroads have strict government-approved procedures for testing the air brake systems when making up trains in a yard or picking up cars en route. These generally involve connecting the air brake hoses, charging up the brake system, setting the brakes and manually inspecting the cars to ensure the brakes are applied, and then releasing the brakes and manually inspecting the cars to ensure the brakes are released. Particular attention is usually paid to the rearmost car of the train, either by manual inspection or via an automated end-of-train device, to ensure that brake pipe continuity

exists throughout the entire train. When brake pipe continuity exists throughout the train, failure of the brakes to apply or release on one or more cars is an indication that the cars' triple valves are malfunctioning. Depending on the location of the air test, the repair facilities available, and regulations governing the number of inoperative brakes permitted in a train, the car may be set out for repair or taken to the next terminal where it can be repaired.

Standardization

The modern air brake is not identical with the original airbrake as there have been slight changes in the design of the triple valve, which are not completely compatible between versions, and which must therefore be introduced in phases. That said, the basic air brakes used on railways worldwide are remarkably compatible.

Vacuum brakes

The main competitor to the air brake is the vacuum brake, which operates on negative pressure. The vacuum brake is a little simpler than the air brake, with an ejector with no moving parts on steam engines or a mechanical or electrical "exhauster" on a diesel or electric locomotive replacing the air compressor. Disconnection taps at the ends of cars are not required as the loose hoses are sucked onto a mounting block.

However, the maximum pressure is limited to atmospheric pressure, so that all the equipment has to be much larger and heavier to compensate. This disadvantage is made worse at high altitude. The vacuum brake is also considerably slower acting in both applying and releasing the brake; this requires a greater level of skill and anticipation from the driver. Conversely, the vacuum brake had the advantage of gradual release long before the Westinghouse automatic air brake, which was originally only available in the direct-release form still common in freight service.

A primary fault of vacuum brakes is the inability to easily find leaks. In a positive air system, a leak is quickly found due to the escaping pressurized air. This problem left the British railways in a terrible condition, where trains would have to be stopped at the top of grades to set the manual brakes on each car. Purchase and maintenance of a mechanical air pump on hundreds of engines is nothing compared to keeping the vacuum line in good order across a fleet of tens of thousands of freight cars.

Electro-vacuum brakes have also been used with considerable success on South African electric multiple unit trains. Despite requiring larger and heavier equipment as stated above, the performance of the electro-vacuum brake approached that of contemporary electro-pneumatic brakes. However, their use has not been repeated.

