



Handbook of Rail Technologies

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WORLD TECHNOLOGIES

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Chapter- 1

25 kV AC Railway Electrification

The **25 kV Alternating current railway electrification system** is commonly used in railways worldwide, especially on high-speed lines.

Overview

This electrification system is ideal for railways that cover long distances and/or carry heavy traffic. After some experimentation before World War II in Hungary and in the Black Forest (Germany), it came into widespread use in the 1950s.

One of the reasons why it was not introduced earlier was the increased clearance distances required where it ran under bridges and in tunnels. Another reason was the lack of suitable control and rectification equipment before the development of solid-state rectifiers and related technology.

Railways using older, lower-capacity direct current systems such as France, Russia, South Africa, Spain, Italy, Belgium, Slovakia and The Netherlands have introduced or are introducing 25 kV AC instead of 3 kV DC/1.5 kV DC for their new high-speed lines.

The Channel Tunnel uses 25 kV, 50 Hz.

History

The first successful operational and regular use of the 50 Hz system dates back to 1931, tests having run since 1922. It was developed by Kálmán Kandó in Hungary. He used 16 kV AC at 50 Hz, asynchronous traction, and an adjustable number of (motor) poles. The first electrified line for testing was Budapest–Dunakeszi–Alag. The first fully electrified line was Budapest–Győr–Hegyeshalom (part of the Budapest–Vienna line). Although Kandó's solution showed a way for the future, railway operators outside of Hungary showed a lack of interest in the design.

The first railway to use this system was completed in 1951 by SNCF and ran between Aix-les-Bains and La-Roche-Sur-Foron in southern France, initially at 20 kV, but converted to 25 kV in 1953. The 25 kV system was then adopted as standard in France, but since substantial amounts of mileage south of Paris had already been electrified at

1,500 V DC, the SNCF also continued some major new DC electrification projects, until dual-voltage locomotives were developed in the 1960s.

The main reason why electrification at this voltage had not been used before was the lack of reliability of mercury-arc-type rectifiers that could fit on the train. This in turn related to the requirement to use DC series motors, which required the current to be converted from AC to DC and for that a rectifier is needed. Until the early 1950s, mercury-arc rectifiers were difficult to operate even in ideal conditions and were therefore unsuitable for use in the railway industry.

It was possible to use AC motors (and some railways did, with varying success), but they did not have an ideal characteristic for traction purposes. This was because control of speed is difficult without varying the frequency and reliance on voltage to control speed gives a torque at any given speed that is not ideal. This is why DC series motors were the best choice for traction purposes, as they can be controlled by voltage, and have an almost ideal torque vs speed characteristic.

In the 1990s, high-speed trains began to use lighter, lower-maintenance three-phase AC induction motors. The N700 Shinkansen uses a three-level converter to convert 25 kV single-phase AC to 1,520 V AC (via transformer) to 3,000 V DC (via phase-controlled rectifier with thyristor) to a maximum 2,300 V three-phase AC (via a Variable Voltage, Variable Frequency inverter using IGBTs with Pulse Width Modulation) to run the motors. The system works in reverse for regenerative braking.

The choice of 25 kV was not based on a neat and tidy ratio of the supply voltage, but rather related to the efficiency of power transmission as a function of voltage and cost. For a given power level, a higher voltage allows for a lower current and usually better efficiency at the greater cost for high-voltage equipment. It was found that 25 kV was an optimal point, where an even higher voltage would still improve efficiency but not by a significant amount in relation to the higher costs incurred by the need for greater clearance and larger insulators.

Disadvantages

A 25 kV AC system uses only one phase of the normal three-phase power supply. This results in an imbalance on the three-phase supply which may affect other customers. This can be overcome by installing static VAR compensators or reducing the traction load when the imbalance becomes unacceptable. The system is not insulated from the distribution network, like other systems. Older locomotives and the recuperating electrodynamic brakes on newer locomotives, create electrical noise. It is not necessarily practical to filter this noise from the electricity distribution network and this has led some countries to prohibit the use of recuperating brakes.

The high voltage leads to a requirement for a slightly higher clearance in tunnels and under overbridges.

To avoid short circuits, the high voltage must be protected from moisture. Weather events, such as "the wrong type of snow", have caused failures in the past. An example occurred in December 2009, when four Eurostar trains broke down inside the Channel Tunnel.

Distribution networks

Electric power from a generating station is transmitted to grid substations via overhead pylons at high voltage. In the United Kingdom, this will be 400 kV, 275 kV or 132 kV. Different voltages are used in other countries. This power is transmitted using a three-phase distribution system.

At the grid substation, a step-down transformer is connected across two of the three phases of the high-voltage supply. The transformer lowers the voltage to 25 kV which is supplied to a railway feeder station located beside the tracks. SVCs are used for load balancing and voltage control.

Nevertheless, in some cases dedicated single phase AC powerlines were built which run to substations with single phase AC transformers. Such lines were built to supply the French TGV.

Standardisation

Railway electrification using 25 kV, 50 Hz AC has become an international standard. There are two main standards that define the voltages of the system:

- BS EN 50163:2004 - "Railway applications. Supply voltages of traction systems"
- IEC 60850 - "Railway Applications. Supply voltages of traction systems"

The permissible range of voltages allowed are as stated in the above standards and take into account the number of trains drawing current and their distance from the substation.

Electrification system	Lowest non-permanent voltage	Lowest permanent voltage	Nominal voltage	Highest permanent voltage	Highest non-permanent voltage
25,000 V, AC, 50 Hz	17,500 V	19,000 V	25,000 V	27,500 V	29,000 V

This system is now part of the European Union's Trans-European railway interoperability standards (1996/48/EC "Interoperability of the Trans-European high-speed rail system" and 2001/16/EC "Interoperability of the Trans-European Conventional rail system").

Variations

Systems based on this standard but with some variations have been used.

25 kV AC at 60 Hz

In countries where 60 Hz is the normal grid power frequency, 25 kV at 60 Hz is used for the railway electrification.

- In the United States, newer electrified portions of the Northeast Corridor intercity passenger line and New Jersey Transit commuter lines.
- In western Japan, Shinkansen lines (using 1,435 mm (4 ft 8 ½ in) gauge) use 60 Hz, contrasting eastern parts which use 50 Hz.
- In Canada on the Deux-Montagnes Line of the Montreal Metropolitan transportation Agency,
- In Pakistan on Pakistan Railways (using 1,676 mm (5 ft 6 in) gauge),
- In South Korea on Korail and in Taiwan on Taiwan High Speed Rail (both using 1,435 mm (4 ft 8 ½ in) gauge).

6.25 kV AC

Early 50 Hz AC railway electrification in the United Kingdom used sections at 6.25 kV AC where there was limited clearance under bridges and in tunnels. Rolling stock was dual-voltage with automatic switching between 25 kV and 6.25 kV. The 6.25 kV sections were converted to standard 25 kV AC as a result of research work that demonstrated that the distance between live and earthed equipment could be reduced from that originally thought to be necessary.

The research was done using a steam engine beneath a bridge at Crewe. A section of 25 kV overhead line was slowly brought closer to the earthed metalwork of the bridge whilst being subjected to the steam from the locomotive's chimney. The distance at which a flashover occurred was measured and this was used as a basis from which new clearances between overhead equipment and structures were derived.

50 kV AC

Occasionally 25 kV is doubled to 50 kV to obtain greater power and increase the distance between substations. Such lines are usually isolated from other lines to avoid complications from interrunning. Examples are:

- The Black Mesa and Lake Powell Railroad which is an isolated coal railway (60 Hz).
- The Tumbler Ridge Subdivision of BC Rail (60 Hz).
- The Sishen-Saldanha iron ore railway (50 Hz).

Boosted voltage

For TGV world speed record runs in France the voltage was temporarily boosted, to 29.5 kV and 31 kV at different times.

25kV in the narrow gauge lines

- In Taiwan (60 Hz).
- In Tunisia (50 Hz).
- In Queensland, Australia (50 Hz).
- In New Zealand

Multi-system locomotives and trains

Trains that can operate on more than one voltage, say 3 kV/25 kV, are established technologies. Some locomotives in Europe are capable of using four different voltage standards.



Chapter- 2

Axle Counter



An axle counter detection point in the UK

An **axle counter** is a device on a railway that detects the passing of a train in lieu of the more common track circuit. A counting head (or 'detection point') is installed at each end of the section, and as each axle passes the head at the start of the section, a counter increments. A detection point comprises two independent sensors, therefore the device can detect the direction of a train by the order in which the sensors are passed. As the train passes a similar counting head at the end of the section, the counter decrements. If the net count is evaluated as zero, the section is presumed to be clear for a second train.

This is carried out by safety critical computers called 'evaluators' which are centrally located, with the detection points located at the required sites in the field. The detection points are either connected to the evaluator via dedicated copper cable or via a telecommunications transmission system. This allows the detection points to be located significant distances from the evaluator. This is useful when using centralised interlocking equipment but less so when signalling equipment is distributed at the lineside in equipment cabinets.

Advantages

Unlike track circuits, axle counters do not require insulated rail joints to be installed. This avoids breaking the continuity of long welded rails for insulated joints to be inserted. Such joints introduce a weak point in the rail, where a broken rail is more likely to occur. The cause of many track circuit failures can be traced to problems with insulated rail joints.

Axle counters are particularly useful on electrified railways as they eliminate traction bonding and impedance bonds.

Axle counters require no bonding and less cabling in comparison to track circuits, and are therefore generally less expensive to install and maintain.

Axle counters do not suffer problems with railhead contamination, e.g. due to rust or compacted leaf residue, that can affect the correct operation of track circuits.

Axle counters are used in places such as wet tunnels (such as the Severn Tunnel), where ordinary track circuits are unreliable. Axle counters are also useful on steel structures (such as the Forth Bridge), which prevent the normal operation of track circuits. Axle counters are also useful on long sections where several intermediate track circuits may be saved.

Experience with axle counters in mainland Europe shows that they regularly achieve up to five times the reliability of track circuits carrying out the same function. This has immediate improvement in service reliability as track circuit failure is often the most significant cause of train delay. It also has safety benefits as it reduces the use of degraded modes of operation outside of the control of the signalling system due to failure.

A Frauscher axle counter sensor, for example, can be 8,500m from the evaluation unit, while the latest ALTPRO axle counter sensor model ZK24 can even go up to 49km from the unit.

Disadvantages

Axle counters may 'forget' how many axles are in a section for various reasons such as a power failure. A manual override is therefore necessary to reset the system. This manual override introduces the human element which may be unreliable. An accident occurred in the Severn Tunnel and is thought to be due to improper restoration of an axle counter. This, however, was not proven during the subsequent inquiry.

Fail safety

Axle counters only provide intermittent positive indication of a rail vehicle as it passes a fixed location. If the counter unit fails or becomes disconnected, a train will pass undetected into a block that would otherwise be regarded as unoccupied. Track circuits provide continuous real time detection over a track segment and any loss of power or disconnected wire results in a safe signal indication to the train. Track circuits also allow for the use of clips that instantly shunt the circuit and mark the track as occupied. These can be used by crews or maintenance personnel to quickly report an unsafe condition or mark a section of track out of service. Modern axle counter equipment transmits data from the trackside apparatus to the indoor equipment via telegrams, across an ISDN line. This results in the section of line being monitored showing occupied in the event of persisting technical fault or loss of telegrams. The section then requires a reset command and further interaction to restore to service.

Broken rails

The track circuit provides additional functionality of detecting many, however not all, kinds of broken rails, though only to a limited extent in AC traction areas and not in the common rail in DC traction areas. Axle counters offer no such facility. However, experience has shown that broken rails often occur near the insulated block joints which are used to electrically isolate adjacent track circuits. Since axle counters do not require such block joints, the risk of having a broken rail is significantly reduced.

Siding and shunting movements

Axles counters have problems maintaining correct counts when train wheels stop directly on the counter mechanism. This can prove problematic at stations or other areas where cars are shunted, joined and divided. Also, where main lines have hand operated switches to siding, spur or loop tracks the use of counters is more costly to implement to detect trains appearing and disappearing from a track segment.

In Auckland, New Zealand, axle counters will be used on the main lines, but any headshunts connected to sidings will use ordinary track circuits.

Electromagnetic brakes

Magnetic brakes are used on high speed trains (maximum speed greater than 160 km/h). These are physically large pieces of metal mounted on the bogie of the vehicle, only a few centimetres above the track. They can sometimes be mistakenly detected by axle counters as another axle. This can happen only on one side of a track block, because of magnetic field curvature, defects of track geometry, or other issues, leading the signalling system into confusion and also requiring reset of the detection memory. The modern AzLM variant of axle counter is 'eddy current' brake proof and the magnetic effect of the braking system described above is overcome, therefore count information remains stable even when a vehicle fitted with magnetic brakes is braking whilst traversing the rail contacts of a detection point.

Reset and restoration

There are four methods of securing the reset and restoration of axle counters into service:

- **Preparatory reset** uses the internal logic of the axle counter system to enforce that a train must proceed through a reset section at slow speed, by holding its output as 'occupied' until the train is successfully detected as passing through the section. This logically proves the section free of obstruction and therefore allows the section to change its output to 'clear'. It is problematic for a long track section due to the long time required for the train to pass at a slow speed.
- **Conditional reset** (with aspect restriction) has the section reset only if the last count was in the outward direction. This at least shows that any trains in the section at time of reset were moving out. The signal protecting the reset section is held at danger by signalling logic outside of the axle counter evaluator to enforce a low speed 'sweep' of the section prior to restoration to service.
- **Un-conditional reset** (no aspect restriction) has the section reset irrespective of the last count action. The protecting signals are cleared immediately after a reset. In the UK, this type of reset is used under 'EPR' 'Engineer's Possession Reminder' and a series of procedures are carried out to ensure the section of line is clear of vehicles and tools before the reset is performed.
- **Co-operative reset** requires both the technician and signaller to co-operate to reset and then restore the section into service. This type of reset is now only used on schemes which fringe on an existing scheme which utilizes this type of reset arrangement.

Most countries use a variation of the above four methods, sometimes with varying amounts of automation or human input.

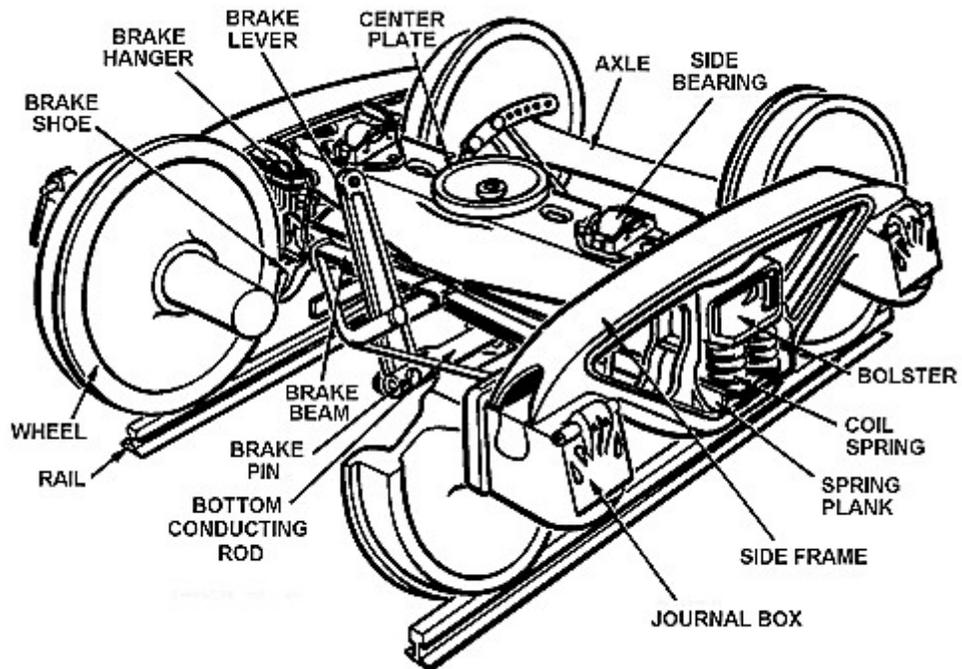
Makes

-  Frauscher
-  Siemens
-  Thales
-  GE Transportation
-  Stesalit Ltd.
-  GGTronics.
-  CEL
-  Duvine
-  DD830 Argenia Systems Inc.
-  Zvonimir Viduka - Croatia
-  ALTPRO - Croatia

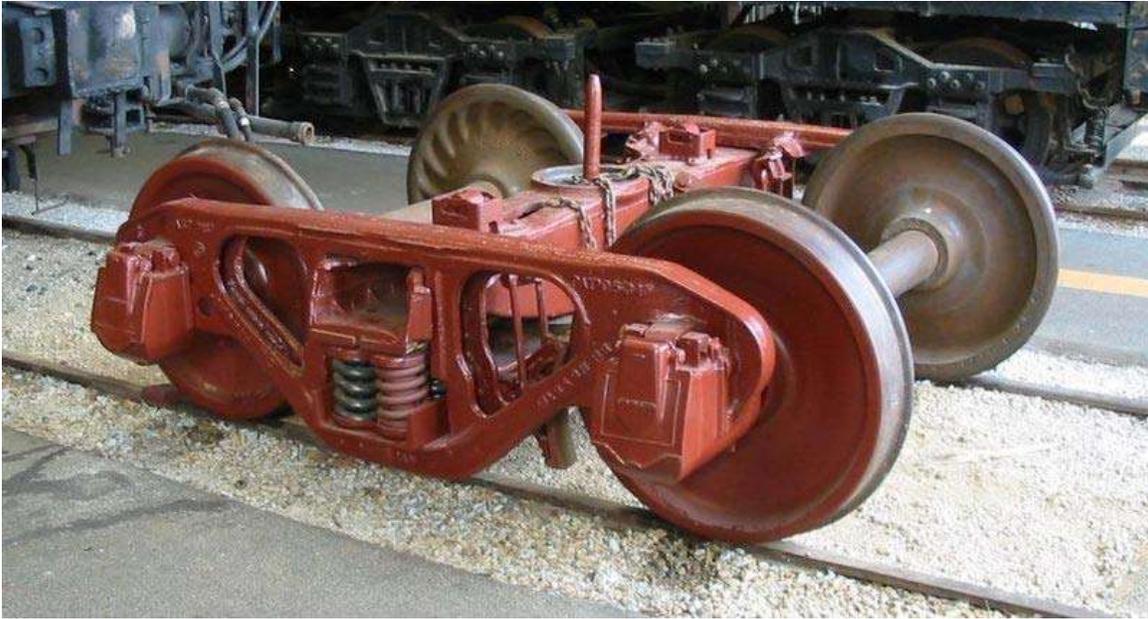
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Chapter- 3

Bogie



US-style railroad truck with journal bearings



Bettendorf-style freight car truck displayed at the Illinois Railway Museum. This one uses journal bearings.

A **bogie** is a wheeled wagon or trolley. In mechanics terms, a bogie is a chassis or framework carrying wheels, attached to a vehicle. It can be fixed in place, as on a cargo truck, mounted on a swivel, as on a railway carriage or locomotive, or sprung as in the suspension of a caterpillar tracked vehicle.

Railway

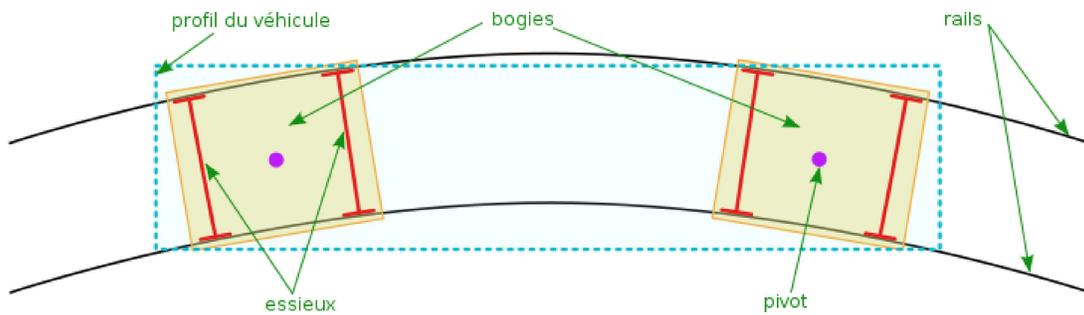
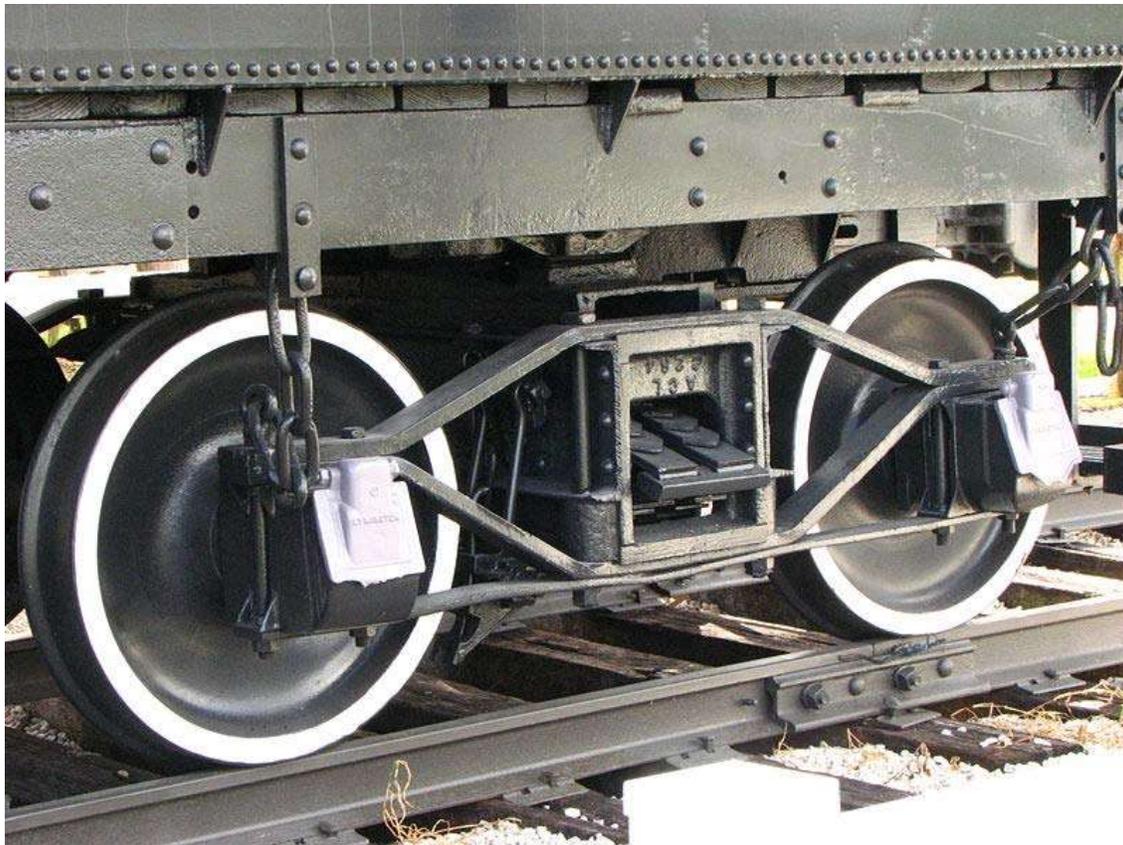


Diagram showing bogie function



Archbar type truck with journal bearings as used on some steam locomotive tenders. A version of the archbar truck was at one time also used on US freight cars



Bogie of a SBB Eurocity passenger car, as seen from underneath

A **bogie** in the UK, or a **wheel truck**, or simply **truck** in North America, is a structure underneath a train to which axles (and, hence, wheels) are attached through bearings. In Indian English, bogie may also refer to an entire railway carriage.

The first British railway to build coaches with bogies, instead of rigidly-mounted axles, was the Midland Railway in 1874.

Bogies serve a number of purposes:

- Support of the rail vehicle body.
- Stability on both straight and curved track.
- Ensuring ride comfort by absorbing vibration and minimizing centrifugal forces when the train runs on curves at high speed.
- Minimizing generation of track irregularities and rail abrasion.

Usually two bogies are fitted to each carriage, wagon or locomotive, one at each end. An alternate configuration often is used in articulated vehicles, which places the bogies (often jacob's bogies) under the connection between the carriages or wagons.

Most bogies have two axles as it is the simplest design, but some cars designed for extremely heavy loads have been built with up to five axles per bogie. Heavy-duty cars may have more than two bogies using span bolsters to equalize the load and connect the bogies to the cars.

Usually the train floor is at a level above the bogies, but the floor of the car may be lower between bogies, such as for a double decker train to increase interior space while staying within height restrictions, or in easy-access, stepless-entry low-floor trains.

Key components of a bogie include:

- The bogie frame itself. This can be of inside frame type where the main frame and bearings are between the wheels, or (more commonly) of outside frame type where the main frame and bearings are outside the wheels.
- Suspension to absorb shocks between the bogie frame and the rail vehicle body. Common types are coil springs, or rubber airbags.
- At least one wheelset, composed of an axle with a bearings and wheel at each end.
- Axle box suspension to absorb shocks between the axle bearings and the bogie frame. The axle box suspension usually consists of a spring between the bogie frame and axle bearings to permit up and down movement, and sliders to prevent lateral movement. A more modern design uses solid rubber springs.
- Brake equipment. Two main types are used: brake shoes that are pressed against the tread of the wheel, and disc brakes and pads.
- In powered vehicles, some form of transmission, usually an electrically powered traction motors or a hydraulically powered torque converter.

The connections of the bogie with the rail vehicle allows a certain degree of rotational movement around a vertical axis pivot (bolster), with side bearers preventing excessive movement. More modern bolsterless bogie designs omit these features, instead taking advantage of the sideways movement of the suspension to permit rotational movement.

Examples

BR1 bogie

The British Railways Mark 1 coach brought into production in 1950 utilised the BR1 bogie, which was rated to run at 90 mph (145 km/h). The wheels were cast as a one-piece item in a pair with their axle. The simple design involved the bogie resting on four leaf springs (one spring per wheel) which in turn were connected to the axles. The leaf springs were designed to absorb any movement or resonance and to have a damping effect to benefit ride quality.

Each spring was connected to the outermost edge of the axle by a roller bearing contained in oil-filled axle box. The oil had to be topped up at regular maintenance times to avoid the bearing running hot and seizing.

There was also a heavy-duty version designated BR2.

Commonwealth bogie



Commonwealth bogie as used on BR Mark 1 and CIE Park Royals.

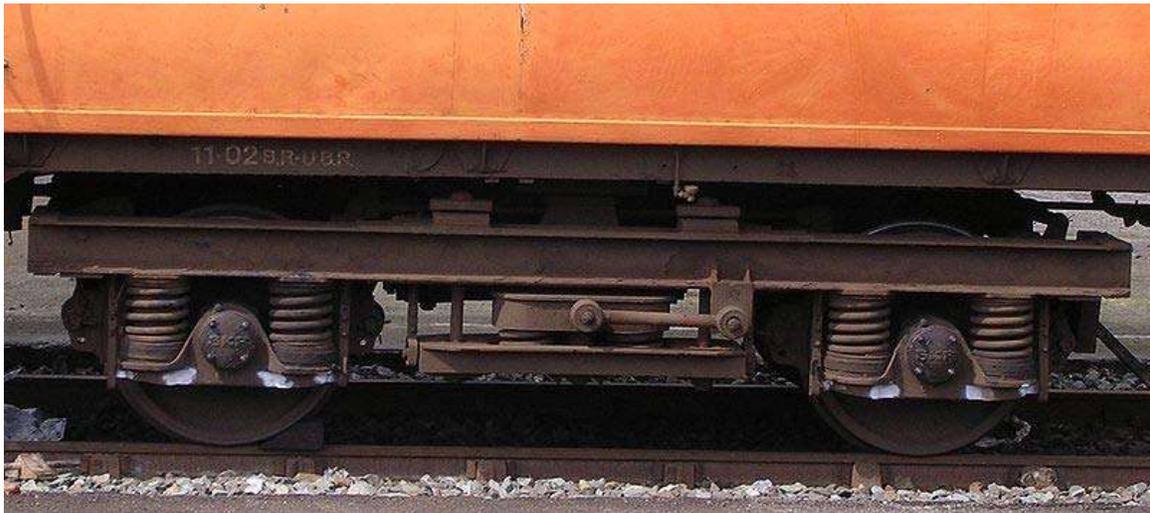
The Commonwealth bogie, manufactured by SKF or Timken, was introduced in the late 1950s for all BR Mark 1 vehicles. It was a heavy, cast-steel design weighing about 6.5

long tons (6.6 t) with sealed roller bearings on the axle ends, avoiding the need to maintain axle box oil levels.

The leaf springs were replaced by coil springs (one per wheel) running vertically rather than horizontally. The advanced design gave a better ride quality than the BR1, being rated for 100 miles per hour (160 km/h).

The side frame of the bogie was usually of bar construction, with simple horn guides attached, allowing the axleboxes vertical movements between them. The axleboxes had a cast steel equaliser beam or bar resting on them. The bar had two steel coil springs placed on it and the bogie frame rested on the springs. The effect was to allow the bar to act as a compensating lever between the two axles and to use both springs to soften shocks from either axle. The bogie had a conventional bolster suspension with swing links carrying a spring plank.

B4 bogie



B4 bogie as used on BR Mark 2 and Irish Cravens

The B4 bogie was introduced in 1963. It was a fabricated steel design as versus cast iron and was lighter than the Commonwealth, weighing in at 5 long tons (5.08 t). It also had a speed rating of 100 miles per hour (160 km/h).

Axle/spring connection was again with fitted roller bearings. However, now two coil springs rather than one were fitted per wheel.

Only a very small amount of Mark 1 stock was fitted with the B4 bogie from new, it being used on the Mark 1 only to replace worn out BR1 bogies. The British Rail Mark 2 coach however carried the B4 bogies from new. A heavier duty version, the B5, was standard on Southern Region Mk1 based EMUs from the 1960s onwards. Some Mark 1 catering cars had mixed bogies—a B5 under the kitchen end, and a B4 under the seating end. Some of the B4 fitted Mark 2s, as well as many B4 fitted Mark 1 BGs were allowed

to run at 110 miles per hour (180 km/h) with extra maintenance, particularly of the wheel profile, and more frequent exams.

BT10 Bogie



BT10 High speed bogie as used on MK3

The BT10 bogie was introduced on the British Rail Mark 3 coach in the 1970s. Each wheel is separately connected to the bogie by a swing-arm axle.

There is dual suspension:

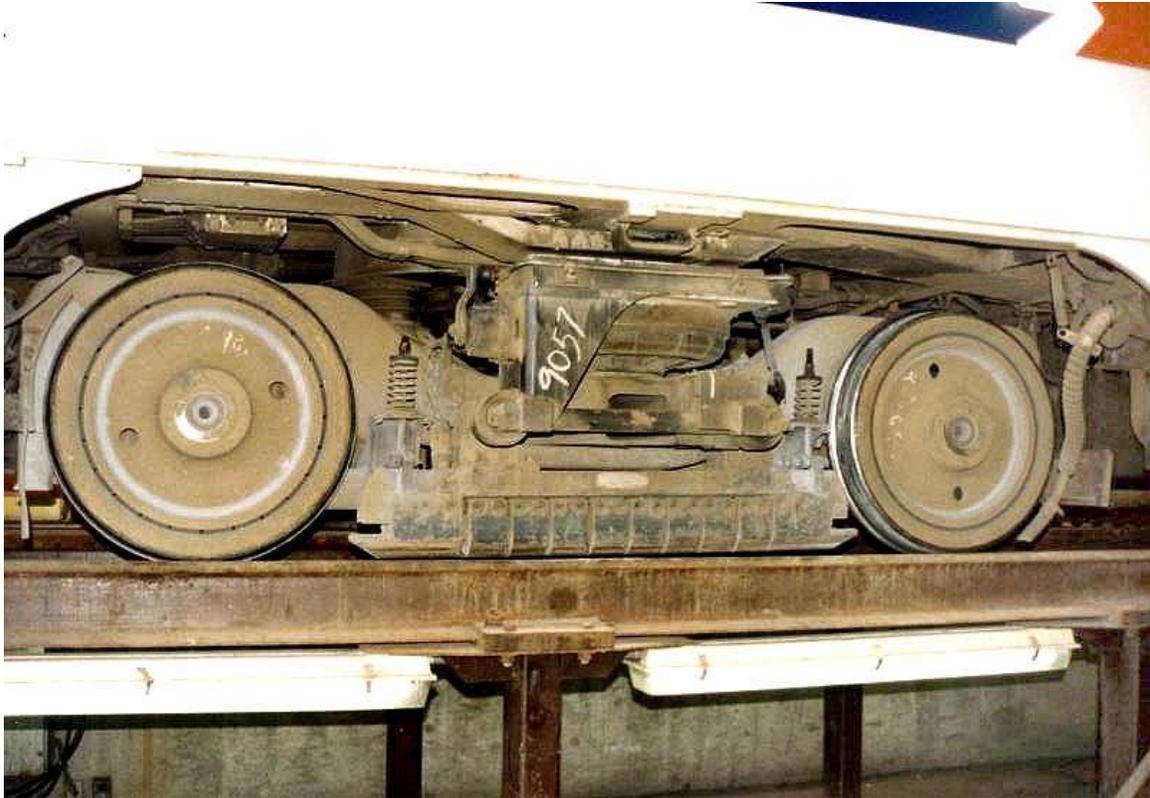
- primary suspension via a coil spring and damper mounted on each axle.
- secondary suspension via two air springs mounted on the pivot plank. This is connected to the bogie by pendulum links. A constant coach height is maintained by air valves.

Locomotives

Most diesel locomotives and electric locomotives are carried on bogies (trucks - US). Trucks used in the USA include AAR type A switcher truck, Blomberg B, HT-C truck and Flexicoil.

Tramway

Modern



Side view of a SEPTA PCC car bogie

Tram bogies are much simpler in design because of their axle load, and the tighter curves found on tramways mean that tram bogies almost never have more than two axles. Furthermore, some tramways have steeper gradients and vertical as well as horizontal curves, which means that tram bogies often need to pivot on the horizontal axis as well.

Some articulated trams have bogies located under articulations, a setup referred to as a Jacobs bogie. Often low-floor trams are fitted with non-pivoting bogies and many tramway enthusiasts see this as a retrograde step, as it leads to more wear of both track and wheels and also significantly reduces the speed at which a tram can round a curve. The only 100% low floor tram with pivoting bogies - Škoda ForCity - uses the Jacobs bogie.

Historic

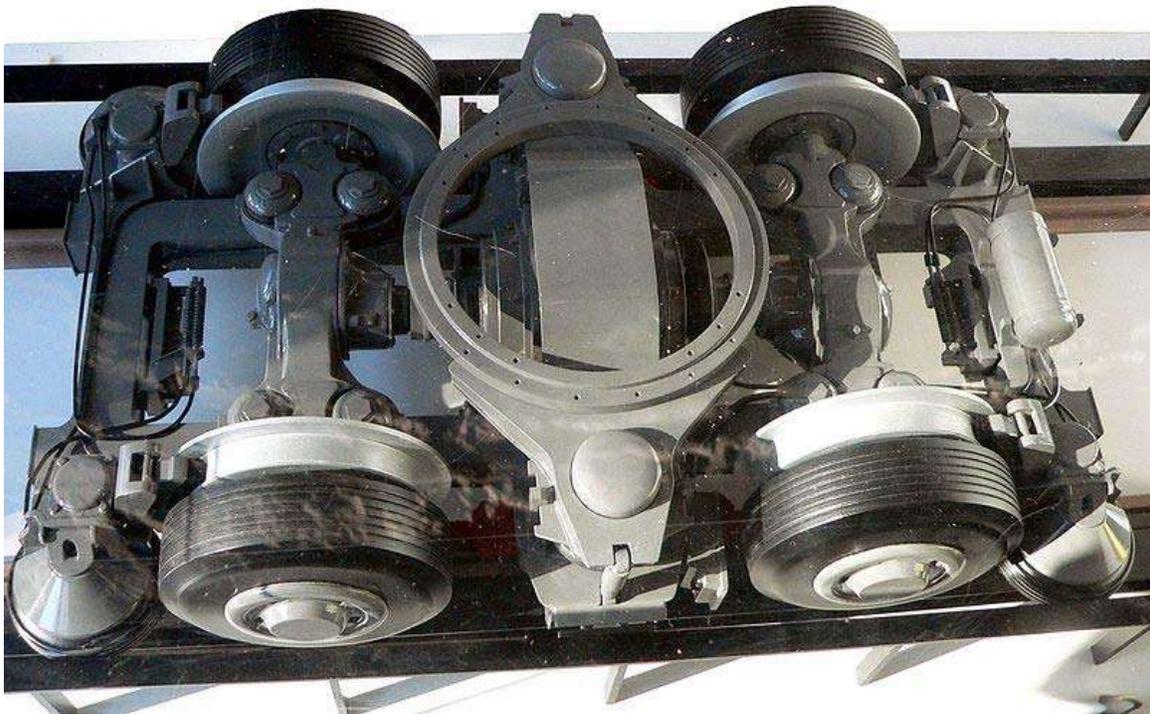
In the past, many different types of bogie ("truck") have been used under tramcars, e.g. "Brill", "Peckham" and "maximum traction". A maximum traction truck has one driving

axle with large wheels and one non-driving axle with smaller wheels. The bogie pivot is located off-centre so that more than half the weight rests on the driving axle.

Tracked vehicles

Some tanks and other tracked vehicles have bogies as external suspension components. This type of bogie usually has two or more road wheels and some type of sprung suspension to smooth the ride across rough terrain. Bogie suspensions keep much of their components on the outside of the vehicle, saving internal space. Although vulnerable to antitank fire, they can often be repaired or replaced in the field.

Hybrid systems



Model of the pneumatic bogie system of a MP 89 carriage used on the *Meteor* metro

Rubber-tyred metro trains utilise a specialised version of railway bogies. As well as the standard running wheels (rubber instead of steel) there are additional horizontal guide wheels in front of and behind the running wheels.

Variable gauge axles

To overcome breaks of gauge some bogies are being fitted with variable gauge axles (VGA) so that they can operated on two different gauges. These include the SUW 2000 system from ZNTK.

Chapter- 4

Buchli Drive

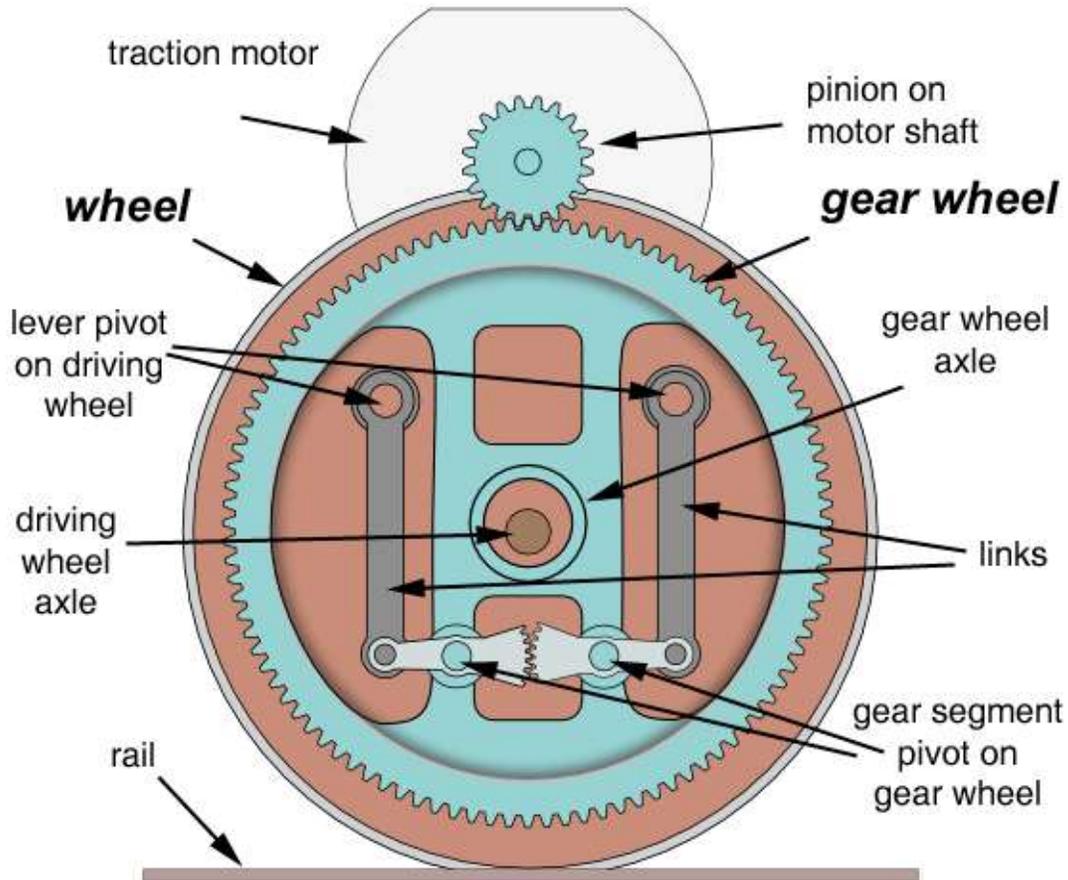


Buchli-Toggle drive with inner frame

The **Buchli drive** is a transmission system used in electric locomotives. It was named after its inventor, Swiss engineer Jakob Buchli. The drive is a fully spring-loaded drive, in which each floating axle has an individual motor, that is placed in the spring mounted locomotive frame. The weight of the driving motors is completely disconnected from the driving wheels, which are exposed to movement of the rails.

First used in electric locomotives from the 1920s, the Buchli drive made possible the construction of faster and more powerful locomotives that required larger and heavier traction motors. The system minimises the impact on rail tracks due to the reduction in the overall unsprung weight. Although the drive was very successful through the 1930s, it is little used in modern locomotives, having been replaced with smaller, simpler drives that exhibit less imbalance and allow higher speeds.

Construction



Buchli-Toggle-drive

In a Buchli drive a driven gear wheel is securely fixed to the locomotive frame. Inside this gear wheel are two levers, coupled to gear segments that mesh with one another. The

other end of the levers is coupled via universal joints to tension bars, which are then coupled via more universal joints to the driving rail wheel.

Vertical movement of the driving wheel results in the gear segments moving due to the internal mechanism, and the driving wheel can move in a horizontal or vertical direction with respect to the gear wheel, while still transferring the momentum of the gear wheel.

A disadvantage of the drive was the large number of moving parts, which demanded frequent lubrication and careful maintenance. As a result the Buchli drive system was mainly used on express train locomotives, as there were no other drive systems that gave the same performance at high speeds. However, at higher speeds the drive components became unbalanced, causing issues at speeds over 140 km per hour.

Standard design

The Buchli drive was exported to other rail companies as one sided separate traction motor drive, usually with an inside frame.

The motor framework with the wheelset bearing is located between the wheel disks of the driving wheels. The gear wheel, which is housed in an auxiliary frame outside the driving wheels and is surrounded by a protective casing, is on one side of the driving wheels. Each gear wheel is driven by an individual traction motor, which is located above the gear wheel in the locomotive body.

With this implementation, a strongly one-sided weight distribution occurs in the underframe through the remote gear wheels. In order to maintain stability of the locomotive on the longitudinal axis, heavy equipment inside the locomotive body must be arranged on the opposite side of the drive equipment.

Locomotives with a Buchli drive also typically have an asymmetrical appearance: on one side, the bearings of the drive wheels are visible, on the other side, they are almost completely covered by the wheel cover box of the gear wheels.

Other designs



Two Ae 4/7 on a trial run in 2007. Note the difference in appearance; both sides can be seen

In addition to the standard implementation, there were also the following variations:

Outside frame

The engine framework with the driving wheel housing is outside the wheel disks of the driving wheels. The driving wheel is enclosed by a quill camped in the locomotive cabinet, on which the gear wheel sits. Examples included the Pennsylvania Railroad O1b, and the Deutsche Reichsbahn ET11.01.

Group drive

The motor is arranged between the floating axles. A common pinion or a pinion on both motor end drives the gear wheels of the neighbouring axes. U.S. Patent 1,683,674 described this design, but vehicles implementing it are not known.

Bilateral drive

The driving wheel is coupled with two gear wheels, and the motor has a pinion on both sides. The taps in the wheel disk are warped about 90 degrees against each other so that

the drive imbalance can be reduced. This version of the driver was used for greater driving power.

However with this arrangement, there is the danger of mechanical stress in the drive components. Examples included the French express train locomotives: SNCF 2D2 5400, SNCF 2D2 5500, SNCF 2D2 9100.

Two motors per axis

Two driving motors work on one common gear wheel, which is interconnected with a driving wheel. Examples include the Pennsylvania Railroad O1b.

Locomotive with Buchli drive



SBB-CFF-FFS Ae 4/7 class locomotive

Nearly 240 locomotives of the SBB with Buchli drive were in use for over sixty years. The SBB Ae 3/6I class locomotives were in operation from 1921 to 1994. French tracks had 100 express train locomotives using the Buchli drive, in service for fifty years.

- SBB-CFF-FFS, Switzerland
 - SBB Be 2/5 (Prototype locomotive) (Deutsch)
 - SBB Ae 4/8 (Prototype locomotive) (Deutsch)
 - SBB Ae 3/6 I (Deutsch)
 - SBB Ae 4/7
 - SBB Ae 8/14 (11801)(Deutsch)

- Deutsche Reichsbahn, Germany
 - E 16 (116) (Deutsch)
 - ET 11.01 double railcars Bo'2'+2'Bo'. Constructed in 1938, implementation without frame. The vehicle was rebuilt in the 1960s and the Buchli drive system was removed
- SNCF
 - SNCF Class 2D2 5400 (mutual drive) (Français)
 - SNCF Class 2D2 5500 (mutual drive) (Français)
 - SNCF Class 2D2 9100 (mutual drive) (Français)
- Indonesian national railway
 - 3000 - 4 Stk 1'Do1' locomotives for the 1.5 kV electrification system, manufactured by Werkspoor in the Netherlands in 1924, scrapped 1976 or thereabouts. At this locomotive was placed on the Java rack railway for the first time.image
- Japanese Government Railways
 - 7000 - (1A)Bo(A1), constructed in 1926, later renumbered as the ED54 class (???)
- Indian Railways
 - EC/1 4002 - 2'Co2' - constructed in 1927.
- RENFE
 - RENFE series 272, ordered by predecessor company NORTE, 12 constructed in 1928 as the Stk 2'Co'Co'2' for a 1.5 kV supply voltage.
- Paulista-Railway, Brazil
 - 320, 1'Do1', constructed in 1932.
- Czechoslovak State Railways
 - E 465.0 - 2 Stk 1'Do1' locomotive for 1.5 kV supply voltage. Built in 1927 and scrapped in 1962
- Pennsylvania Railroad, United States
 - Pennsylvania Railroad O1b - 2 Stk 2'Bo2' locomotives. Built with inside frame and two driving motors per axle.
- Circumvesuviana, Italy
 - 1'Do1' locomotive, type and number unknown.