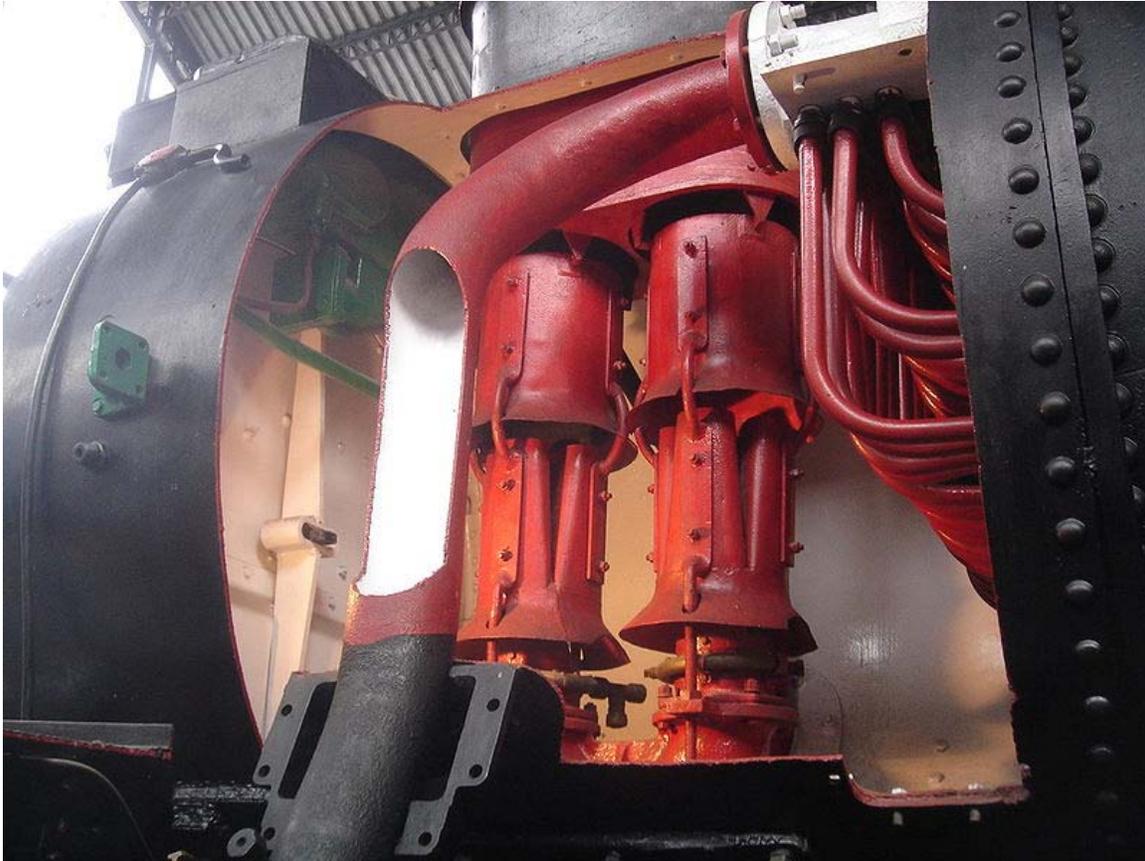
Chapter 14

Steam Locomotive Exhaust System and Steam Locomotive Condensing Apparatus

Steam locomotive exhaust system



Simple blastpipe arrangement



Later double chimney, with Kylchap blastpipes

The **Steam locomotive exhaust system** consists of those parts of a steam locomotive which together discharge exhaust steam from the cylinders in order to increase the draught through the fire. It usually consists of the blastpipe(or first stage nozzle), smokebox, and chimney, although later designs also include second and third stage nozzles.

History

The primacy of discovery of the effect of directing the exhaust steam up the chimney as a means of providing draft through the fire is the matter of some controversy, Ahrons (1927) devoting significant attention to this matter. The exhaust from the cylinders on the first steam locomotive – built by Richard Trevithick – was directed up the chimney, and he noted its effect on increasing the draft through the fire at the time. At Wylam Timothy Hackworth also employed a blastpipe on his earliest locomotives, but it is not clear whether this was an independent discovery or a copy of Trevithick's design. Shortly after Hackworth George Stephenson also employed the same method, and again it is not clear whether that was an independent discovery or a copy of one of the other engineers.

The locomotives at the time employed either a single flue boiler or a single return flue, with the fire grate at one end of the flue. For boilers of this design the blast of a

contracted orifice blastpipe was too strong, and would lift the fire. It was not until the development of the multitubular boiler that the centrally positioned, contracted orifice blastpipe became standard. The combination of multi-tube boiler and steam blast are often cited as the principal reasons for the high performance of *Rocket* of 1829 at the Rainhill Trials.

Description

Soon after the power of the steam blast was discovered it became apparent that a smokebox was needed beneath the chimney, to provide a space in which the exhaust gases emerging from the boiler tubes can mix with the steam. This had the added advantage of allowing access to collect the ash drawn through the fire tubes by the draught. The blastpipe, from which steam is emitted, was mounted directly beneath the chimney at the bottom of the smokebox.

The steam blast is largely self-regulating: an increase in the rate of steam consumption by the cylinders increases the blast, which increases the draught and hence the temperature of the fire.

Modern locomotives are also fitted with a *blower*, which is a device that releases steam directly into the smokebox for use when a greater draught is needed without a greater volume of steam passing through the cylinders. An example of such situation is when the regulator is closed suddenly, or the train passes through a tunnel. If a single line tunnel is poorly ventilated, a locomotive entering at high speed can cause a rapid compression of the air within the tunnel. This compressed air may enter the chimney with substantial force. This can be extremely dangerous if the firebox door is open at the time. For this reason the blower is often turned on in these situations, to counteract the compression effect.

Later development

The aim of exhaust system development is to obtain maximum smokebox vacuum with minimum back pressure on the pistons.

Little development of the basic principles of smokebox design took place until 1908, when the first comprehensive examination of steam-raising performance was carried out by W.F.M. Goss of Purdue University. These principles were adopted on the Great Western Railway by Churchward.