Chapter- 5

Catch Points



Trap points and a sand drag protect the exit of a station passing loop (left), while catch points stop vehicles from running away down a steep slope (right).

Catch points and **trap points** are types of turnout which act as railway safety devices. Both work by guiding railway carriages and trucks from a dangerous route onto a separate, safer track. Catch points are used to derail vehicles which are out of control on steep slopes (known as *runaways*). Trap points are used to protect main railway lines from unauthorised vehicles moving onto them from sidings or branch lines. Either of these track arrangements may lead the vehicles into a **sand drag** or **safety siding**, track arrangements which are used to safely stop them after they have left the main tracks.

A derail is another device used for the same purposes as catch and trap points.

Trap points

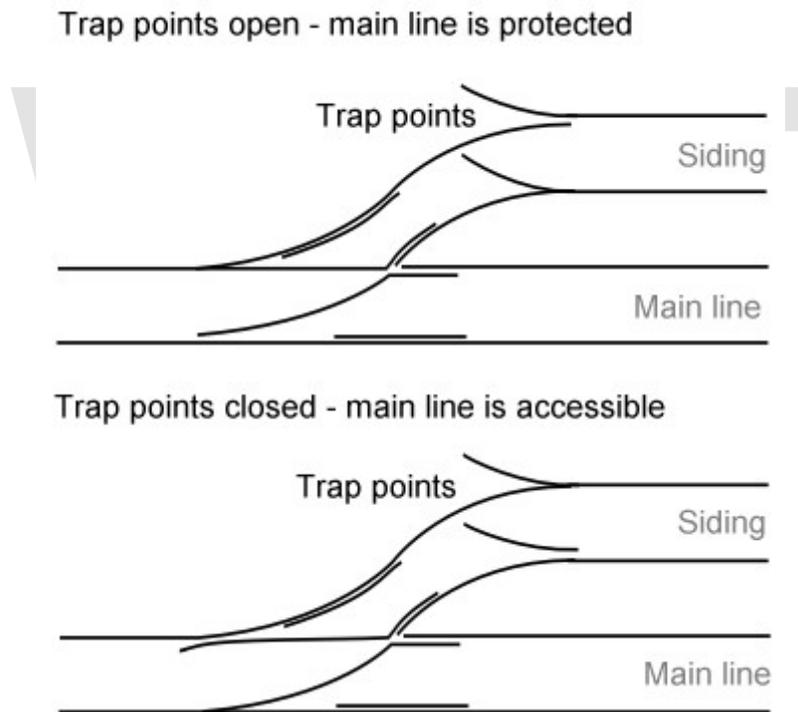


Diagram showing the use of trap points to protect the main line at the exit of a siding



An insulated track circuit interrupter fitted to trap points

Trap points are found at the exit from a siding or where a secondary track joins a main line. A facing turnout is used to prevent any unauthorised movement that may otherwise obstruct the main line. The trap points also prevent any damage that may be done by a vehicle passing over points not set for traffic joining the main line. In the United Kingdom, the use of trap points at siding exits is required by government legislation.

An unauthorised movement may be due to a runaway wagon, or may be a train passing a signal at danger. When a signal controlling passage onto a main line is set to "danger", the trap points are set to derail any vehicle passing that signal. Interlocking is used to make sure that the signal cannot be set to allow passage onto the main line until the trap points have been aligned to ensure this movement can take place.

Trap points should preferably be positioned to ensure that any unauthorised vehicle is stopped a safe distance from the main line. However, due to space limitations, it is not always possible to guarantee this.

If the lines are track circuited, then a track circuit interrupter will be fitted to one of the run-off rails in order to break the track circuit and set main line signals to 'danger'.

Types of trap points

There are several different ways of constructing trap points:

- A *single tongue trap* consists of only one switch rail, leading away from the main line to a short tongue of rail. This is usually placed in the rail furthest from the main line.
- *Double trap points* are a full turnout, leading to two tongues. Usually the tongue nearer the main line is longer than the other.
- *Trap points with a crossing* are double trap points where the tongues of rail are longer, so that the trap point rail nearest the main line continues over the siding rail with a common crossing or frog.
- A *trap road with stops* is a short dead-end siding leading to some method of stopping a vehicle, such as a sand drag or buffer stop.
- *Wide to gauge trap points* have switches that work in opposite directions and are therefore either both open or both closed. Vehicles derailed at these points will tend to continue in a forward direction rather than being thrown to one side. Wide to gauge points are typically found on sidings situated between running lines.

The type of trap points to be used depends on factors such as the gradient of the siding, and whether locomotives enter the siding.

- *Independent switches* are a kind of wide to gauge switch which are part of two separate crossovers. There are three positions: part of crossover A to left; wide to gauge switches; part of crossover B to right. A good place to view these independent switches are at both ends of Platforms 1 and 2 at Hornsby railway station, Sydney.

Types of trap points



Double trap points protecting the South Wales Main Line at the exit of Stoke Gifford Rail Yard near Bristol Parkway railway station



Double trap points with much longer rails, at Castle Cary railway station



A trap road with buffer stops at the railway station of *Allersberg*, on the Nuremberg-Munich high-speed rail line

Catch points

Catch points are used where track follows a rising gradient. They are used to derail (or "catch") any unauthorised vehicles travelling down the gradient. This may simply be a vehicle that has accidentally been allowed to run away down the slope, or could be a wagon that has decoupled from its train. In either case, the runaway vehicle could collide with a train further down the slope, causing a serious accident.

Catch points may consist of a full turnout or a single switch blade. In some cases, on a track that is only traversed by uphill traffic, trailing point blades are held in a position to derail any vehicle travelling downhill. However, any traffic travelling in the correct (uphill) direction can pass over the turnout safely, pushing the switch blades into the appropriate position. Once the wheels have passed, the catch points are forced back into the derailing position by springs. In these cases, a lever may be provided to temporarily override the catch points and allow safe passage down the gradient in certain controlled circumstances.

The use of catch points became widespread in the United Kingdom after the Abergele train disaster, where runaway wagons containing paraffin oil (kerosene) collided with an express train. Catch points continued to be used in the UK until the mid-20th Century. At

this time, continuous automatic brakes, which automatically stop any vehicles separated from their train, were widely adopted, making catch points largely obsolete.

Sand drag

In some cases, catch points and trap points direct vehicles into a *sand drag* or *safety siding*, also sometimes called an *arrestor bed*. This may be a siding simply leading to a mound of sand, gravel or other granular material, or a siding where the rails are within sand-filled troughs. This method of stopping a vehicle travelling at speed is preferred over a buffer stop as there is less shock to the vehicle involved.

Chock block

A cheap and simple alternative to a catchpoint or derail is a chock block, which is a piece of timber that can be positioned and locked over one of the rails at the end of a siding to protect the main line from runaways. In order for the siding to be used the chock block must be removed.



Chapter- 6

Corridor Connection



A British Railways Mark 1 coach fitted with a corridor connection of the Pullman type

A **Corridor connection** (or **Gangway connection**) is a flexible connector fitted to the end of a railway coach to enable passage from one coach to another without falling out of the train.

History

Coaches

The London and North Western Railway (LNWR) was the first British railway to provide passengers with the means to move from one coach to another whilst the train was in motion. In 1869 the LNWR built a pair of saloons for the use of Queen Victoria; these had six-wheel underframes (the bogie coach did not appear in Britain until 1874), and the gangway was fitted to only one end of each coach. The Queen preferred to wait until the train had stopped before using the gangway.



This British locomotive has a centre buffing plate similar to the lower portion of a Pullman vestibule

In 1887, George M. Pullman introduced his patented vestibule cars. Older railroad cars had open platforms at their ends, which was used both for joining and leaving the train, but could also be used to step from one car to the next. This practice was dangerous, and

so Pullman decided to enclose the platform to produce the vestibule. For passing between cars, there was a passageway in the form of a steel-framed rectangular diaphragm mounted on a buffing plate above the centre coupler. The vestibule prevented passengers from falling out; it protected passengers from the weather when passing between cars; and in the event of an accident, the design was such that the cars were less likely to override each other, and so the risk of telescoping was much reduced. Pullman's vestibule cars were first used in 1887; amongst the first to use them was the Pennsylvania Railroad on the *Pennsylvania Limited* service to Chicago.

The Great Northern Railway introduced the Gould-design gangway connection to Great Britain in 1889, when E.F. Howlden was Carriage and Wagon Superintendent.

On 7 March 1892, the Great Western Railway (GWR) introduced a set of coaches on their Paddington to Birkenhead service; it was the first British side-corridor train where a corridor connection was provided between all the coaches, and was to the design of William Dean. The purpose was not to enable passengers to move around the train, but to allow the guard to reach any compartment quickly; electric bells were provided so that he could be summoned. When the guard was not so required, he kept the communicating doors locked; passengers could still use the corridor within the coach in order to reach the toilet. The gangway connections of the early GWR corridor coaches were offset to one side. Some coaches intended for use at the ends of trains had the gangway connection fitted at only one end. The GWR introduced restaurant cars in 1896; corridor connections were fitted, but passengers wishing to use the restaurant car were expected to board it at the start of their journey, and remain there: the gangway connections were still not for public use.



A GWR coach fitted with a British Standard gangway connection of the "suspended" type

On 17 May 1923, the GWR introduced some new coaches on their South Wales services; some of these coaches had British Standard gangway connections and screw couplers as used on many other GWR coaches; some had Pullman-type gangway connections and Laycock "buckeye" couplers; and there were some with one type at one end, and the other end having the other type. In 1925 the GWR started to use the "suspended" form of gangway connection instead of the "scissors" pattern. From 1938, GWR coaches which were expected to need coupling to LNER or SR coaches were fitted with gangway adaptors, to allow the dissimilar types to be connected.

From the beginning, the London, Midland and Scottish Railway used the British Standard type of corridor connector, in its "scissors" pattern as used by the GWR. Some coaches which needed to run on to LNER or SR lines were given gangway adaptors, so that coaches fitted with the Pullman gangway could be coupled safely.

On the formation of British Railways on 1 January 1948, it was decided to produce a new range of standard coaches, instead of perpetuating existing designs; however, the new types needed to be compatible with the old. Two of the pre-BR companies (the GWR and the London, Midland and Scottish Railway) favoured the British Standard gangway, whereas the other two (the London and North Eastern Railway and the Southern Railway) used the Pullman type. In the design of their new Mark 1 coaches, British Railways decided to standardise on the Pullman type in view of its resistance to telescoping. These gangways consisted of a flat steel plate, having a large aperture for the passageway; at the bottom it was rivetted to the buffing plate, whilst the top was supported on the coach end by two telescopic spring units. On the coach end was a wooden doorframe; this was connected to the faceplate by a flexible diaphragm made from plasticised asbestos. When two coaches were coupled, a curtain was used to cover the inside surfaces of the diaphragms and faceplates. The doorframe was fitted with a lockable door, of either sliding or hinged type, depending on the interior layout of that end of the coach.



A preserved LNER post office stowage tender with offset gangway connection

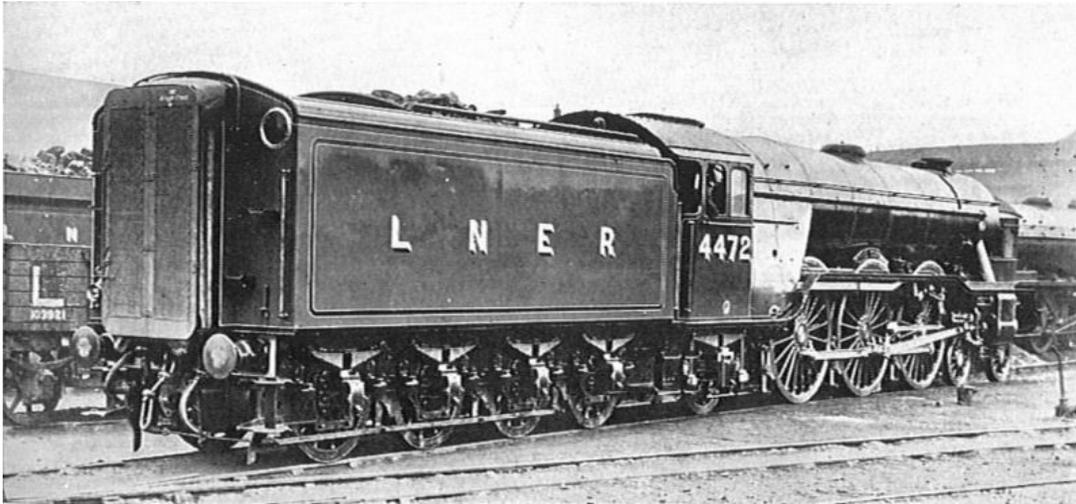
Travelling Post Office

Coaches built for the Travelling Post Office (TPO) services normally had their corridor connections offset to one side. There were two main reasons: there was a perceived security risk should these coaches be coupled to ordinary passenger-carrying coaches, the differing gangway positions minimising the risk of intrusion; and more space was available for sorting tables, the postal workers being able to walk in a straight line between vans without disturbing the sorters. A disadvantage was that when a van was added to a TPO train, it might need to be turned around before it could be used. After the formation of British Railways, most new Mark 1 TPO vans were provided with centre gangways, although a batch which were intended to work with older vans were given offset gangways. These were altered to the standard arrangement in 1973; until then, they had been the only BR Mark 1 gangwayed coaches not to have the Pullman gangway.

Locomotives

The London and North Eastern Railway (LNER) decided that from the start of their summer timetable on 1 May 1928, the *Flying Scotsman* service would run non-stop over the 392.7 miles (632.0 km) between London King's Cross and Edinburgh Waverley. The locomotives to be used were of that railway's class A1, and the schedule was for the

journey to be completed in $8\frac{1}{4}$ hours. This was too long to allow a single crew to handle without rest; means were therefore sought by which the crew could be changed at approximately the half-way point.



LNER Class A1 4-6-2 with corridor tender. Circular window of passageway at upper right of tender rear.



A preserved corridor tender. The passageway runs along the side closest to the camera; the top of the passageway may be seen at the rear

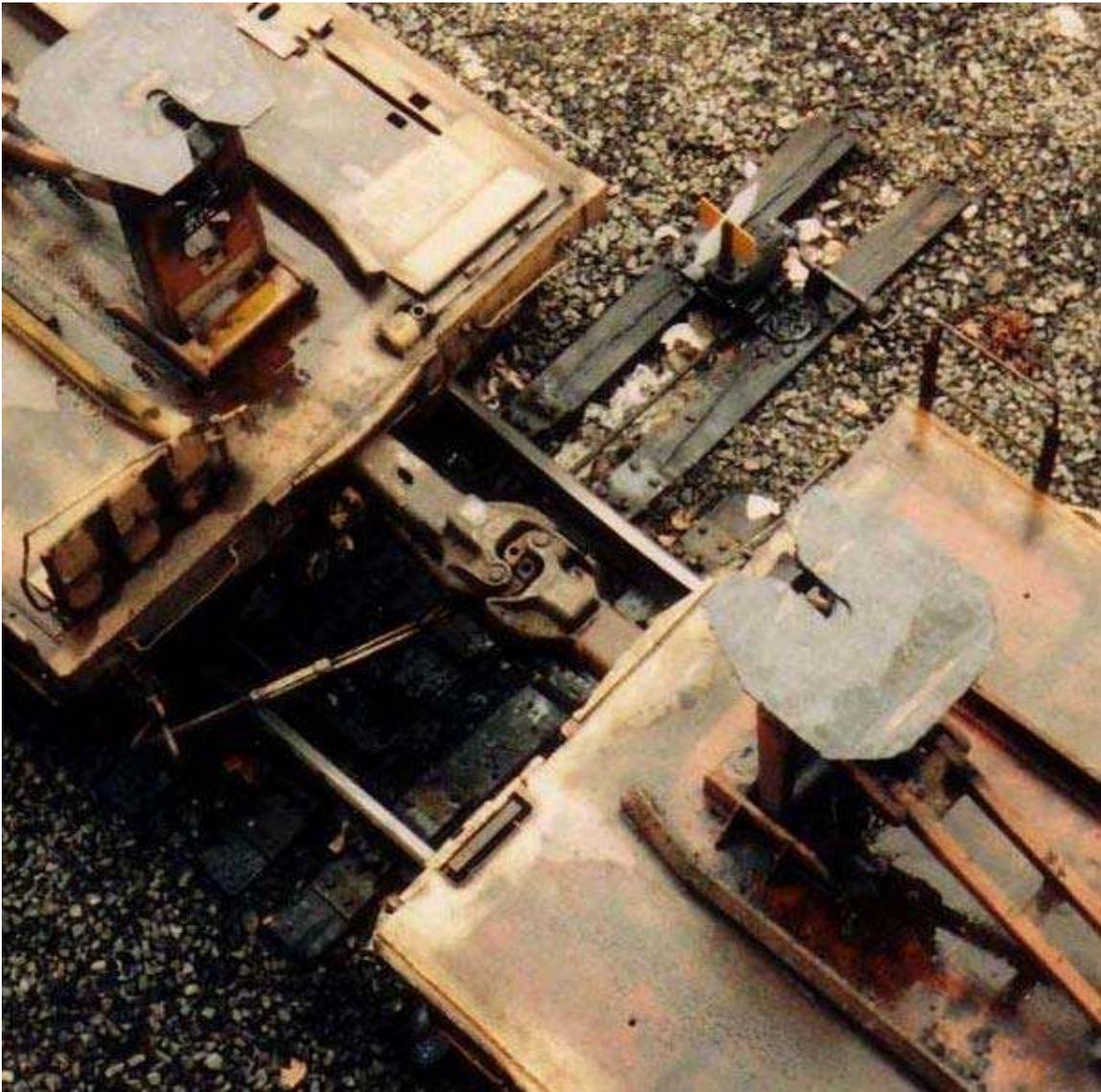
The LNER's locomotive design team, headed by Nigel Gresley, produced a new design of tender which was slightly longer than the old, but built as high and wide as possible without compromising the loading gauge. A passageway was incorporated along the right-hand side, and at the rear end a Pullman type gangway connection was fitted, together with a buckeye coupler, both of which were compatible with LNER coaches; the gangway was of concertina pattern, and was pressed against the corresponding gangway on the leading coach by means of sprung pistons. Although a normal gangway connection was used, the passageway through the tender was only 5 feet (1.52 m) high and 18 inches (0.46 m) wide, and the floor of the passage was 2 feet (0.61 m) above the bottom of the water tank, giving a high step at both ends. The passageway was illuminated by a single circular window in the tender rear panel, placed high up and to the right of the corridor connection. Ten of these tenders were placed in service between April and September 1928, of which three were attached to new locomotives of Class A3; two were attached to existing Class A3 locomotives, and five attached to Class A1 locomotives. The design was patented by Gresley in August 1928.

In service, the relief crew travelled in the front coach of the train, and as the train approached the half-way point, they left their seats and made their way forward through the corridor tender to the locomotive cab. On their arrival, the previous crew then handed over the controls and went back to the seats in the train which had been vacated by the relief crew.

Another corridor tender was built in 1929 for use with the new Class W1 4-6-4 no. 10000; four more were built in 1935 with the first four locomotives of the new Class A4, and a final seven were built with the 1937 batch of Class A4 locomotives, making a total of 22. The original ten were reconditioned in 1936–7 and attached to other Class A4 locomotives. In May 1948, the 1929-built corridor tender was transferred to a locomotive of Class A4, after which all 22 remained with this class until withdrawal.

Chapter- 7

Coupling



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.

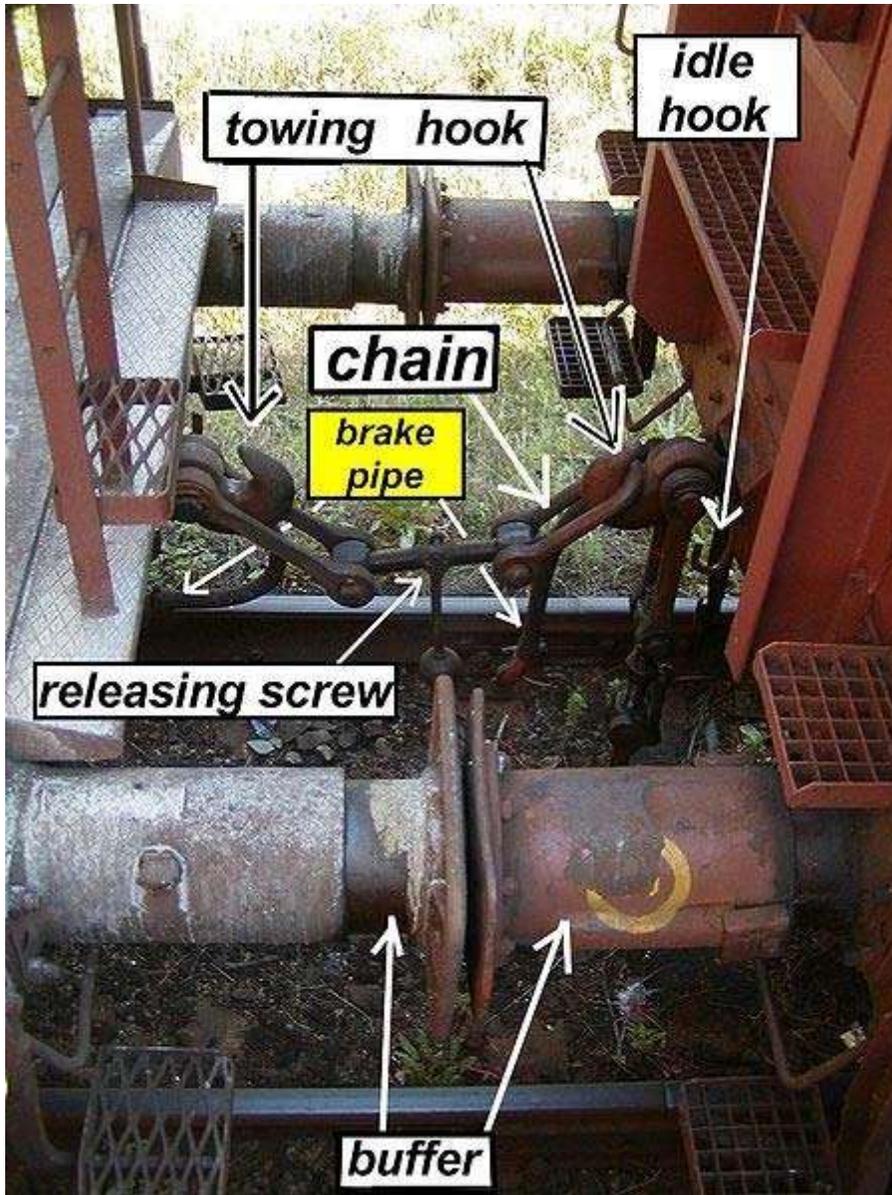
Buffers and chain



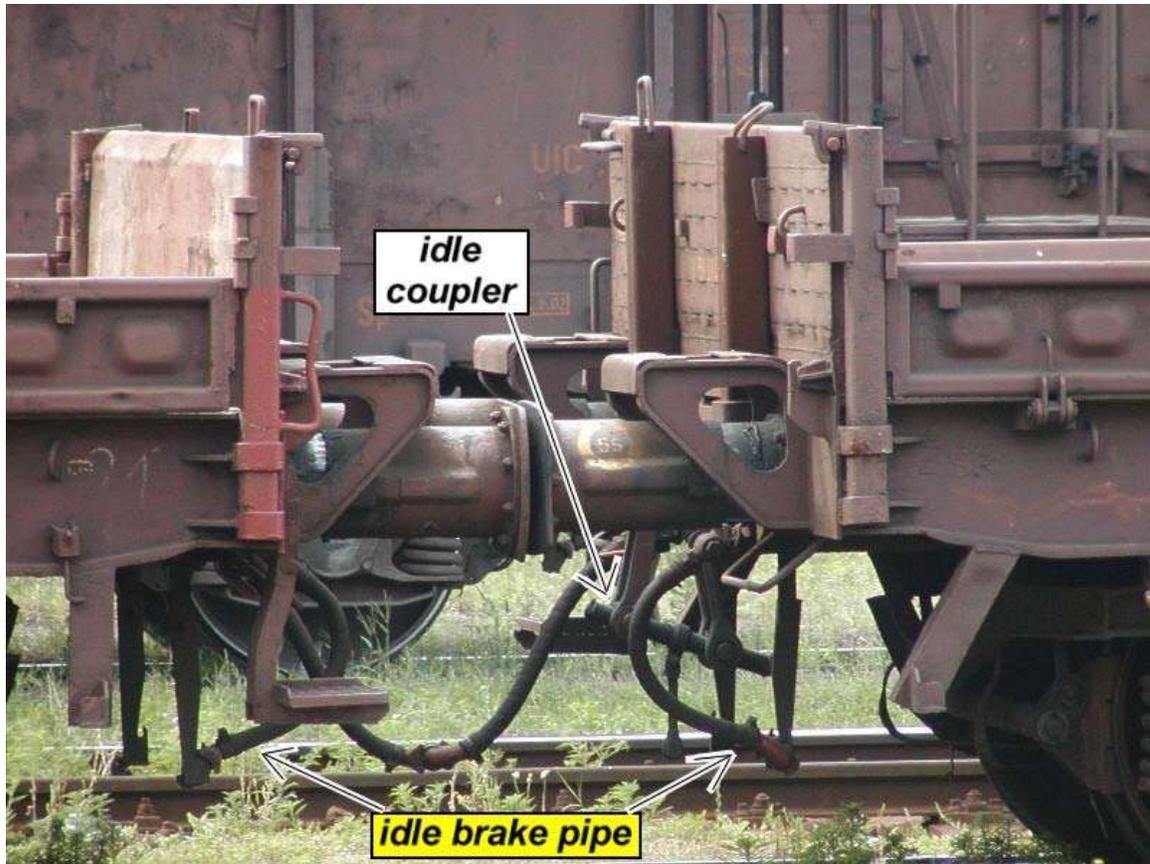
Traditional buffer-and-chain coupler



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

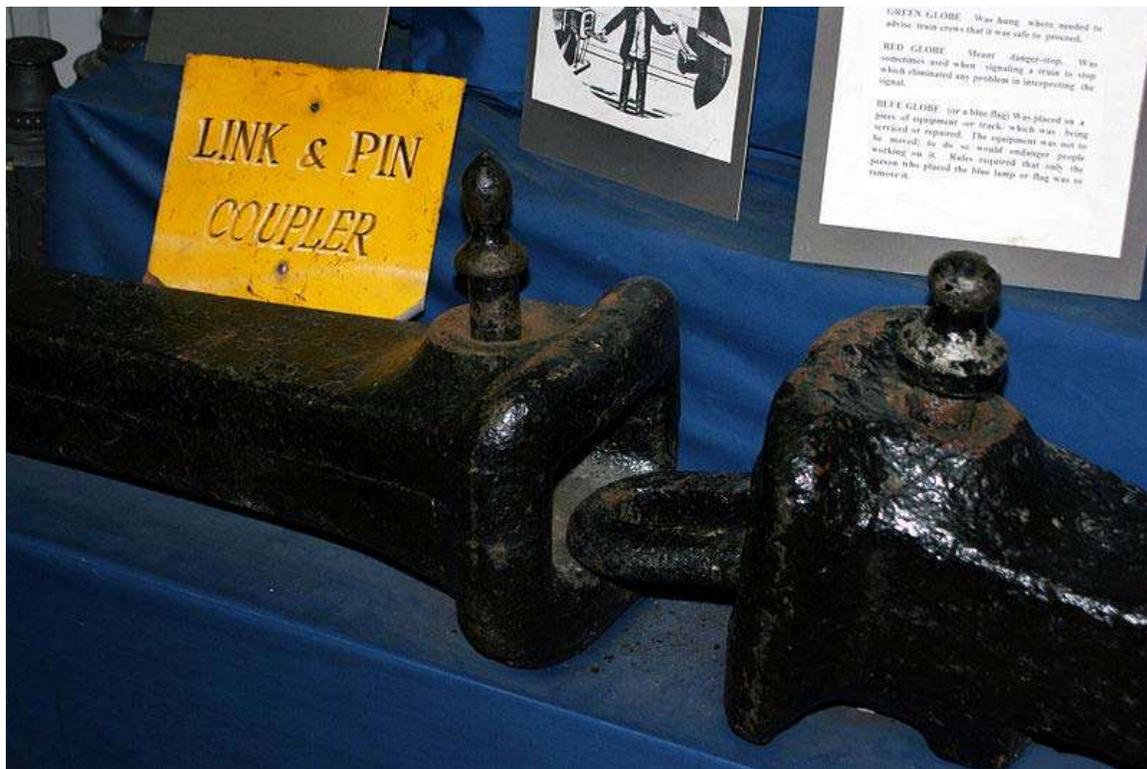


The narrow gauge "buffer-&-chain" coupler, called *Balancierhebelkupplung*

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.

Automatic couplers

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

Janney coupler

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

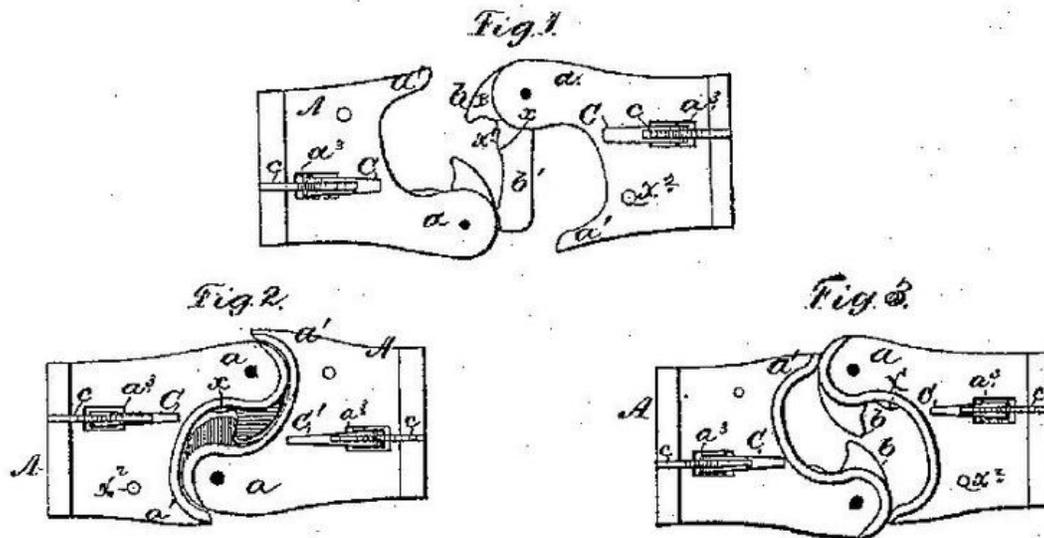


Diagram of the top view of Janney's coupler design as published in his patent application in 1873.

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 coupler



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

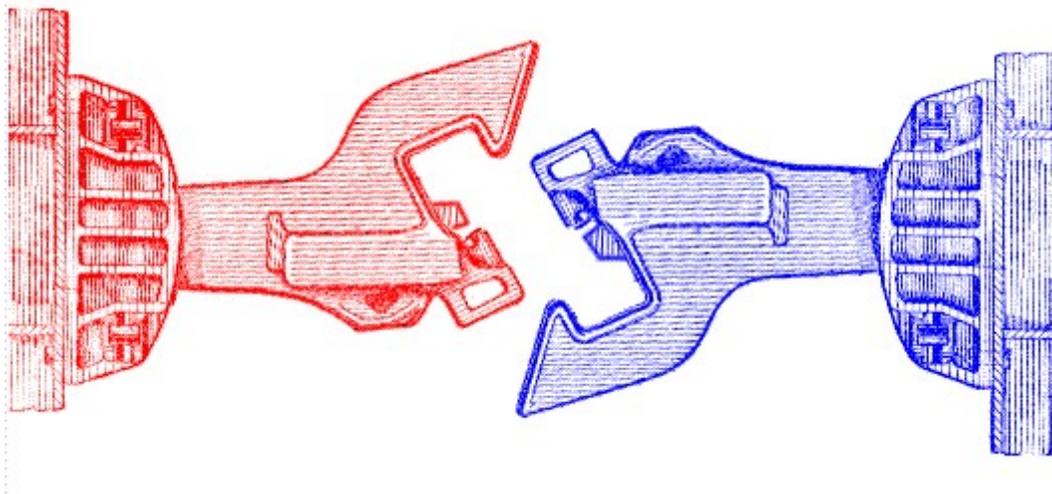


Standard AAR Type E couplers performing their function in a freight train.

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

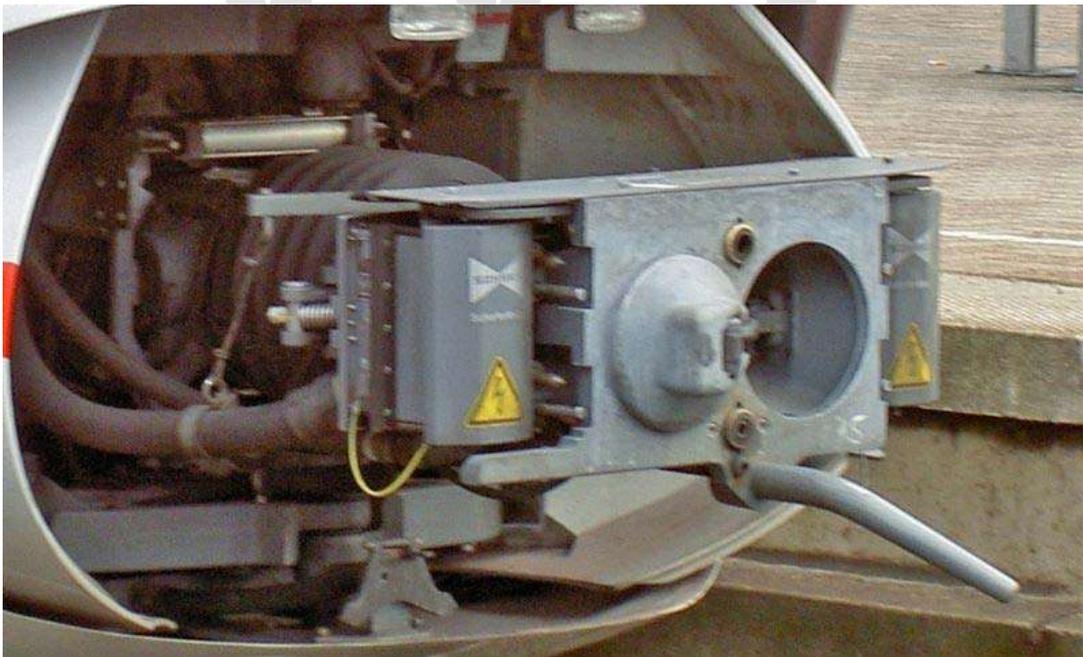
MFCs are 'fully automatic' couplers that make all connections between the rail vehicles (mechanical, air brake and electrical) without human intervention, in contrast to autocouplers which just handle the mechanical aspects. The majority of trains fitted with these types of couplers are multiple units,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



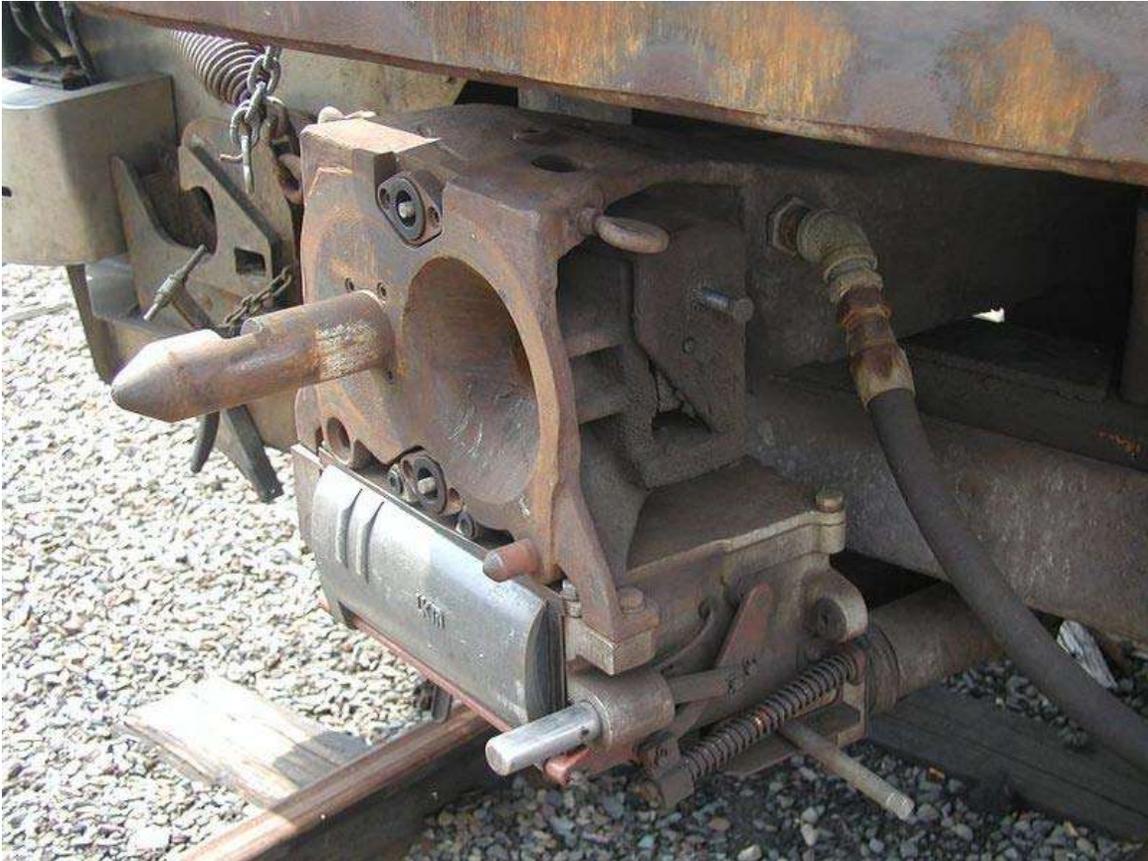
BSI



APTA, Type "H", Tightlock coupling



Wedgelock



Budd Pin and cup coupler

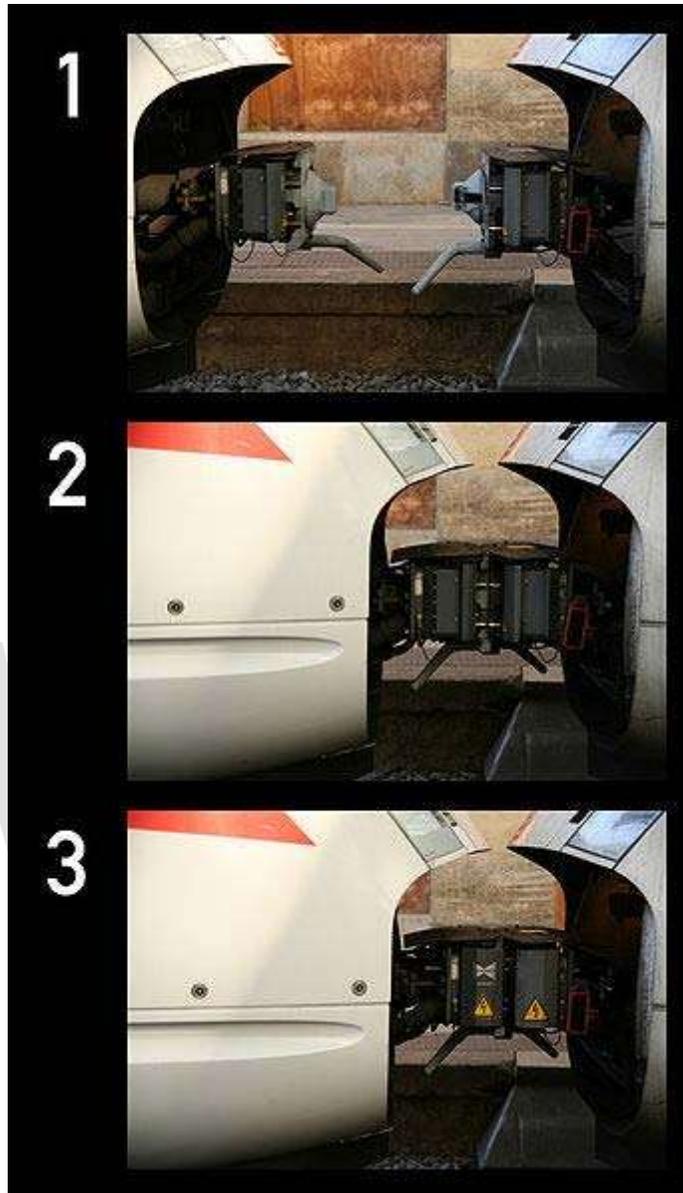
Westinghouse H-2 MU coupler

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

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.

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.

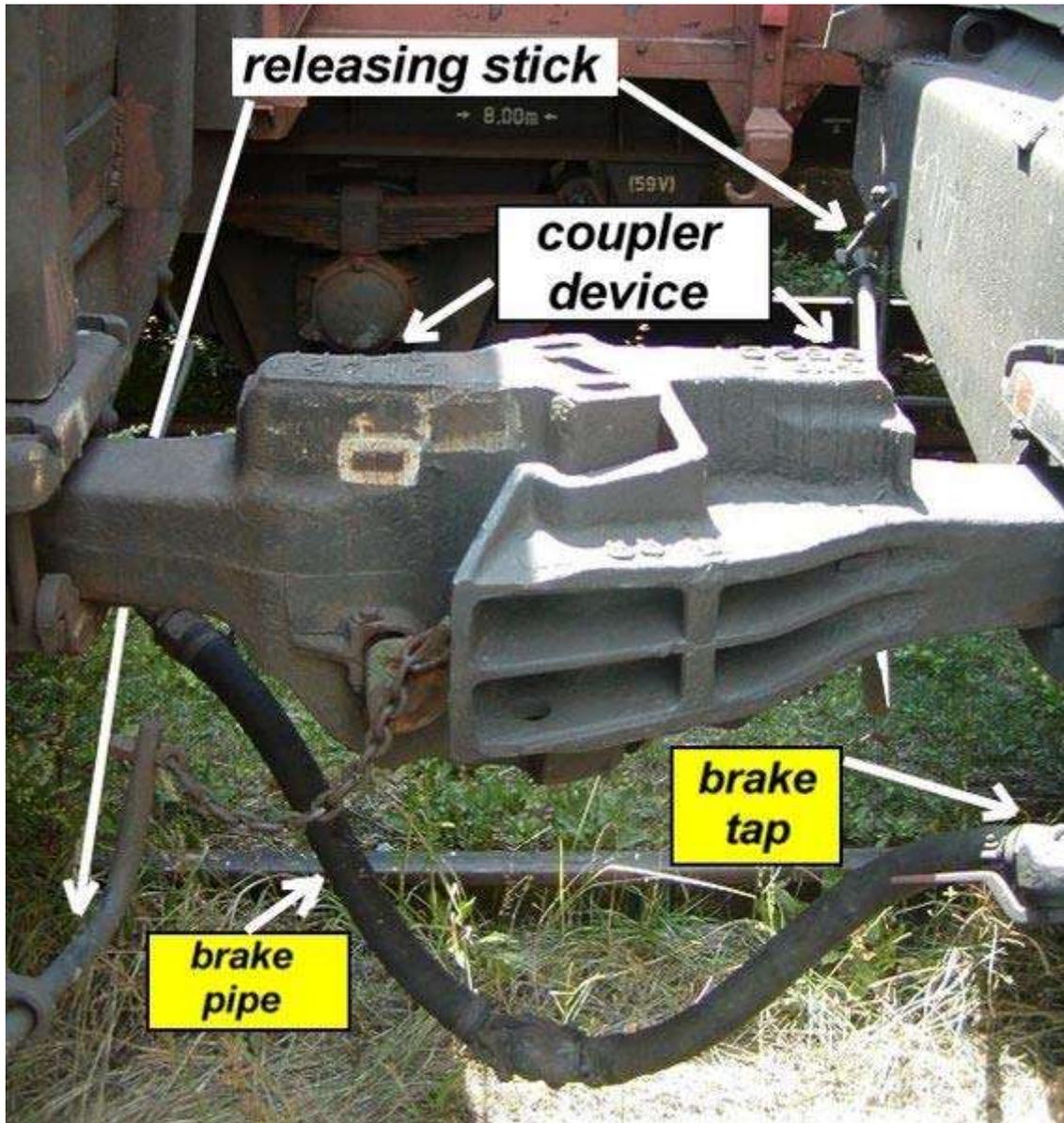
United States

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

In British 00 scale developed by Tri-ang (similar to H0 scale) models the 'tension lock' coupler is standard. This is similar in operation to the meatchopper type of coupling. 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 and which can be easily unplugged as required.

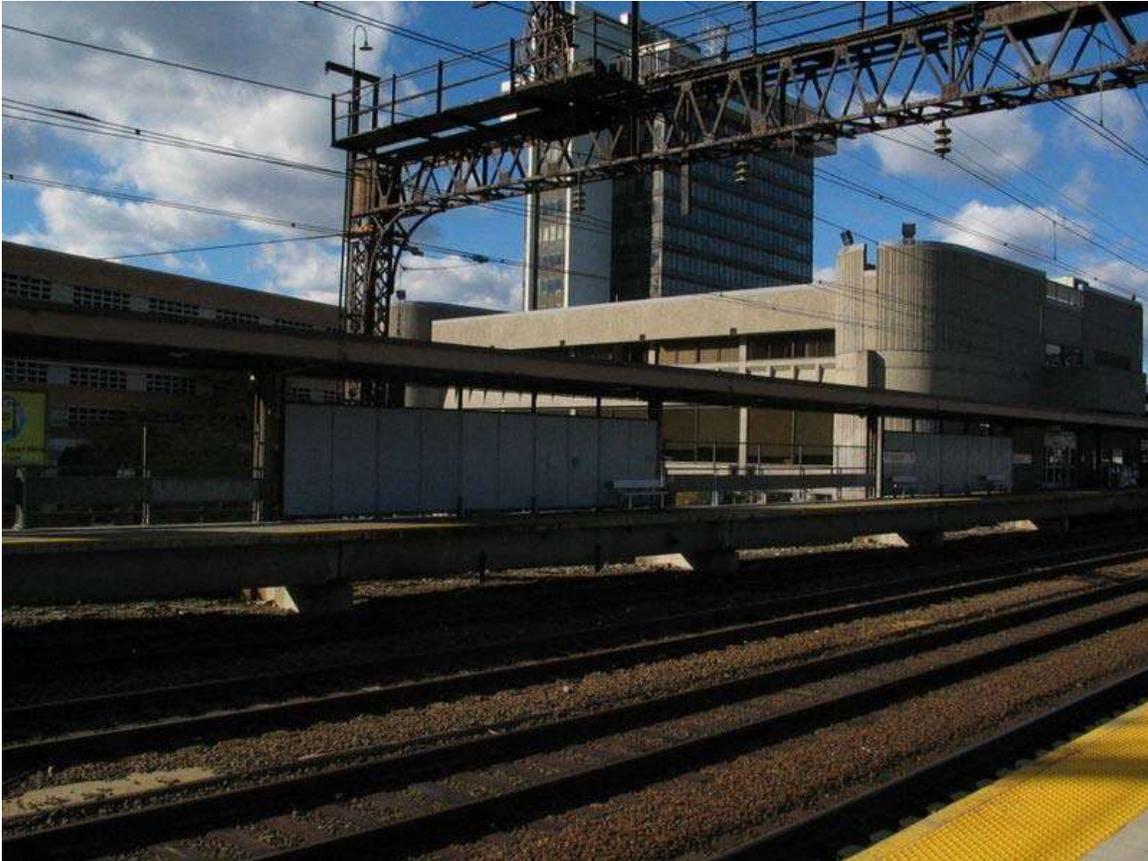
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Chapter- 8

Railway Electrification System



Electric locomotives under the wires in Sweden



Overhead wire and catenary in Bridgeport, Connecticut, United States

A **railway electrification system** supplies electrical energy to railway locomotives and multiple units so that they can operate without having an on-board prime mover. There are several different electrification systems in use throughout the world. Railway electrification has many advantages but requires significant capital expenditure for installation.