Andre Chapelon made a significant improvement with his Kylchap exhaust which incorporated a *Kyala spreader* (second stage nozzle) and third stage cowl between the blastpipe (first stage nozzle) and chimney. This became popular at the end of the steam era (early-mid 20th century) and was used on the Nigel Gresley's Mallard which holds the official world speed record for steam locomotives. Other contemporary designs include the Giesl, and Lemaître exhausts which achieve the same aim by different means.

Further development was carried on by Chapeleon's friend Livio Dante Porta, who developed the Kylpor, Lempor and Lemprex exhausts systems, and also developed sophisticated mathematical models to optimise their use for specific locomotives.

With the demise of commercial steam operations on mainline railways worldwide, there has been little funding for further development of steam locomotive technology, despite advances in materials technology and computer modelling techniques which might have enabled further improvements to efficiency.

Steam locomotive condensing apparatus

A **steam locomotive condensing apparatus** differs in purpose from the usual closed cycle steam engine condenser, in that its function is primarily either to recover water, or to avoid excessive emissions to the atmosphere, rather than maintaining a vacuum to improve both efficiency and power. It takes the form of a series of pipes, valves and other ancillary equipment usually attached to an otherwise conventional steam locomotive. The apparatus takes the exhaust steam that would normally be lost up the funnel and routes it through a heat exchanger, into the normal water tanks. Installations vary depending on the purpose, design and the type of locomotive to which it is fitted.

Purpose

Unlike the surface condenser often used on a steam turbine, the condensing apparatus on a steam locomotive does not normally increase the power output. In fact it may reduce it considerably. Whilst more power is potentially available by expanding down to a vacuum, the corresponding low density (high specific volume) implies extremely bulky low pressure cylinders or a turbine would be needed to actually extract it. So with a more practical volume ratio the condenser pressure would be near atmospheric rather than at a more typical low pressure, and the temperature would be correspondingly higher. In exhausting hot steam to the condenser, the temperature gradient between the exhaust steam and the cooling water is greater, so that a smaller heat exchange surface area is needed than would be required for typical stationary or ship-based steam plant of similar power. However none of the energy in the hot steam is available to do mechanical work. The potential improvement in thermal efficiency expected from including the condenser in the cycle is therefore not usually realised within the space constraints of a typical locomotive, indeed losses due to viscous friction in the condenser piping is likely to reduce the power output over what was achievable from simply venting to atmosphere. There are two usual reasons for fitting such equipment, reducing exhaust emissions and increasing range.

Reduced exhaust emissions

Underground railways



Mersey Railway locomotive, showing the prominent exhaust pipes leading back to the water tanks

Originally developed for the Metropolitan Railway to allow their locomotives to work the tunnels of the London Underground. This system was devised by Daniel Gooch and developed by Beyer Peacock. Steam is diverted from the exhaust steam pipes into the water tanks via condensing pipes within the same tanks. The water in the tanks could quickly heat up near boiling point, reducing the condensing effect on the exhaust steam. It was not unknown for the tanks to be emptied and refilled with cold water on a regular basis. Ordinary injectors will not work with hot water (until hot-water injectors were developed) so condensing locomotives were usually fitted with axle-driven boiler feedwater pumps. When not working in tunnels, the steam was directed to the blast pipe and up the funnel in the usual way.

Roadside tramways

In Britain, locomotives working on roadside steam tramways were required by law to have condensers. Water tank condensers (as above) were sometimes used but air-condensers were more common. A steam tram engine usually had a full-length roof and this was surmounted by a nest of air-cooled copper tubes in which the exhaust steam was condensed. Kitson & Co. made many engines of this type. The system was satisfactory

for tram engines (which were very low-powered) but would not have worked for larger railway locomotives.

Increased range

Generally this was a more sophisticated installation that used forced air cooling to condense the exhaust steam. The system was intended to reduce the problems of getting enough water to steam locomotives running through desert and very arid areas.

Locomotives fitted with a condensing apparatus

- Metropolitan Railway A Class 4-4-0T
- Metropolitan Railway B Class 4-4-0T
- Great Northern Railway (later LNER) Class N2 0-6-2T
- GWR 9700 Class 0-6-0PT (a variation on the 5700 Class)
- Mersey Railway 0-6-4T No.5 "Cecil Raikes" (preserved at the Museum of Liverpool)
- South African Class 25 4-8-4