Characteristics of electric traction

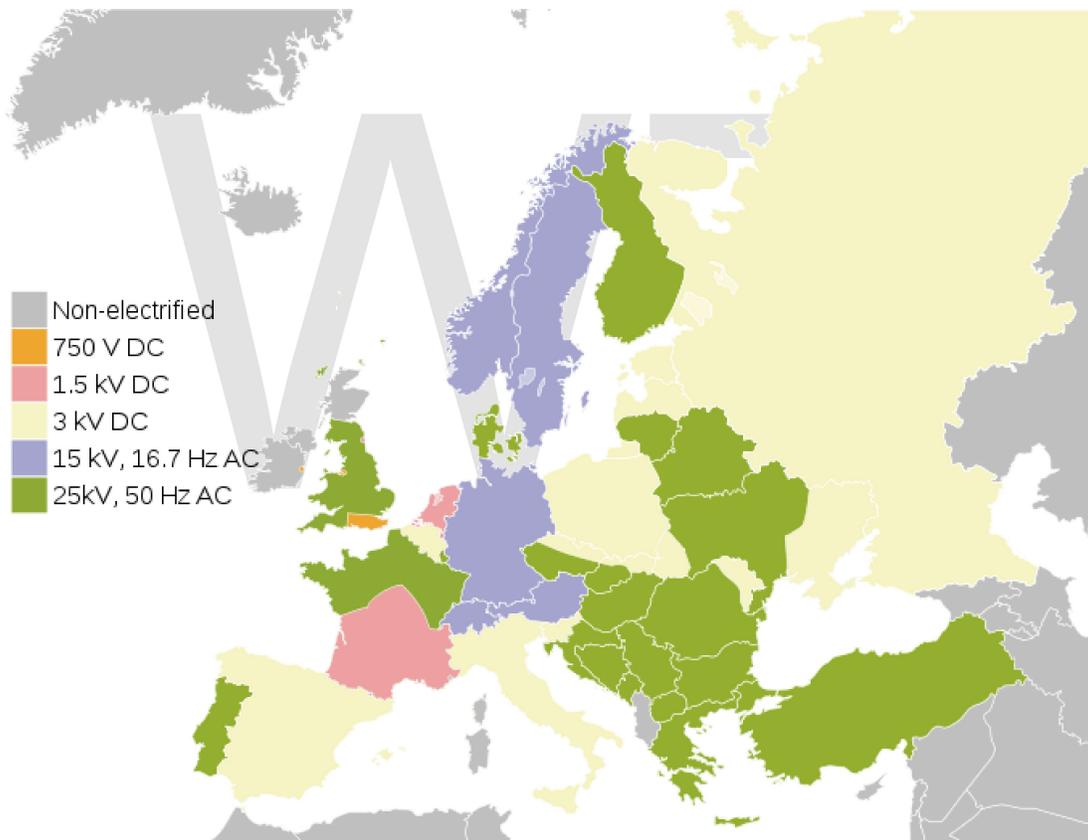
The main advantage of electric traction is a higher power-to-weight ratio than forms of traction such as diesel or steam that generate power on board. Electricity enables faster acceleration and higher tractive effort on steep gradients. On locomotives equipped with regenerative brakes, descending gradients require very little use of air brakes as the locomotive's traction motors become generators sending current back into the supply system and/or on-board resistors, which convert the excess energy to heat.

Other advantages include the lack of exhaust fumes at point of use, less noise and lower maintenance requirements of the traction units. Given sufficient traffic density, electric trains produce fewer carbon emissions than diesel trains, especially in countries where electricity comes primarily from non-fossil sources.

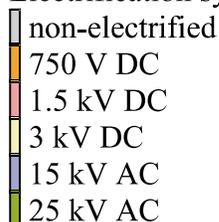
A fully electrified railway has no need to switch between methods of traction thereby making operations more efficient. Two countries that approach this ideal are Switzerland and Hong Kong, but both use more than one system, so unless multi-system locomotives or other rolling stock is used, a switch of traction method may still be required.

The main disadvantages are the capital cost of the electrification equipment, most significantly for long distance lines which do not generate heavy traffic. Suburban railways with closely-spaced stations and high traffic density are the most likely to be electrified and main lines carrying heavy and frequent traffic are also electrified in many countries. Also, if the overhead wiring breaks down in some way, all trains can be brought to a standstill.

Classification



Electrification systems in Europe:



1) High speed lines in France, Spain, Italy, United Kingdom, the Netherlands, Belgium and Turkey operate under 25 kV.

Electrification systems are classified by three main parameters:

- Voltage
- Current
 - Direct current (DC)
 - Alternating current (AC)
 - Frequency
- Contact System
 - third rail
 - overhead line (catenary)

Standardised voltages

Six of the most commonly used voltages have been selected for European and international standardisation. These are independent of the contact system used, so that, for example, 750V DC may be used with either third rail or overhead lines (the latter normally by trams).

There are many other voltage systems used for railway electrification systems around the world, and the list of current systems for electric rail traction covers both standard voltage and non-standard voltage systems.

The permissible range of voltages allowed for the standardised voltages is as stated in standards BS EN 50163 and IEC 60850. These take into account the number of trains drawing current and their distance from the substation.

Electrification system	Lowest non-permanent voltage	Lowest permanent voltage	Nominal voltage	Highest permanent voltage	Highest non-permanent voltage
600 V DC	400 V	400 V	600 V	720 V	800 V
750 V DC	500 V	500 V	750 V	900 V	1 kV
1,500 V DC	1,000 V	1,000 V	1,500 V	1,800 V	1,950 V
3 kV DC	2 kV	2 kV	3 kV	3 kV	3 kV
15 kV AC, 16.7 Hz	11 kV	12 kV	15 kV	17.25 kV	18 kV
25 kV AC, 50 Hz	17.5 kV	19 kV	25 kV	27.5 kV	29 kV

Direct current

Early electric systems used low-voltage DC. Electric motors were fed directly from the traction supply and were controlled using a combination of resistors and relays that connected the motors in parallel or series.

The most common DC voltages are 600 V and 750 V for trams and metros and 1,500 V, 650/750 V third rail for the former Southern Region of the UK and 3 kV overhead. The lower voltages are often used with third or fourth rail systems, whereas voltages above 1 kV are normally limited to overhead wiring for safety reasons. Suburban trains (*S-Bahn*) lines in Hamburg, Germany, operate using a third rail with 1,200 V, the French SNCF Culoz-Modane line in the Alps used 1,500 V and a third rail until 1976, when a catenary was installed and the third rail was removed. In the UK, south of London, 750 V third rail is used while, for inner London, 650 V is used to allow inter-running with London Underground which uses a 650 V fourth rail system but with the 4th (centre) rail connected to the running rails in inter-running areas.

During the mid-20th century, rotary converters or mercury arc rectifiers were used to convert utility (mains) AC power to the required DC voltage at feeder stations. Today, this is usually done by semiconductor rectifiers after stepping down the voltage from the utility supply.

The DC system is quite simple but it requires thick cables and short distances between feeder stations because of the high currents required. There are also significant resistive losses. In the United Kingdom, the maximum current that can be drawn by a train is 6,800 A at 750 V. The feeder stations require constant monitoring and, on many systems, only one train or locomotive is allowed per section. The distance between two feeder stations at 750 V on third-rail systems is about 2.5 km (1.6 mi). The distance between two feeder stations at 3 kV is about 25 km (16 mi).

If auxiliary machinery, such as fans and compressors, is powered by motors fed directly from the traction supply, they may be larger because of the extra insulation required for the relatively high operating voltage. Alternatively, they can be powered from a motor-generator set, which offers an alternative way of powering incandescent lights which otherwise would have to be connected as series strings (bulbs designed to operate at traction voltages being particularly inefficient). Now solid-state converters (SIVs) and fluorescent lights can be used.

Overhead systems



The Tyne and Wear Metro is the only United Kingdom system that uses 1,500 V DC.

1,500 V DC is used in the Netherlands, Japan, Hong Kong (parts), Ireland, Australia (parts), India (around the Mumbai area alone, to be converted to 25 kV AC like the rest of the country), France, New Zealand (Wellington) and the United States (Chicago area on the Metra Electric district and the South Shore Line interurban line). In Slovakia, there are two narrow-gauge lines in the High Tatras (one a cog railway). In Portugal, it is used in the Cascais Line and, in Denmark, on the suburban S-train system.



Nottingham Express Transit in United Kingdom uses a 750 V DC overhead, in common with most modern tram systems.

In the United Kingdom, 1,500 V DC was used in 1954 for the Woodhead trans-Pennine route (now closed); the system used regenerative braking, allowing for transfer of energy between climbing and descending trains on the steep approaches to the tunnel. The system was also used for suburban electrification in East London and Manchester, now converted to 25 kV AC.

3 kV DC is used in Belgium, Italy, Spain, Poland, the northern Czech Republic, Slovakia, Slovenia, western Croatia, South Africa and former Soviet Union countries (also using 25 kV 50 Hz AC). It was also formerly used by the Milwaukee Road's extensive electrification across the Continental Divide and by the Delaware, Lackawanna & Western Railroad (now New Jersey Transit, converted to 25 kV AC) in the United States.

600 V DC is used by Milan's network of tramways and trolleybuses.

Third rail



A bottom-contact third rail on the Amsterdam Metro, the Netherlands

Most electrification systems use overhead wires, but third rail is an option up to about 1,200 V. While use of a third rail does not require the use of DC, in practice, all third-rail systems use DC because it can carry 41% more power than an AC system operating at the same peak voltage. Third rail is more compact than overhead wires and can be used in smaller-diameter tunnels, an important factor for subway systems.

Third rail systems can be designed to use top contact, side contact or bottom contact. Top contact is less safe, as the live rail is exposed to people treading on the rail unless an insulating hood is provided. Side- and bottom-contact third rail can easily have safety shields incorporated, carried by the rail itself. Uncovered top-contact third rails are vulnerable to disruption caused by ice, snow and fallen leaves.

DC systems (especially third rail systems) are limited to relatively low voltages and this can limit the size and speed of trains and cannot use low-level platform and also limit the amount of air-conditioning that the trains can provide. This may be a factor favouring overhead wires and high voltage AC, even for urban usage. In practice, the top speed of trains on third-rail systems is limited to 100 mph (160 km/h) because, above that speed, reliable contact between the shoe and the rail cannot be maintained.

Some road operating trams (streetcars) used conduit third-rail current collection. The third rail was below street level. The tram picked up the current through a plough (U.S. "plow") accessed through a narrow slot in the road. In the United States, much (though not all) of the former streetcar system system in Washington, D.C. (discontinued in 1962) was operated in this manner to avoid the unsightly wires and poles associated with electric traction. The same was true with Manhattan's former streetcar system. The evidence of this mode of running can still be seen on the track down the slope on the northern access to the abandoned Kingsway Tramway Subway (in central London,

United Kingdom), where the slot between the running rails is clearly visible, and on P and Q Streets west of Wisconsin Avenue in the Georgetown neighborhood of Washington DC, where the abandoned tracks have not been paved over. The slot can easily be confused with the similar looking slot for cable trams/cars (indeed, in some cases, the conduit slot was originally a cable slot). The disadvantage of conduit collection included much higher initial installation costs, higher maintenance costs, and problems with leaves and snow getting in the slot. For this reason, in Washington, D.C. cars on some lines converted to overhead cable on leaving the city center, a worker in a "plow pit" disconnecting the plow while another raised the trolley pole (hitherto hooked down to the roof) to the now-present overhead wire. In New York City for the same reasons of cost and operating efficiency outside of Manhattan overhead wire was used. Finally, a new approach to avoiding overhead wires is that taken by the "second generation" tram/streetcar system in Bordeaux, France (entry into service of the first line in December 2003; original system discontinued in 1958) with its APS (alimentation par sol -- ground current feed). This involves a third rail which is not in a slot but runs flush with the surface like the tops of the running rails. The circuit is divided into segments with each segment energized in turn by sensors from the car as it passes over it, the remainder of the third rail remaining "dead". Since each energized segment is completely covered by the lengthy articulated cars, and goes dead before being "uncovered" by the passage of the vehicle, there is no danger to pedestrians. At least initially there were teething troubles in terms of maintaining current feed, however, and the fact that the system is used exclusively in the historic center, with the cars on leaving this zone converting to conventional overhead pickup, underlines how, esthetics aside, for streetcars/trams it is hard to beat the overhead wire system in terms of overall efficiency.

Fourth rail



Arcs like this are normal and occur when the collection shoes of a train drawing power reach the end of a section of power rail.



With top-contact third (and fourth) rail a heavy shoe suspended from a wooden beam attached to the bogies collects power by sliding over the top surface of the conductor rail.

The London Underground in England is one of the few networks that uses a four-rail system. The additional rail carries the electrical return that, on third rail and overhead networks, is provided by the running rails. On the London Underground, a top-contact third rail is beside the track, energized at +420 V DC and a top-contact fourth rail is located centrally between the running rails at -210 V DC, which combine to provide a traction voltage of 630 V DC. The same system was used for Milan's earliest underground line, Milan Metro's line 1, whose more recent lines use an overhead catenary.

This scheme was introduced because of the problems of return currents, intended to be carried by the earthed (grounded) running rails, flowing through the iron tunnel linings instead. This can cause electrolytic damage and even arcing if the tunnel segments are not electrically bonded together. The problem was exacerbated because the return current also had a tendency to flow through nearby iron pipes forming the water and gas mains. Some of these, particularly Victorian mains that predated London's underground railways, were never constructed to carry currents and had no adequate electrical bonding between pipe segments. The four-rail system solves the problem. Although the supply has an artificially created earth point, this connection is derived by using resistors which ensures that stray earth currents are kept to manageable levels.



London Underground track at Ealing Common on the District Line, showing the third and fourth rails beside and between the running rails

London's sub-surface underground railways also operate on the four-rail scheme since, in a number of areas (for example the Piccadilly Line and Metropolitan Line services to Uxbridge), sub-surface and deep-level stock run on the same tracks.

On lines shared with National Rail third-rail stock, the centre 'negative' rail is connected to the return running rail, allowing both types of train to operate.

A system proposed (but not used) by the South Eastern and Chatham Railway around 1920 was 1,500 V DC four-rail. Technical details are scarce but it is likely that it would have been a *mid-earth* system with one conductor rail at +750 volts and the other at -750 volts. This would have facilitated conversion to 750 V DC three-rail at a later date.

A few lines of the Paris Métro in France also operate on a four-rail power scheme but for a very different reason. It is not strictly a four-rail scheme as they run on natural rubber tyres running on a pair of narrow roadways made of steel and, in some places, concrete. Since the tyres do not conduct the return current, two conductor rails are provided outside of the running 'roadways', so at least electrically it fits as a four-rail scheme. The trains

are designed to operate from either polarity of supply, because some lines use reversing loops at one end, causing the train to be reversed during every complete journey (intended to save having to "change ends" by having the operator walk to the other end of the train to make the former last car the lead car in the new direction).

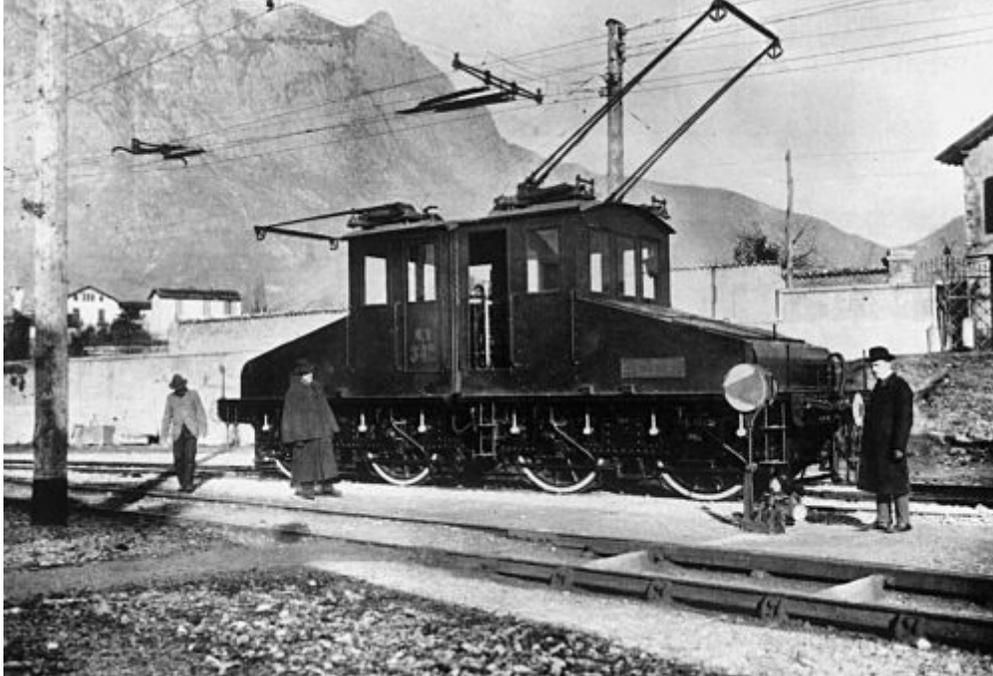
Alternating current

These are overhead electrification systems. Alternating current can be transformed to lower voltages inside the locomotive. This allows much higher voltages and therefore smaller currents along the line, which means smaller energy losses along long railways.

Low-frequency alternating current



15 kV 16.7 Hz AC traction current used in Switzerland



The world's first AC locomotive in Valtellina (1898–1902). Power supply: 3-phase 15 Hz AC, 3000 V, (AC motor 70 km/h). It was designed by Kálmán Kandó in Ganz Company, Hungary.

Common DC commutating electric motors can also be fed with AC (universal motor), because reversing the current in both stator and rotor does not change the direction of torque. However, the inductance of the windings made early designs of large motors impractical at standard AC distribution frequencies. In addition, AC induces eddy currents, particularly in non-laminated field pole pieces, that cause overheating and loss of efficiency. In the previous century, five European countries, including Germany, Austria, Switzerland, Norway and Sweden, standardized on 15 kV 16 $\frac{2}{3}$ Hz (one-third of the normal mains frequency) single-phase AC in an attempt to alleviate such problems. On 16 October 1995, Germany, Austria and Switzerland changed the designation from 16 $\frac{2}{3}$ Hz to a *nominal* frequency of 16.7 Hz (though the actual frequency has not changed, its designation has). In the United States (with its 60 Hz distribution system), 25 Hz (an older, now-obsolete standard mains frequency) is used at 11 kV between Washington, D.C. and New York City and between Harrisburg, Pennsylvania and Philadelphia. A 12,500 V 25 Hz section between New York City and New Haven, Connecticut was converted to 60 Hz in the last third of the 20th century.

In the UK, the London, Brighton and South Coast Railway pioneered overhead electrification of its suburban lines in London, London Bridge to Victoria being opened to traffic on 1 December 1909. Victoria to Crystal Palace via Balham and West Norwood opened in May 1911. Peckham Rye to West Norwood opened in June 1912. Further extensions were not made owing to the First World War. Two lines opened in 1925 under the Southern Railway serving Coulsdon North and Sutton railway station. The lines were

electrified at 6.7 kV 25 Hz. It was announced in 1926 that all lines were to be converted to DC third rail and the last overhead electric service ran in September 1929.

In such a system, the traction motors can be fed through a transformer with multiple taps. Changing the taps allows the motor voltage to be changed without requiring power-wasting resistors. Auxiliary machinery is driven by small commutating motors powered from a separate low-voltage winding of the main transformer.

The use of low frequency requires that electricity be converted from utility power by motor-generators or static inverters at the feeding substations, or generated at altogether separate traction powerstations.

Since 1979, the three-phase induction motor has become almost universally used. It is fed by a static four-quadrant converter which supplies a constant voltage to a pulse-width modulator inverter that supplies the three-phase variable frequency to the motors.

Polyphase alternating current systems



3 phase pantograph on a Corcovado Rack Railway train in Brazil



Train using a multiphase electrification system on the Petit train de la Rhune, France

The majority of the Italian State railway system three-phase system was 3,300 V at 15–16.7 Hz. With such a low frequency, the locomotives did not need gearing. It is also possible to use the polyphase system regeneratively, as on the Italian State railway's mountain lines, where a loaded train descending could supply much of the power for a train ascending. Experimental polyphase installations in Italy in the 1930s used higher voltage (10 kV) at industrial frequencies (45 or 50 kHz).

In the United States, the Great Northern Railway's (Cascade Tunnel) first electrified line (1909–1927) was at 6,600 V, 25 Hz.

The main complexity with three-phase systems is the need for three conductors (including the rails), hence two overhead conductors. Early locomotives on the Italian State Railways used a wide bow collector which covered both wires but later locomotives used two pantographs side-by-side. In the United States, a pair of trolley poles were used.

They worked well with a maximum speed limit of 15 mph. The dual conductor pantograph system is used on four mountain railways that continue to use three phase power (Corcovado Rack Railway in Rio de Janeiro, Brazil, Jungfraubahn and Gornergratbahn in Switzerland and the Petit train de la Rhune in France).

Standard frequency alternating current

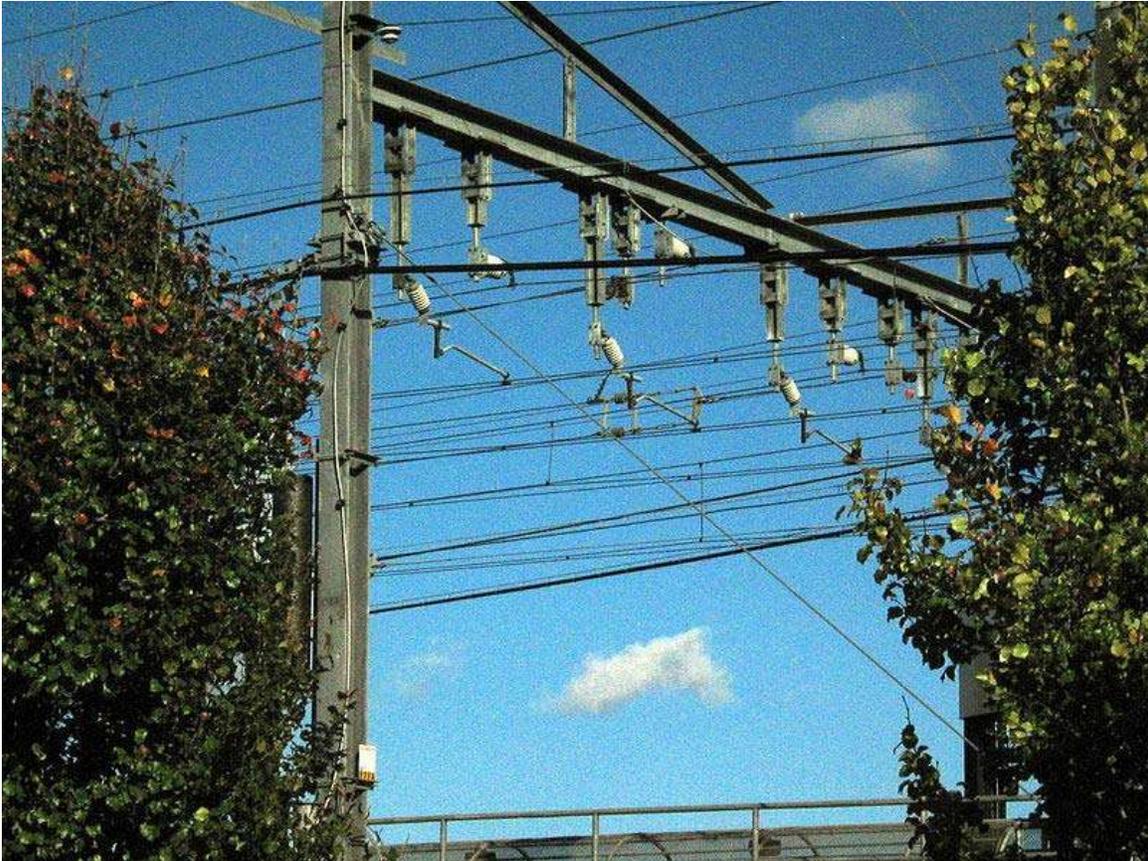
Only in the 1950s after development in France (20 kV then 25 kV) and former Soviet Union countries (25 kV) did the standard-frequency single-phase alternating current system become widespread, despite the simplification of a distribution system which could use the existing power supply network.

The first attempts to use standard-frequency single-phase AC were made in Hungary since 1923, by the Hungarian Kálmán Kandó on the line between Budapest-Nyugati and Alag, using 16 kV at 50 Hz. The locomotives carried a four-pole rotating phase converter feeding a single traction motor of the polyphase induction type at 600 to 1,100 V. The number of poles on the 2,500 hp motor could be changed using slip rings to run at one of four synchronous speeds. The tests were a success so, from 1932 until 1960s, trains on the Budapest-Hegyeshalom line (towards Vienna) regularly used the same system. A few decades after the second world war, the 16 kV was changed to the Russian and later French 25 kV system.

Today, some locomotives in this system use a transformer and rectifier to provide low-voltage pulsating direct current to motors. Speed is controlled by switching winding taps on the transformer. More sophisticated locomotives use thyristor or IGBT circuitry to generate chopped or even variable-frequency alternating current (AC) that is then supplied to the AC induction traction motors.

This system is quite economical but it has its drawbacks: the phases of the external power system are loaded unequally and there is significant electromagnetic interference generated as well as significant acoustic noise.

A list of the countries using the 25 kV AC 50 Hz single-phase system can be found in the list of current systems for electric rail traction.



Close-up view of catenary on Northeast Corridor, United States

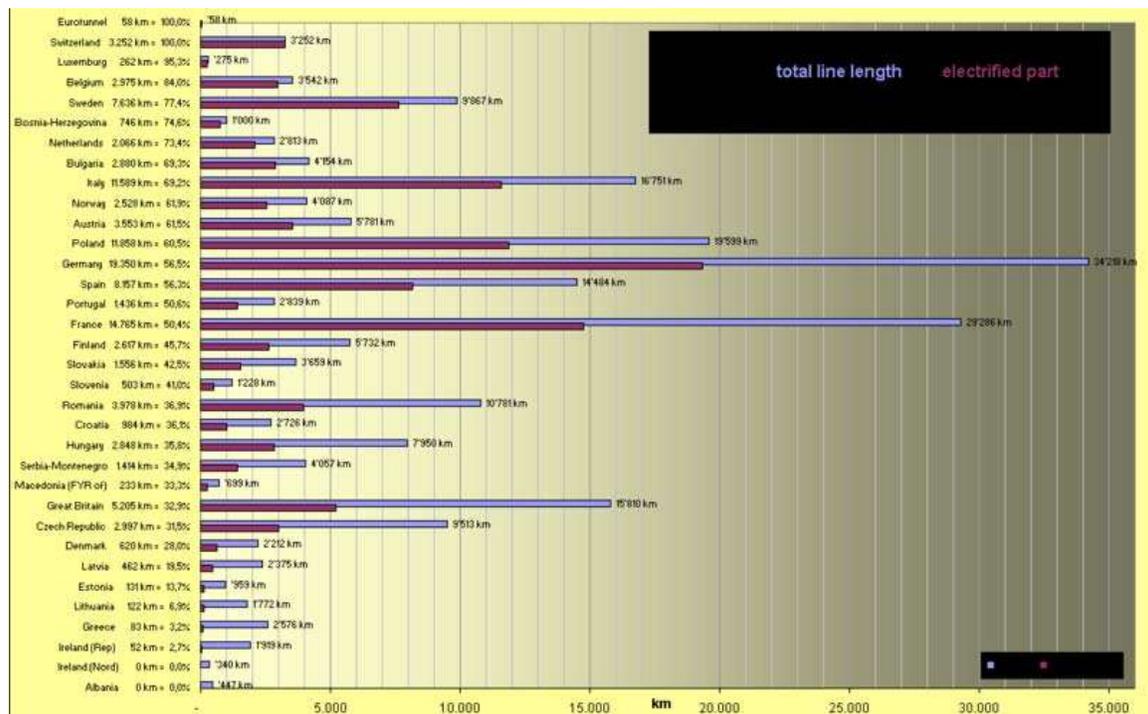
The United States commonly uses 12.5 and 25 kV at 25 Hz or 60 Hz. 25 kV, 60 Hz AC is the preferred system for new high-speed and long-distance railways, even if the railway uses a different system for existing trains.

To prevent the risk of out-of-phase supplies mixing, sections of line fed from different feeder stations must be kept strictly isolated. This is achieved by *Neutral Sections* (also known as *Phase Breaks*), usually provided at feeder stations and midway between them although, typically, only half are in use at any time, the others being provided to allow a feeder station to be shut down and power provided from adjacent feeder stations. Neutral Sections usually consist of an earthed section of wire which is separated from the live wires on either side by insulating material, typically ceramic beads, designed so that the pantograph will smoothly run from one section to the other. The earthed section prevents an arc being drawn from one live section to the other, as the voltage difference may be higher than the normal system voltage if the live sections are on different phases and the protective circuit breakers may not be able to safely interrupt the considerable current that would flow. To prevent the risk of an arc being drawn across from one section of wire to earth, when passing through the neutral section, the train must be coasting and the circuit breakers must be open. In many cases, this is done manually by the driver. To help them, a warning board is provided just before both the neutral section and an advanced warning some distance before. A further board is then provided after the neutral section

to tell the driver to re-close the circuit breaker, although the driver must not do this until the rear pantograph has passed this board. In the UK, a system known as Automatic Power Control (APC) automatically opens and closes the circuit breaker, this being achieved by using sets of permanent magnets alongside the track communicating with a detector on the train. The only action needed by the driver is to shut off power and coast and therefore warning boards are still provided at and on the approach to neutral sections.

On French high-speed rail lines, the UK High Speed 1 Channel Tunnel rail link and in the Channel Tunnel itself, neutral sections are negotiated automatically.

World electrification



Railway electrification in Europe by country

In 2006, 240,000 km (25% by length) of the world rail network was electrified and 50% of all rail transport was carried by electric traction.

Advantages and disadvantages

Advantages include:

- lower running cost of locomotives and multiple units
- lower maintenance cost of locomotives and multiple units
- higher power-to-weight ratio, resulting in
 - fewer locomotives

- faster acceleration
- higher practical limit of power
- higher limit of speed
- less noise pollution (quieter operation)
- reduced power loss at higher altitudes
- lack of dependence on crude oil as fuel
- less environmental pollution, but not if electricity is produced by fossil fuels

Disadvantages include:



Large cargo may require special cars

- upgrading brings significant cost,
 - especially where tunnels and bridges and other obstructions have to be altered for clearance
 - alterations or upgrades will be needed on the railway signalling to take advantage of the new traffic characteristics

Trade-offs include:

- Maintenance costs of the lines may be increased, but many systems claim lower costs due to reduced wear-and-tear from lighter rolling stock. There are additional maintenance costs associated with the electrical equipment but, if there is sufficient traffic, reduced track and engine maintenance costs can exceed the costs of this maintenance.



Most overhead electrifications do not allow sufficient clearance for a double-stack car.

- Network effects are a large factor with electrification. When converting lines to electric, the connections with other lines must be considered. Some electrifications have eventually been removed because of the through traffic to non-electrified lines. If through traffic is to have any benefit, time consuming engine switches must occur to make such connections or expensive dual mode engines must be used. This is mostly an issue for long distance trips, but many lines come to be dominated by through traffic from long-haul freight trains (usually running coal, ore, or containers to or from ports). In theory, these trains could enjoy dramatic savings through electrification, but it can be too costly to extend electrification to isolated areas, and unless an entire network is electrified, companies often find that they need to continue use of diesel trains even if sections are electrified. The increasing demand for container traffic which is more efficient when utilizing the double-stack car also has network effect issues with existing electrifications due to insufficient clearance of overhead electrical lines for these trains, but electrification can be built or modified to have sufficient clearance, at additional cost.

Additionally, there are issues of connections between different electrical services, particularly connecting intercity lines with sections electrified for commuter traffic, but also between commuter lines built to different standards. This can cause electrification of

certain connections to be very expensive simply because of the implications on the sections it is connecting. Many lines have come to be overlaid with multiple electrification standards for different trains to avoid having to replace the existing rolling stock on those lines. Obviously, this requires that the economics of a particular connection must be more compelling and this has prevented complete electrification of many lines. In a few cases, there are diesel trains running along completely electrified routes and this can be due to incompatibility of electrification standards along the route.

Summary of advantages and disadvantages:

- Lines with low frequency of traffic may not be feasible for electrification (especially using regenerative braking), because lower running cost of trains may be overcome by the higher costs of maintenance. Therefore most long-distance lines in North America and many developing countries are not electrified due to relatively low frequency of trains.
- The power range of diesel locomotives begins at the power of the strongest steam engines, while the power range of electric locomotives begins at the high end of diesel locomotives. For passenger operation it is theoretically possible to provide enough power with diesel engines but, at higher speeds, this proves costly and impractical. Therefore, almost all high speed trains are electric.
- The high power of electric locomotives gives them the ability to pull freight at higher speed over gradients; in mixed traffic conditions this increases capacity when the time between trains can be decreased. The higher power of electric locomotives and an electrification can also be a cheaper alternative to a new and less steep railway if train weights are to be increased on a system.

Energy efficiency

There is a significant amount of published material that concludes that electric trains are more energy efficient than diesel-powered trains and, with suitable energy production, can have a smaller carbon dioxide footprint. Some of the reasons include:

- electric trains are generally lighter than self powered versions (eg diesel traction);
 - they do not have to carry the weight of prime movers, transmission and fuel.
 - this is partially offset, however, by the weight of electrical control equipment, and in the case with high-voltage AC by the weight of traction transformers, which may be particularly heavy with low frequency AC (e.g. 16.7 Hz.).
- the electricity may be generated from various energy sources which are more efficient than a diesel engine, as well as lessening reliance on petroleum products and reducing carbon dioxide emissions, including;
 - nuclear power,
 - renewable resources (e.g. hydroelectricity, wind generation, etc.),

- large fossil fuel using power stations with greater efficiency (although they may still have a relatively large carbon footprint).
- under certain conditions, some suitably equipped electric trains can use regenerative braking to return power to the electrification system so that it may be used elsewhere;
 - by other vehicles within the network section;
 - often implemented in tram networks, where there is a high density of vehicles in each fairly short powered section,
 - on high voltage mainlines where there may be several trains within each long section,
 - on mountainous lines where trains may be scheduled such that one is ascending whilst another descends;
 - in some form of energy storage, such as flywheel energy storage so that it may be used later (eg to accelerate a train from a station at which it has recently stopped)
 - some systems, such as most 25 kV AC systems in the UK, are able to return excess energy to the public network.

According to widely accepted global energy reserve statistics, the reserves of liquid fuel are much less than gas and coal (at 42, 167 and 416 years respectively). Most countries with large rail networks do not have significant oil reserves and those that did, like the United States and Britain, have exhausted much of their reserves and have suffered declining oil output for decades. Therefore, there is also a strong economic incentive to substitute oil for other fuels. Rail electrification is often considered an important route towards consumption pattern reform.

External cost

The external cost of railway is lower than other modes of transport but the electrification brings it down further if it is sustainable.

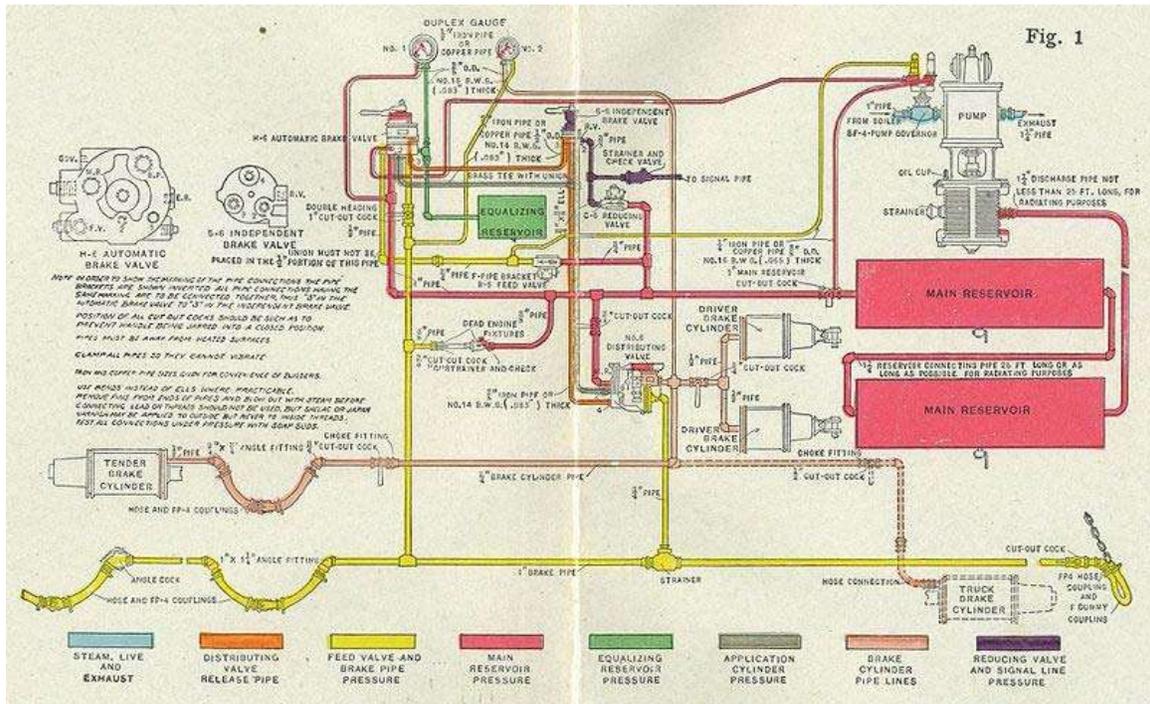
Also, the lower cost of energy from well to wheel and the ability to reduce pollution and greenhouse gas in the atmosphere according to the Kyoto Protocol is an advantage.

Research and development

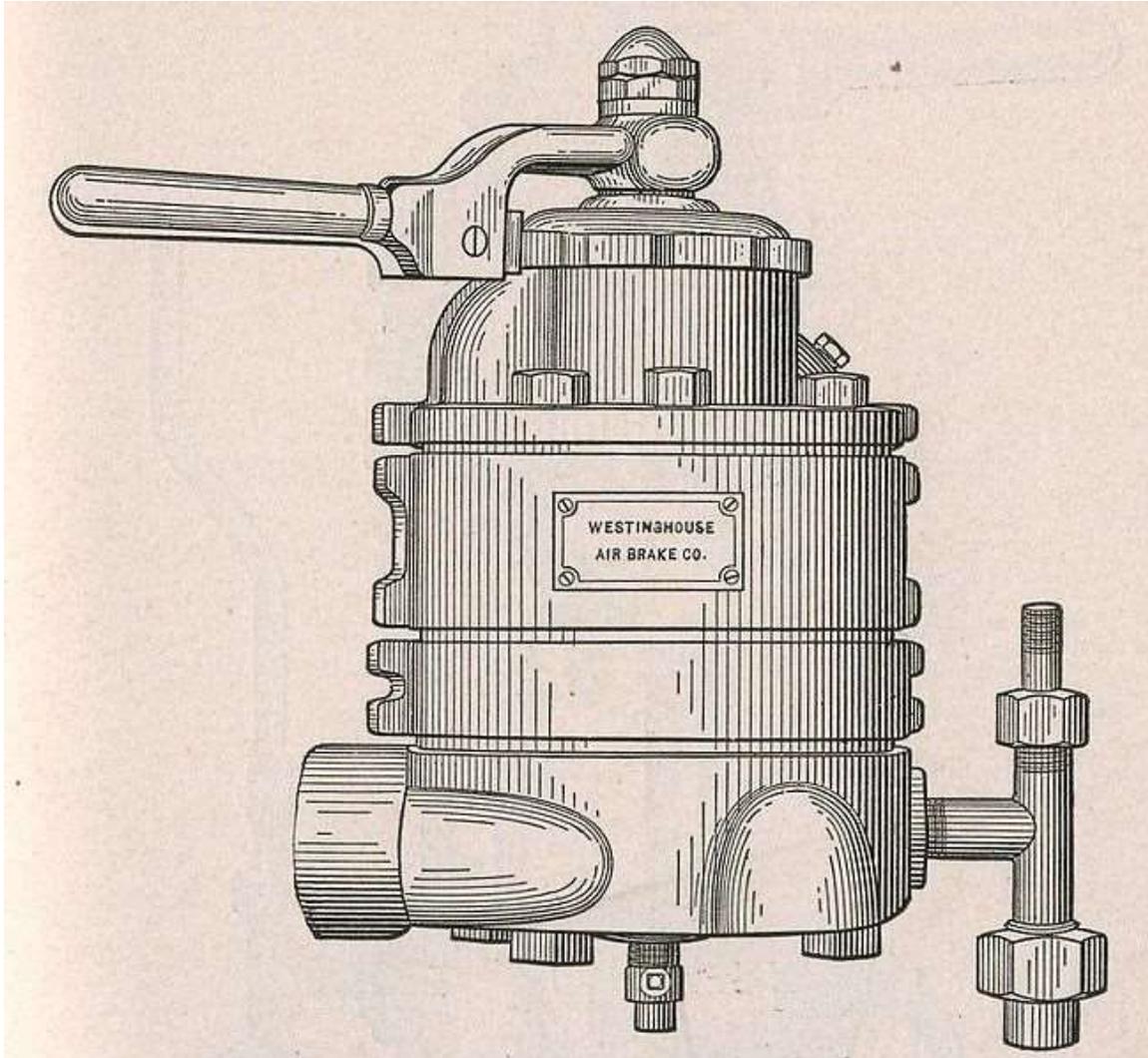
Another result of electrification is the effect on locomotive and wagon productivity and it is going to be more effective by more railway research in this field. The trend of technology in railway electrification is very important to adopt the efforts for better results, for example the trend from GTO (Gate turn-off thyristor) to IGBT (Insulated-gate bipolar transistor) for more powerful locomotives with higher reliability is one of the elements of Technology roadmap (TRM) and the loop to have a mature system as in Maturity road mapping with the Technology transfer provision.

Chapter- 9

Railway Air Brake



Piping diagram from 1920 of a Westinghouse E-T Air Brake system on a locomotive



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.

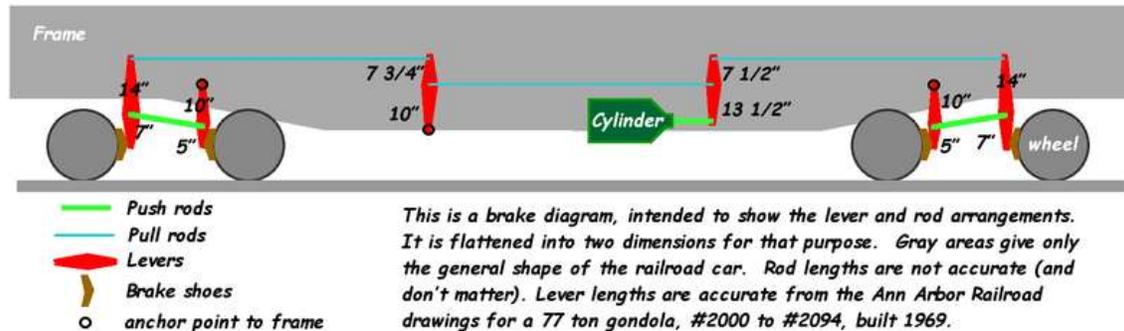
Complicating matters, the manually operated brakes had limited effectiveness and controlling a train's speed in mountainous terrain was a dicey affair. Occasionally, the brakemen simply could not set enough brakes to a degree where they were able to reduce speed while descending a grade, which usually 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, which sends the air into the conductor's face 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.

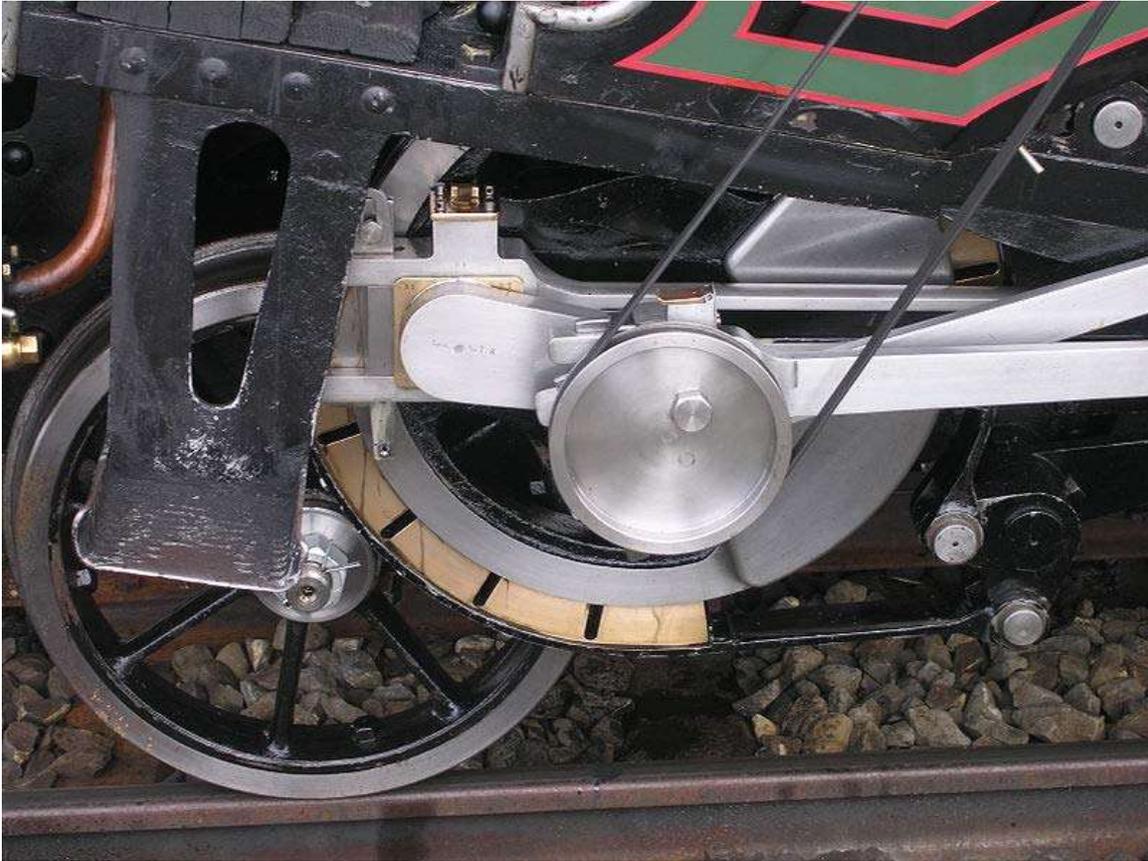
Electro-vacuum brakes have also been used with considerable success on South African electric multiple unit trains. Despite requiring larger and heavier equipment as stated above, the performance of the electro-vacuum brake approached that of contemporary electro-pneumatic brakes. However, their use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

Chapter- 10

Railway Brake



A traditional clasp brake: the brake shoe (brown) bears on the surface (tyre) of the wheel (red), and is operated by the levers (grey) on the left



The braking system of the 1873 year steam locomotive

Brakes are used on the cars of railway trains to enable deceleration, control acceleration (downhill) or to keep them standing when parked. While the basic principle is familiar from road vehicle usage, operational features are more complex because of the need to control multiple linked carriages and to be effective on vehicles left without a prime mover. Clasp brakes are one type of brakes historically used on trains.

Early days

In the earliest days of railways, braking technology was primitive. The first trains had brakes operative on the locomotive tender and on vehicles in the train, where "porters" or, in the United States brakemen, travelling for the purpose on those vehicles operated the brakes. Some railways fitted a special deep-noted brake whistle to locomotives to indicate to the porters the necessity to apply the brakes. All the brakes at this stage of development were applied by operation of a screw and linkage to brake blocks applied to wheel treads, and these brakes could be used when vehicles were parked. In the earliest times, the porters travelled in crude shelters outside the vehicles, but "assistant guards" who travelled inside passenger vehicles, and who had access to a brake wheel at their posts supplanted them.

The braking effort achievable was limited, and an early development was the application of a steam brake to locomotives, where boiler pressure could be applied to brake blocks on the locomotive wheels. It was also unreliable, as the application of brakes by guards depended upon them hearing and responding quickly to a whistle for brakes.

As train speeds increased, it became essential to provide some more powerful braking system capable of instant application and release by the train driver, described as a *continuous* brake because it would be effective continuously along the length of the train.

In the UK, the Abbots Ripton rail accident in January 1876 was aggravated by the long stopping distances of express trains without continuous brakes, which -it became clear- in adverse conditions could considerably exceed those assumed when positioning signals. This had become apparent from the trials on railway brakes carried out at Newark in the previous year, to assist a Royal Commission then considering railway accidents . In the words of a contemporary railway official, these

showed that under normal conditions it required a distance of 800 to 1200 yards to bring a train to rest when travelling at 45 1/2 to 48 1/2 mph, this being much below the ordinary travelling speed of the fastest express trains. Railway officials were not prepared for this result and the necessity for a great deal more brake power was at once admitted

More precise results from the Newark trials are not to hand; trials conducted after Abbots Ripton reported the following (for an express train roughly matching one of those involved, like it on a 1 in 200 fall, but unlike it braking under favorable conditions)

Braking system	Train speed (mph)	Stopping distance (yards)	Stopping time (s)
Continuous (vacuum)	45	410	26
Continuous (vacuum)	45	451	30
3 brake vans	40.9	800	59
2 brake vans	40.9	631	44
2 brake vans	45	795	55
1 brake van	45	1125	70

However there was no clear technical solution to the problem, because of the necessity of achieving a reasonably uniform rate of braking effort throughout a train, and because of the necessity to add and remove vehicles from the train at frequent points on the journey. (At these dates, unit trains were a rarity).

The chief types of solution were:

- The chain brake, such as the Heberlein brake, in which a chain was connected continuously along the train. When pulled tight it activated a friction clutch that used the rotation of the wheels to tighten a brake system at that point; this system has severe limitations in length of train capable of being handled, and of achieving good adjustment.

- Hydraulic brakes. As with car brakes; actuating pressure to apply brakes was transmitted hydraulically. These found some favour in the UK (e.g. with the Midland and Great Eastern Railways), but even in the UK problems were found with the water used as brake fluid freezing



Rotair Valve Westinghouse Air brake Company

- The Westinghouse air brake system. In this system, air reservoirs are provided on every vehicle and the locomotive charges the train pipe with a positive air pressure, which releases the vehicle brakes and charges the air reservoirs on the vehicles. If the driver applies the brakes, his brake valve releases air from the train pipe, and triple valves at each vehicle detect the pressure loss and admit air from the air reservoirs to brake cylinders, applying the brakes. The Westinghouse

system uses smaller air reservoirs and brake cylinders than the corresponding vacuum equipment, because a moderately high air pressure can be used. However, an air compressor is required to generate the compressed air and in the earlier days of railways, this required a large reciprocating steam air compressor, and this was regarded by many engineers as highly undesirable.

- The simple vacuum system. An ejector on the locomotive created a vacuum in a continuous pipe along the train, allowing the external air pressure to operate brake cylinders on every vehicle. This system was very cheap and effective, but it had the major weakness that it became inoperative if the train became divided or if the train pipe was ruptured.
- The automatic vacuum brake. This system was similar to the simple vacuum system, except that the creation of vacuum in the train pipe exhausted vacuum reservoirs on every vehicle and *released* the brakes. If the driver applied the brake, his driver's brake valve admitted atmospheric air to the train pipe, and this atmospheric pressure applied the brakes against the vacuum in the vacuum reservoirs. Being an automatic brake, this system applies braking effort if the train becomes divided or if the train pipe is ruptured. Its disadvantage is that the large vacuum reservoirs were required on every vehicle, and their bulk and the rather complex mechanisms were seen as objectionable.

Note: there are a number of variants and developments of all these systems.

The Newark trials showed the braking performance of the Westinghouse air-brakes to be distinctly superior

Braking system	Train speed (mph)	Stopping distance (yards)	Time to stop (s)	Deceleration (g)	Rails
Westinghouse automatic	52	304	19	0.099	dry
<i>Clark hydraulic</i>	52	404	22.75	0.075	dry
Smith vacuum	49.5	483	29	0.057	dry
<i>Clark and Webb chain</i>	47.5	479	29	0.056	dry
Barker hydraulic	50.75	516	32	0.056	dry
Westinghouse vacuum	52	576	34.5	0.052	wet
<i>Fay mechanical</i>	44.5	388	27.5	0.057	wet
Steel & McInnes air	49.5	534	34.5	0.051	wet

but for other reasons it was the vacuum system that was generally adopted on UK railways.

Later British practice

In British practice, only passenger trains were fitted with continuous brakes until about 1930; goods and mineral trains ran at slower speed and relied on the brake force from the locomotive and tender and the brake van—a heavy vehicle provided at the rear of the train and occupied by a guard.

Goods and mineral vehicles were provided with hand brakes by which the brakes could be applied by a hand lever operated by staff on the ground. These hand brakes were used where necessary when vehicles were parked but also when these trains needed to descend a steep gradient; the train then stopped before descending and the guard walked forward to pin down the handles of sufficient brakes to give adequate braking effort. Early goods vehicles had brake handles on one side only and random alignment of the vehicles gave the guard sufficient braking but, from about 1930, so-called "either-side" brake handles were provided. These trains, not fitted with continuous brakes were described as "unfitted" trains and they survived in British practice until about 1985. However, from about 1930, semi-fitted trains were introduced, in which some goods vehicles were fitted with continuous brakes and a proportion of such vehicles marshalled next to the locomotive gave sufficient brake power to run at somewhat higher speeds than unfitted trains.

In the early days of diesel locomotives, a purpose-built brake tender was attached to the locomotive to increase braking effort when hauling unfitted trains. The brake tender was low, so that the driver could still see the line and signals ahead if the brake tender was propelled (pushed) ahead of the locomotive, which was often the case.

By 1878 there were over 105 patents for braking systems, most of which were obviously stillborn.

Continuous brakes

As train loads, gradients and speeds increased, braking became a problem. In the late 19th century, significantly better *continuous brakes* started to appear. The earliest type of continuous brake was the *chain brake* which used a chain, running the length of the train, to operate brakes on all vehicles simultaneously.

The chain brake was soon superseded by air operated or vacuum operated brakes. These brakes used hoses connecting all the wagons of a train, so the driver could apply or release the brakes with a single valve in the locomotive.

These continuous brakes can be simple or automatic, the essential difference being what happens should the train break in two. With simple brakes, pressure is needed to apply the brakes, and all braking power is lost if the continuous hose is broken for any reason. Simple non-automatic brakes are thus useless when things really go wrong, as is shown with the Armagh rail disaster.

Automatic brakes on the other hand use the air or vacuum pressure to hold the brakes off against a reservoir carried on each vehicle, which applies the brakes if pressure/vacuum is lost in the train pipe. Automatic brakes are thus largely "fail safe", though faulty closure of hose taps can lead to accidents such as the Gare de Lyon accident.

The standard Westinghouse Air Brake has the additional enhancement of a triple valve, and local reservoirs on each wagon that enable the brakes to be applied fully with only a slight reduction in air pressure, reducing the time that it takes to release the brakes as not all pressure is voided to the atmosphere.

Non-automatic brakes still have a role on engines and first few wagons, as they can be used to control the whole train without having to apply the automatic brakes.

Types

Air versus vacuum brakes

In the early part of the 20th century, many British railways employed vacuum brakes rather than the air brakes used in America and much of the rest of the world. The main advantage of vacuum was that the vacuum can be created by a steam ejector with no moving parts (and which could be powered by the steam of a steam locomotive), whereas an air brake system requires a noisy and complicated compressor.

However, air brakes can be made much more effective than vacuum brakes for a given size of brake cylinder. An air brake compressor is usually capable of generating a pressure of 90 psi (620 kPa) vs only 15 psi (100 kPa) for vacuum. With a vacuum system, the maximum pressure differential is atmospheric pressure (14.7 psi or 101 kPa at sea level, less at altitude). Therefore, an air brake system can use a much smaller brake cylinder than a vacuum system to generate the same braking force. This advantage of air brakes increases at high altitude, e.g. Peru and Switzerland where today vacuum brakes are used by secondary railways. The much higher effectiveness of air brakes and the demise of the steam locomotive have seen the air brake become ubiquitous; however, vacuum braking is still in use in India, in Argentina and in South Africa, but this will be declining in near future.

Air brake enhancements

One enhancement of the automatic air brake is to have a second air hose (the main reservoir or main line) along the train to recharge the air reservoirs on each wagon. This air pressure can also be used to operate loading and unloading doors on wheat wagons and coal and ballast wagons. On passenger coaches, the main reservoir pipe is also used to supply air to operate doors and air suspension.

Electropneumatic brakes

A higher performing **EP** brake has a train pipe delivering air to all the reservoirs on the train, with the brakes controlled electrically with a 3-wire control circuit. This can give seven levels of braking, from mild to severe, and allows the driver greater control over the level of braking used, which greatly increases passenger comfort. It also allows for faster brake application, as the electrical control signal is propagated effectively instantly to all vehicles in the train, whereas the change in air pressure which activates the brakes in a conventional system can take several seconds or tens of seconds to propagate fully to the rear of the train. This system is not however used on freight trains due to cost.

The system adopted on the Southern Region of British Railways in 1950 is more fully described at Electro-pneumatic brake system on British railway trains

Electronically controlled pneumatic brakes

Electronically controlled pneumatic brakes (ECP) are a development of the late 20th Century to deal with very long and heavy freight trains, and are a development of the EP brake with even higher level of control. In addition, information about the operation of the brakes on each wagon can be returned to the driver's control panel.

With ECP, a power and control line is installed from wagon to wagon from the front of the train to the rear. Electrical control signals are propagated effectively instantaneously, as opposed to changes in air pressure which propagate at a rather slow speed limited in practice by the resistance to air flow of the pipework, so that the brakes on all wagons can be applied simultaneously rather than from front to rear. This prevents wagons at the rear "shoving" wagons at the front, and results in reduced stopping distance and less equipment wear.

There are two brands of ECP brakes under development, one by New York Air Brake and the other by Wabtec. A single standard is desirable, and it is intended that the two types be interchangeable.

Examples



Loco from Uganda with Norwegian (Meatchopper) couplings and brake hose. Because the hose is small in diameter, it is suspected that these are air brakes.

Reversibility

Brake connections between wagons may be simplified if wagons always point the same way, such as in Tasmania. An exception would be made for locomotives which are often turned on turntables or triangles.

On the new Fortescue railway opened in 2008, wagons are operated in sets, although their direction changes at the balloon loop at the port. The ECP connections are on one side only and are unidirectional.

Accidents with brakes

- Congo-Kinshasa west of Kananga (2007) - 100 killed.
- Igandu train disaster, Tanzania (2002) – runaway backwards - 281 killed.
- Tenga rail disaster, Mozambique (2002) – runaway backwards - 192 killed.

- Gare de Lyon train accident, France (1988) – valve closed by mistake leading to runaway.
- Chapel-en-le-Frith, Great Britain (1957) – broken steam pipe made it impossible for crew to apply brakes.
- Federal Express (1953) - valve closed by badly designed bufferplate.
- Armagh rail disaster, Northern Ireland (1889) – runaway backwards led to change in law.
- Shipton-on-Cherwell train crash, Oxford (1874) - caused by fracture of a carriage wheel.

WWT

Chapter- 11

Other Rail Technologies

Advanced Train Control System

Advanced Train Control System, usually called ATCS, is a set of specifications designed to document the stated requirements of railroad operational and technical professionals concerning ATCS hardware and software. These specifications are designed to facilitate compatibility and standardization without limiting the internal design approaches of individual suppliers.

Specifications

- **ATCS Specification 110:** Environmental Requirements
- **ATCS Specification 130:** Recommended Practices for Software Quality Assurance
- **ATCS Specification 140:** Recommended Practices for Safety and Systems Assurance
- **ATCS Specification 153:** System Logic - OBC
- **ATCS Specification 154:** System Logic - CDC
- **ATCS Specification 155:** System Logic - WIU
- **ATCS Specification 156:** System Logic - TFT
- **ATCS Specification 160:** Configuration Management Plan
- **ATCS Specification 200:** Communications System Architecture
- **ATCS Specification 210:** Mobile Communications Package
- **ATCS Specification 220:** Front End Processor
- **ATCS Specification 225:** Cluster Controller
- **ATCS Specification 230:** Base Communications Package
- **ATCS Specification 250:** Message Formats
- **ATCS Specification 300:** Locomotive System Architecture
- **ATCS Specification 310:** Locomotive Computer
- **ATCS Specification 311:** Predictive Enforcement Braking
- **ATCS Specification 320:** Locomotive Displays & Controls
- **ATCS Specification 335:** Transponder/Interrogator
- **ATCS Specification 400:** Dispatch System Architecture
- **ATCS Specification 500:** Field Systems Architecture
- **ATCS Specification 530:** Wayside Interface Unit

- **ATCS Specification 600:** Work Vehicle System Architecture
- **ATCS Specification 610:** Track Forces Terminal
- **ATCS Specification 620:** Work Vehicle Display and Control Unit

Automatic Equipment Identification

Automatic Equipment Identification (AEI) is an electronic recognition system in use with the North American railroad industry. Consisting of passive tags mounted on each side of rolling stock, as well as active trackside readers, AEI utilizes RF technology to identify railroad equipment while en route.



Trackside AEI reader

History

Predecessor systems

In the late 1960s, railroads in North America began searching for a system that would allow them to automatically identify rail cars and other rolling stock. Through the efforts of the Association of American Railroads (AAR), a number of companies developed **Automatic Car Identification (ACI)** systems. The AAR selected four systems for extensive field tests. General Electric developed an RFID system, ABEX developed a microwave system, Wabco developed a black and white barcode system, and General Telephone and Electronics (GTE) developed a color barcode system called KarTrak. The RFID system used a tag mounted under the rail car and an interrogator installed between the rails. The other three systems had labels that were mounted on each side of the rail car and a track side scanner.



ACI plate 1

After the initial field tests, the ABEX, Wabco, and the GTE KarTrak ACI systems were selected for a head to head accuracy test on the Pennsylvania Railroad, at Spruce Creek PA. The KarTrak system was declared the winner and selected by the AAR as the standard.

Starting in 1968 all rail car owners were required by the AAR to install ACI labels on their cars. This requirement led to the full scale implementation of the ACI system in the early 1970s. By 1975 90% of all railcars were labeled. The read rate was about 80%, which means that after 7 years of service 10% of the labels had failed from a variety of reasons such as physical damage, and dirt accumulation. The dirt accumulation was most evident on flatcars that had low mounted labels.

The AAR had recognized, from their field tests, that periodic inspection and label maintenance would be a requirement to maintain a high level of label readability. Regulations were instituted for label inspection and repair whenever a railcar was in the repair shop which statistically happened every two years.

Unfortunately the maintenance program never gained sufficient compliance. Without maintenance the read rate failed to improve, and the ACI KarTrak System was eventually abandoned by the late 1970s. Because of this failure, the railroad industry did not seriously search for another system to identify rail cars until the mid-1980s.

Development

Burlington Northern was the first railroad in North America to renew the search for an effective identification system. BN had been closely following the efforts of various maritime shipping companies, such as American President Lines, in their efforts to find a system to automatically identify containers. Based on the maritime companies' success with RF-based identification systems, Burlington Northern began a testing program in 1986.

Burlington Northern initially asked nine vendors to present their identification systems. From this group of nine, Burlington Northern selected two systems for full scale testing. The two vendors selected were General Railway Signal (GRS) and Union Switch & Signal (US&S). The Union Switch and Signal identification system is manufactured by Amtech Corporation of Dallas, Texas.

In January, 1988, Burlington Northern equipped 1,500 taconite (iron ore pellets) rail cars in northern Minnesota each with a GRS and an Amtech transponder. Each vendor also installed three wayside reader sites. All tags were mounted on the sides of the rail cars.

In August, 1988, the Burlington Northern Railroad presented a report on the results of their testing at the Association of American Railroads' Communication and Signal Annual Meeting. They stated that the accuracy of both systems over a six month period was in excess of 99.99%. Based on the spectacular results from both systems, the Burlington Northern asked the Association of American Railroads to form a committee to write an Automatic Equipment Identification (AEI) standard for the North American rail industry, and suggested that the AAR use the current draft ISO standard for container identification as a starting point.

A committee was formed by the Association of American Railroads, charged with the development of an Automatic Equipment Identification standard. Railroads, such as Norfolk Southern Railway, Union Pacific Railroad, CSX Transportation, and Canadian National Railway, began their own testing programs and reported the results to the AAR's AEI Committee.

In August, 1989, the AAR informed various identification system vendors that Amtech's identification technology had been selected as the Automatic Equipment Identification standard.

By the fall of 1989, the AAR's AEI Committee had selected a technology and defined the tag's data format. The only major decision that was still unresolved was the location of the tag on the rail car. This became a very controversial subject for the next nine months, as there were two groups of thought. One group wanted to place tags on the sides of the rail cars and another wanted them underneath. Each location had its advantages and disadvantages in terms of cost and maintainability. The tags were tested and found to operate well in both locations. It was finally decided by the AEI Committee in the summer of 1990 that two tags would be mounted on each rail car, one on each side.



AEI tag affixed to the side of a freight car

In July, 1990, the AAR Committee on Car Service sent a resolution to the O-T General Committee of the AAR to set a mandatory implementation date when all rail cars in interchange service would be tagged. The O-T General Committee is the highest operating committee within the AAR. The O-T General Committee requested that the AEI Committee perform a cost/benefit analysis on mandatory AEI implementation and recommend an implementation schedule. In October, 1990, the O-T General Committee approved the recommended AEI voluntary standard.

With these recommendations, in August, 1991, the O-T General Committee of the Association of American Railroads voted to make the AEI standard mandatory. The mandatory vote was ratified by the Association of American Railroads Board of Directors at their meeting in September, 1991. The mandatory period started on 1 March, 1992, and ended on 31 December, 1994. By the end of this period all 1.4 million rail cars in North American interchange service were to be tagged.

As part of the AAR's adoption of a standard based on Amtech technology, AAR required that Amtech license that technology. At the time of the AAR's 1991 mandate, six vendors sold AEI site equipment. Those vendors were Union Switch & Signal, Safetran, Harmon, VideoMasters, CCTC International in partnership with IBM, and Southern Technologies. As of August 2007, only two of these vendors remain, SAIC (formerly VideoMasters) and Southern Technologies.

Usage

As of 31 December, 1994, Amtech had shipped over 3.1 million tags to railways in North America. The AAR reported that over 95% of the North American rail car fleet was tagged. Over 3,000 readers have been installed by the railways in North America as of the end of 2000. Amtech was bought by TransCore. TransCore is today the most important producer of RFID tags for rail in the world.

The most common mistakes during the implementation of RFID in rail are: - Use of common tags on railcars. Tags must have a MTBF of 20 years or more. It means that the RFID must survive at least the railcar live-time, which is at least 20 years. - Broken tags are not easily changed in a rail environment, totally different from a warehouse environment. Again, MTBF is the key - AEI is not just for maintenance purposes. AEI helps a lot on customer service level improvement and operations optimization.

The AAR's S-918 specifications outline ten recommended frequencies ranging from 902.250 to 921.500 MHz, depending on the location of the reading device (in a yard or trackside), with a nominal transmitting power of 2.0 Watts (measured at the transmitter).

Automatic train operation



Panel of a train capable of running ATO (This is the panel of ex-KCR SP1950 Train)

Automatic train operation (ATO) ensures partial or complete automatic train piloting and driverless functions.

Most systems elect to maintain a driver (train operator) to mitigate risks associated with failures or emergencies.

Many modern systems are linked with Automatic Train Control (ATC) where normal signaller operations such as route setting and train regulation are carried out by the system. The ATO and ATC systems will work together to maintain a train within a defined tolerance of its timetable. The combined system will marginally adjust operating parameters such as the ratio of power to coast when moving and station dwell time, in order to bring a train back to the timetable slot defined for it.

Examples

The earliest ATO system on a full Underground line was on the Barcelona Metro line 2 (now integrated on L5), which ran from 1963 until 1970 on its seven trains. Another

example of one of the earliest examples of ATO was on the Victoria line of the London Underground, opened in 1968. The ATO system performs all functions of the driver except for the opening and closing of the doors. The driver only needs to press two buttons to start the train and, if the way is clear, then the train will automatically proceed to the next station. Many newer systems are now computer-controlled, including London's Docklands Light Railway, the Central Line of the London Underground, Line 14 of the Paris Métro, Line 2, Line 3, 5 and 11 of the Barcelona Metro, Copenhagen Metro, Kelana Jaya Line of Kuala Lumpur Rail Transit System, the Washington Metro, Hong Kong MTR, Manila Light Rail Transit System, North East Line and Circle Line of Singapore MRT, Tokyo Metro Namboku Line, Kobe Municipal Subway, a number of ART- and VAL-based systems and all lines of the São Paulo Metro (only Line 4 - Yellow is driverless, the others have a driver, but also operates in full auto).

2009

- São Paulo Metro Line 4 - Driverless

2008

- Nuremberg -
- Rio Tinto - iron ore railway driverless go ahead

Records

For the purpose of these records, a "driverless" train is defined as one that normally operates fully automatically, with no on-board human intervention.

- Longest fully automatic driverless network: Vancouver SkyTrain, 68.7 km (42.7 mi) on three lines
- Longest partially automatic driverless line: Lille Metro Line 2, 31.7 km (19.7 mi)
- First partially automatic driverless line: London Underground, Victoria Line, 1968
- Longest fully automatic driverless underground line: North East MRT Line, Singapore, 20.0 km (12.4 mi)
- First fully automatic driverless underground line: North East MRT Line, Singapore, 2003

The Dubai Metro (c. 70 km in the first phase, incl. 50 km in one line) and Singapore's Circle MRT Line (33.3 km) are likely to take over the longest network/line and longest underground line records respectively when completed.

The future

Many railways are planning on using ATO in the future. It has been partially implemented on the Delhi Metro with plans of full ATO operations by the year 2013. ATO will be introduced on the London Underground's Northern line in 2011 and on the Jubilee line in October 2010. Although ATO may also be used on the future Crossrail and Thameslink trains, it has not yet been implemented on any UK mainline railways.

Automatic train stop

An **automatic train stop** is a system on a train that will automatically stop a train if certain situations happened (unresponsive train operator, earthquake, disconnected rail, train running over a stop signal, etc) to prevent accidents from happening.

History

The first (mechanical) ATS system was installed in France in 1878. In 1880, most of the (later) Soviet Union started using ATS on its railway lines, the second country to be fitted with ATS. In 1921, Japan started using ATS on the Tokaido Main Line, the third country to do so.

Great Britain and America started using ATS in the 1920s, Germany adopted it in the 1930s and China first used it in the 1950s. By 1980, almost every railway used some form of ATS.

In 1954, Japan introduced **ATS-B**, the first known variant of ATS. In 1967, **ATS-S** (and its various supplements) was invented, the first non-contact-based ATS to be used; in 1974, **ATS-P** was used for the first time, and in 1986, **H-ATS** was invented.

Usage around the world

United States



ATS pickup on the leading truck of a San Diego Coaster F40PH

This is one of the systems prescribed since 1951 by the federal government to allow passenger trains to exceed a speed limit of 79 mph (127 km/h). The term applies to an intermittent system that triggers an alerter in the cab of the locomotive that the engineer must respond to within a set period of time before the brakes are automatically applied. The system has no ability to enforce speeds or signal indications, only the attention of the engineer.

The most popular implementation of ATS was made by the General Railway Signal company and consisted of inductive coils mounted just outside the right hand rail in relation to the direction of travel. When the signal is displaying an indication other than Clear, the inductor is energized and a pick up coil mounted on locomotive or control car would sense the magnetic field and trigger the alarm in the cab.

Although less popular in the east than cab signals, ATS was installed on the New York Central Water Level Route between New York and Chicago, before being later removed by Conrail. The system saw its most extensive use in the Midwestern and Western U.S. For instance, the Chicago and North Western Railway installed ATS on its Chicago area commuter lines as well as its route from Chicago, Illinois to Wyeville, Wisconsin, though it was removed from the latter in 1964. The ATSF installed ATS on much of its transcontinental main line, which is still used by Amtrak's *Southwest Chief* as well as its line between Los Angeles and San Diego, which is still used by Amtrak's *Pacific Surfliner*. The presence of ATS on both lines allows for 90 mph operation.

Japan

Many trains in Japan are equipped with this system. The ATS systems in Japan are slightly similar to those used in the United States, but are mostly transponder-based. Below is a (partial) list of ATS systems that are specific to Japan only:

- **ATS-B** (utilizes a unit that uses power from overhead catenaries to power the ATS-B system)
- **ATS-S** (ATS using S-type transponder, always supplemented with: ATS-SF, ATS-SK, ATS-SM, ATS-SN, ATS-ST or ATS-SW, the last two letters corresponding to the type of transponder used with the S-type transponder)
- **ATS-P** (ATS using pattern renewal transponder, variant is ATS-Ps)
- **H-ATS** (used on the EF66 locomotive since 1986)

New Zealand

In Wellington only a few signals at a converging junction are fitted with mechanical ATS. All electric trains are fitted.

South Korea

Some Korail and subway lines are equipped with this system.

Technology

ATS systems can be mechanical, where an arm is raised on the track to engage a lever on the train to apply the brakes and cut the power. The mechanical systems around the world are generally incompatible. Mechanical systems are not suitable at high speeds, say greater than 110 km/h.

ATS systems can also be non-contact magnetic or inductive. Again they tend to be incompatible. Non contact systems are suitable for high speeds.

Balise



A Siemens Eurobalise in Germany

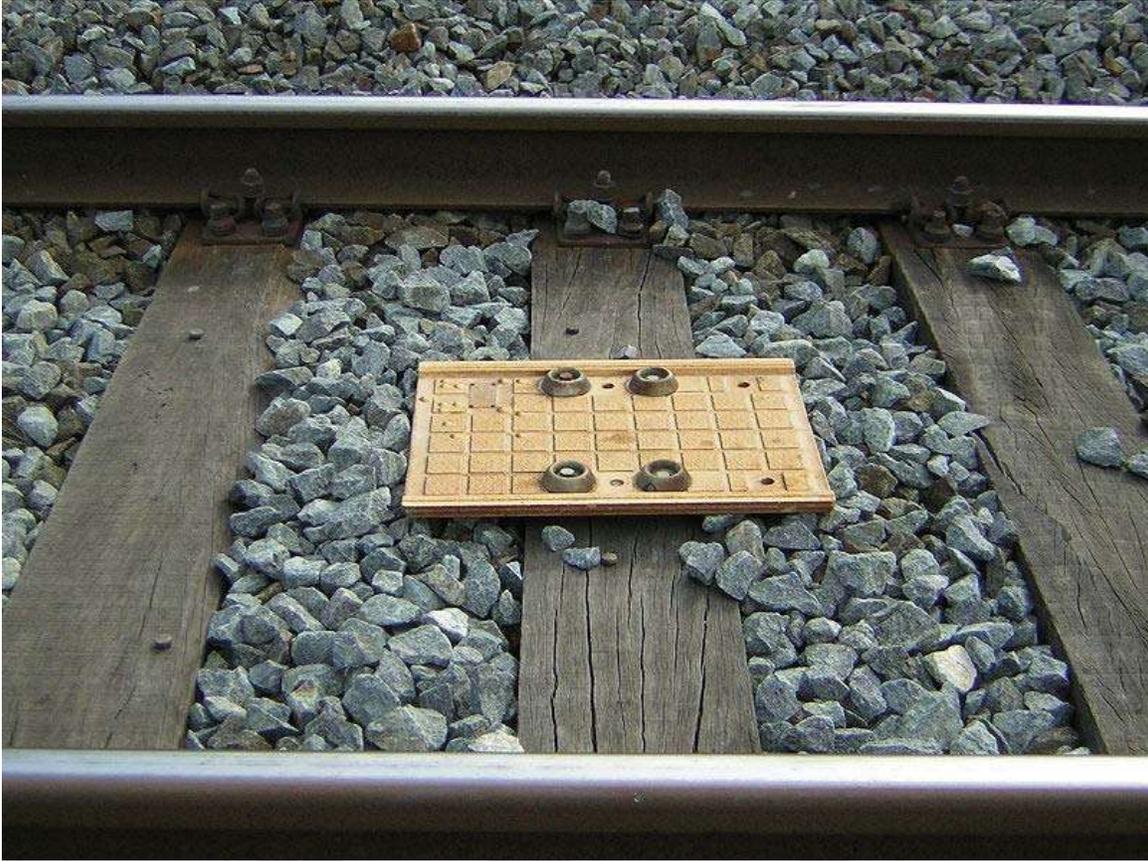
A **balise** is an electronic beacon or transponder placed between the rails of a railway as part of an Automatic Train Protection (ATP) system. The French word "balise" is used to distinguish these beacons from other kinds of beacon.

Balises are used in the KVB signalling system installed on main lines of the French railway network, other than the high-speed Lignes a Grande Vitesse.

Balises constitute an integral part of the European Train Control System, where they serve as 'beacons' giving the exact location of a train. The ETCS signalling system is being gradually introduced on railways throughout the European Union.

A balise which complies with the European Train Control System specification is called a **Eurobalise**.

Overview



Balise EBICAB in the Mediterranean Corridor

A balise typically needs no power source. In response to radio frequency energy broadcast by a Balise Transmission Module mounted under a passing train, the balise either transmits information to the train ('Uplink') or receives information from the train ('Downlink,' this function is rarely used). The transmission rate is sufficient for a complete 'telegram' to be received by a train passing at any speed up to 500 km/h.

A balise may be either a 'Fixed Data Balise,' or 'Fixed Balise' for short, transmitting the same data to every train, or a 'Transparent Data Balise' which transmits variable data, also called a 'switchable' or 'Controllable Balise'. (Note that the word 'fixed' refers to the information transmitted by the balise, not to its physical location. All balises are immobile).

A fixed balise is programmed to transmit the same data to every train. Information transmitted by a fixed balise typically includes: the location of the balise; the geometry of the line, such as curves and gradients; and any speed restrictions. The programming is performed using a wireless programming device. Thus a fixed balise can notify a train of

its exact location, and the distance to the next signal, and can warn of any speed restrictions.

A controllable balise is connected to a Lineside Electronics Unit (LEU), which transmits dynamic data to the train, such as signal indications. Balises forming part of a ETCS Level 1 signalling system employ this capability. The LEU integrates with the conventional (national) signal system either by connecting to the lineside railway signal or to the signalling control tower.

Balises are deployed in pairs so that the train can determine its direction of travel 1->2 from direction 2->1. Extra balises can be installed if the volume of data is too great.

Balises operate with equipment on the train to provide a system that enhances the safety of train operation.

Installation

The balise is typically mounted on or between sleepers in the centre line of the track. The pair of beacons are typically 3 metres apart.

A train travelling in the normal direction will meet the fixed balise and then the switchable balise.

A train travelling at maximum speed of 500 km/h will transmit and receive a minimum of three copies of the telegram while passing over the balise. If more information needs to be transmitted, then a third or fourth balise can be installed.

The train's on-board computer uses the data from the balises to determine the safe speed profile for the line ahead. Enough information is needed to allow the train to come to a safe standstill if required.

The data in the balise also includes the distance to the next balise. This is used to check for missing balises which would otherwise be a potential wrong-side failure.

Balises have been used in Germany to transmit tilting instructions for curves to tilting trains.

At the start and end of ATP equipped territory, a pair of fixed balises turn on and turn off the ATP equipment.

Encoding

Each pair of balises consist of a switchable balise and a fixed balise. A balise transmits a 'telegram' of either 1023 bits or 341 bits. Of this, either 830 bits or 210 bits are available for signalling information. The telegram consists of

- payload (830 or 210 bit)
- control bits (Cb, 3 bit)
- scrambling bits (Sb, 12 bit)
- extra shaping bits (Esb, 10 bit)
- checksum (CheckBits, 85 bit)

The telegram is broadcast in a cyclic manner as the train passes over the balise. To avoid transmission errors the payload is scrambled (avoiding burst errors), substituted with a symbol code of different Hamming distance, and a checksum is added for validity checks. Since the checksum is computed after the symbol substitution the telegram contains extra shaping bits to allow the resulting checksum bits to be filled up in a way that only valid symbols of the chosen channel code are in the telegram where each symbol has 11 bits.

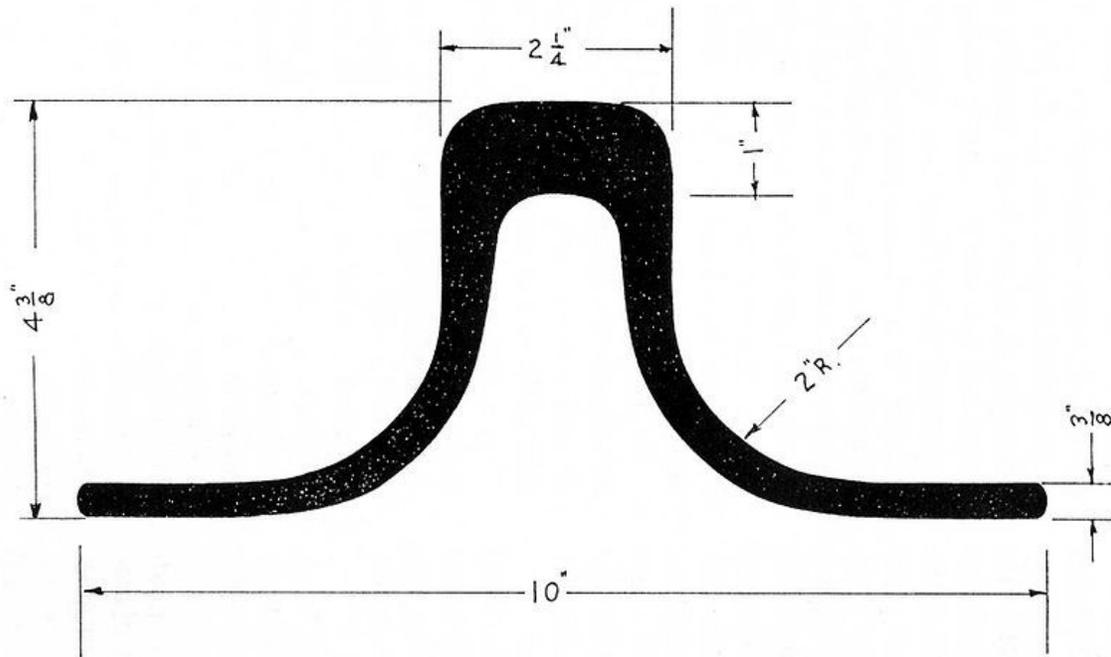
The payload data consists of a header followed by multiple packets defined in the ERTMS protocols. Mandatory packets are Packet 5 - Linking information, Packet 12 - Movement Authority, Packet 21-Gradient, Packet 27 - Static Speed Profile, Packet 255 - End of information. Many applications include optional packets like Packet 3 - National Values, Packet 41 - Level transition and Packet 136 - Infill Location Reference. If the telegram maximum of 830 bits is reached then more packets can be sent in the following balises of the same balise group - with up to 8 balises in a balise group the maximum ERTMS message per balise group can encompass $8 * 830 = 6640$ bit (note that every telegram must contain a header and the trailer packet 255).

A fixed balise transmits a stable message with the movement authorization, including link message, gradient information, speed limitation. Especially in China, it may contain track information.

Manufacture

Balises are made by several different companies; while they may vary in the details, they are manufactured to meet the same standards. The principal manufacturers of Eurobalises belong to a group of six firms (Alstom, Ansaldo STS, Bombardier, Invensys, Siemens, Thales) within the UNIFE federation of railway suppliers. This group cooperated in developing the specifications for Eurobalises. Specifications for Eurobalises are governed by the European Railway Agency.

Barlow rail



S.R.C. BARLOW RAIL 1853.

DDH. 1989.

Cross section of Barlow rail as used by Sydney Railway Company

Barlow rail was a rolled rail section used on early railways. It has wide flaring feet and was designed to be laid direct on the ballast, without requiring sleepers. It was widely adopted on lightly trafficked railways, but was ultimately unsuccessful because of maintenance difficulties.

Usage



A sample of Barlow rail is shown to the rear of a sample of Bullhead rail

In the mid-nineteenth century, railway networks were expanding into areas where lighter traffic was expected. The first cost of conventional railway track was considerable, and cheaper alternatives were sought. The Barlow rail offered this benefit, by avoiding the cost of sleepers and chairs altogether. Laid directly in the ballast, it required no other ancillary equipment; however the rail itself was significantly heavier and more expensive than conventional rails.

In practice it had several disadvantages; in particular there was no gauge tie, so that if the ballast was poorly consolidated, the rails could gradually move independently, resulting in a serious derailment risk. Some modifications involved the provision of tie bars between opposing rails to maintain the gauge.

The wider and heavier rail section was considerably stiffer to lateral bending, and this made smooth alignment in curves difficult, especially at the joints.

On curves, passing vehicle wheels generate a crabbing effect, tending to push the rails apart, and in the absence of sleepers this tended to rotate the rails outward, that is, they tended to tip outwards.

Inventor

The rail profile was invented in 1849 by W.H.Barlow, engineer of the Midland Railway. The design was patented (12438 of 1849)

On 14 May 1850, he presented a paper to the Institution of Civil Engineers in London detailing his ideas and stating that a test section of 125lb/yd rail on the Midland Junction Railway had proven satisfactory.

He admitted that there had been difficulty in rolling the section but this had been overcome by the manufacturers at Middlesbrough.

Application

The rail section was adopted by Brunel for the South Wales Railway

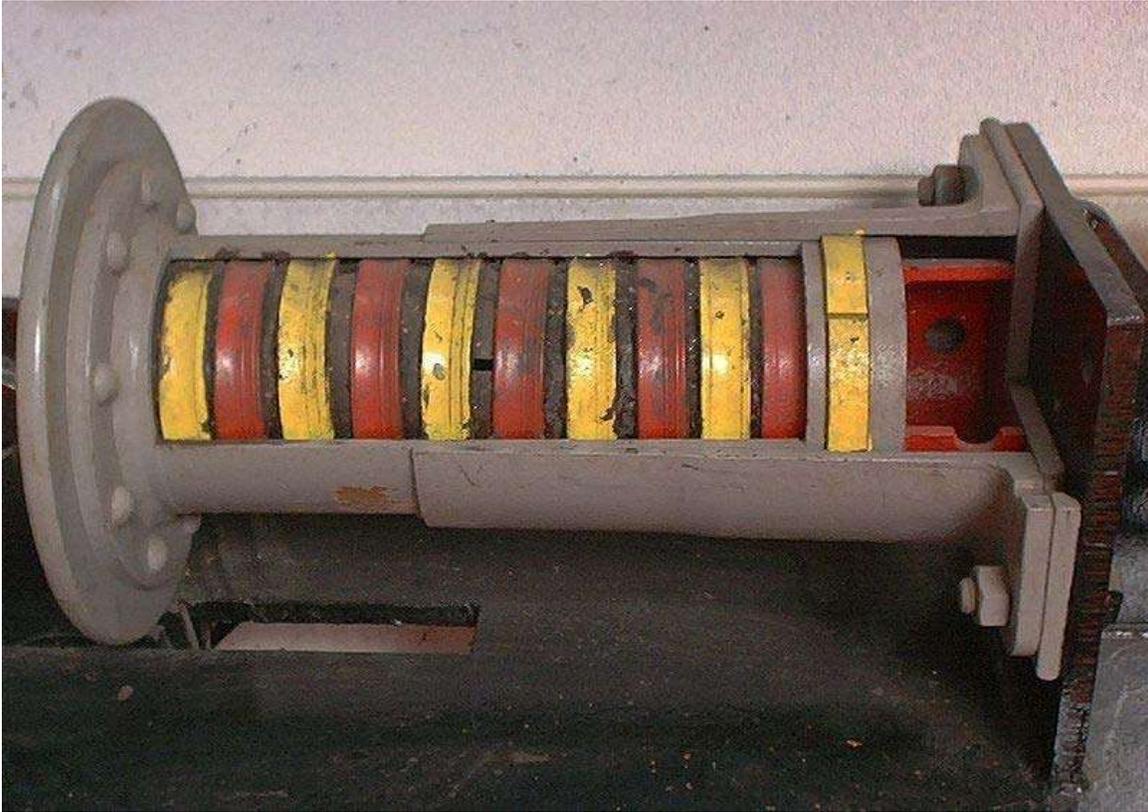
- The South Wales Railway from Swansea to Carmanthen - 1852 Extended towards Milford Haven in 1854
- New South Wales Railways - 1855 - Sydney to Parramatta
- Powerhouse Museum, Sydney
- Didcot Railway Centre, Oxfordshire

Secondary usage

The large extent of Barlow rail laid in the routes influenced by Brunel, and in New South Wales, has left a legacy of fence posts, and in some cases bridge decks:

- South Devon Railway - underbridge
- Conwy Valley Line - underbridge
- Shipton on Cherwell Halt - fencepost
- Dorrigo Steam Railway and Museum
- Fairford branch - structures

Buffer (rail transport)



Cutaway model of a buffer



A pneumatic buffer with sections cut away

A **buffer** is a part of the buffers-and-chain coupling system used on the railway systems of many countries, among them most of those in Europe, for attaching railway vehicles to one another.

Fitted at the ends of the vehicle frames, one at each corner, the buffers are projecting, shock-absorbing pads which, when vehicles are coupled, are brought into contact with those on the next vehicle. The draw chain used between each pair of vehicles includes a screw which is tightened after coupling to shorten the chain and keep the buffers pressed together.

Although the buffers in the very earliest days of railways were rigid (*dumb buffers*), they soon came to be spring-loaded, while those fitted to modern locomotives and rolling stock incorporate oleo-pneumatic shock absorbers.

Dead-end sidings are often fitted with buffer stops to prevent vehicles running off the end of the track. These may consist of a simple transverse beam fixed at buffer height but the buffer stops at passenger stations can be elaborate hydraulic installations capable of absorbing a considerable amount of energy.

Communication-based train control

Communication-based train control (CBTC) is an automated control system for railways that ensures the safe operation of rail vehicles using data communication between various control entities that make up the system.

CBTC is a modern successor of the traditional railway signaling systems which provide a limited control using track circuits, interlockings, and signals.

CBTC technology is part of the same convergence engineering field as the automotive traffic automation systems. Even though the principles of control between the 2 transportation domains are quite different they both are part of the telematics: a CBTC system is based on basic principles from both the automation and telecommunication.

CBTC is the culmination point of a long parallel history of two important technologies that stimulated the development of each other and marked profoundly the development of our society in the last century: railways, telecommunications.

There are multiple generations of CBTC systems based on multiple variations and configurations depending on the providers and operators.

A CBTC can provide different levels of railway automation, grouped in the following major functionalities:

- Automatic Train Protection (ATP)
- Automatic train operation (ATO)
- Automatic Train Supervision (ATS)

CBTC systems range in complexity based on the functionality provided from CBTC systems that provide only the ATP functions to CBTC that provide both the ATP and ATO functions and CBTC that on top of that provide also the ATS functions.

All CBTC systems operate in the same basic way. An off board computer can track all trains operating on track linked to the computer. This allows trains to be spaced closer together than on a manually controlled line. The computer sends information to the computers aboard the train.

This differs from normal Automatic Train Operation (ATO) systems in that the train is actually controlled by the on board computers. Older ATO systems, such as San Francisco's BART, use a system where the off board computers control the train.

Based on the media used for communication the CBTC are categorized in:

- radio-based
- rail-based

- loop-based

The older of the three, rail-based, has been in use in a few systems. Train control signals are sent through the tracks to the train. RF, which has yet to be used on an in service heavy rail Metro application, transmits the signal from wayside equipment.

Deployments

MTA New York City Subway in the United States. The New York City Subway 14th Street-Canarsie Local route (line L) is nearing the completion of tests on the new control system.

CBTC has started commercial operation in Line 6 of Metro de Madrid (Spain): and is about to start (spring 2009) in Line 1.

The CBTCs deployed on transit systems as the SRT line from Toronto, and SkyTrain from Vancouver are based on loop communication.

Trans-Gabon Railway for Hughes satellite based train control system.

Singapore's two MRT lines, North East Line and Circle Line are completely CBTC based.

The Budapest Underground lines 2 and 4 will be fitted with CBTC system.