A short history of railway braking

The first brakes

History of railway brakes starts in 1550, in Europe. In Leberthal's mines, in Alsace (France), the extracted mineral is transported by means of trolleys which iron wheels are rolling on cantrails which are not considered yet as rails. An historian reports that « a piece of wood, mounted horizontally above a wheel, was articulated on the side of the trolley. The driver, who was a child, could thus push it by hand or foot against the circumference of the wheel and moderate the speed of these mine trolleys launched in low gradients ».

Two hundred years later, we are in the middle of the 18th century, and stage transport is growing everywhere in Europe. It can be admitted that these vehicles can be qualified as road vehicles; Nevertheless, they are equipped, in France, with a so called "mechanical" brake system which enabled the driver to apply one or several brake shoes against the wheels without getting off from his seat. These brake shoes are actuated by a transmission controlled by a lever available for the driver: it is a first draft of the centralized control brake system.

The first brake incident...

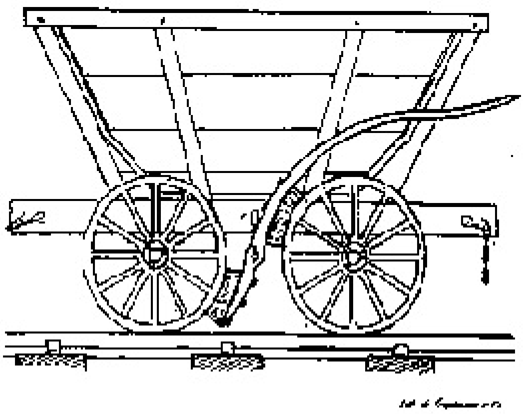
We stay on the "road" for the first brake incident in history, closely linked to the birth of the motor. On November 23rd, 1770, Nicolas-Joseph CUGNOT presents in Arsenal de Paris its now famous "fardier", a trolley equipped with a steam motor. This vehicle was very difficult to control and poorly braked, so that it finishes its run in the outer wall… This incident will stop for long years any experimentation of vehicles, guided or not, without horses: braking is still at this time the key factor which shall follow traction progress.

Let move forward of a few years with the birth of railways in France: following a visit in Le Creusot, one of the birthplaces of industry in France, Louis Jean-Marie DAUBENTON writes in 1782 to George-Louis LECLERC de BUFFON: « All routes are made of pieces of wood, to which are adapted cast iron strips on which are rolling the wheels of the trolleys that drive the coal to the mine; and these wheels are driven so that the trolley cannot go away and is obliged to follow the route that is drawn for it : so that a single horse, even blind, can drive for thousands and more without hindering…. ». The accident of CUGNOT has not been forgotten, and horse traction still affirms its superiority, so that no brake system is required.

The birth of railways in France

The year 1827 is a turning point in the industrial history of France with the birth of railways between Saint Etienne and Andrézieux.

In the downhill direction, the trains, which can be composed of up to 14 vehicles, 5 tons each when loaded (1 ton when empty), moved by means of the simple effect of gravity. They were thus equipped with a brake system on each wagon, made of two brake shoes mounted head to tail on a lever pivoting around an axis linked to the frame of the wagon.



Brake system of a wagon around 1827

Levers were linked one to the other by means of a rope, so that drivers installed on the head wagons and intermediate wagons could actuate the brakes on several wagons simultaneously: the first railway brake system was born, and its architecture was still near, in its basic principle (brake control by a single man), to today's systems…

In the uphill direction, trains were hauled by horses: the locomotive was still to be waited!

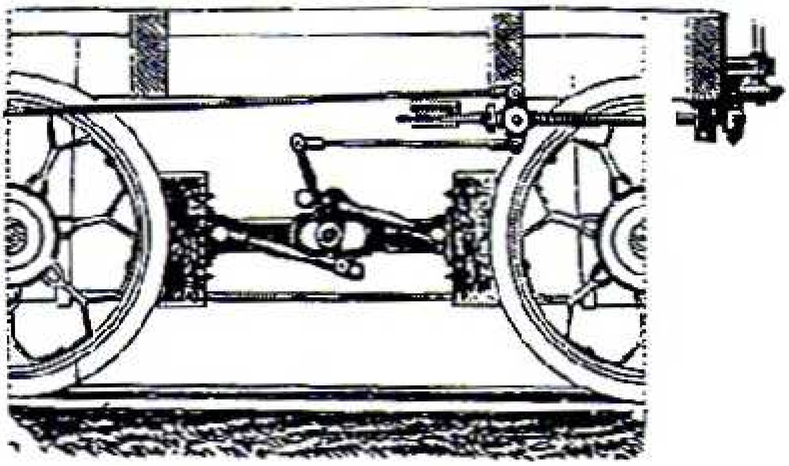
The first locomotives

The latter arrived shortly, as in 1831 are introduced in operation the two first locomotives with tubular boiler built by Marc SEGUIN. An interesting aspect is that the steam distribution in the cylinders was designed so that it was possible to operate in reverse to slow down the train in case of unexpected obstacle on the track: the dynamic brake is thus born at the same time as the railway traction.

The next year (1832), a mechanical brake appears on the tender of the locomotive (SAMSON English locomotive imported in France). It is a tread brake controlled by means of a screw, which enabled a long-term use of the brake without requiring keeping a lever in position, thus providing a better efficiency without tiring the driver. This brake was actuated either by the main driver or by his assistant.

The first passenger trains

The year 1837 represents the real birth of railway braking, with the opening of first regular passenger services between Paris and Saint Germain en Laye. Several types of brakes appear at this time, still based on the principle of a brake shoe applied on the wheel, but actuated in different ways: wedges, rods, gears. Brake shoes are installed on one or both sides of the wheels, in order to increase the braking efficiency and the brake force.

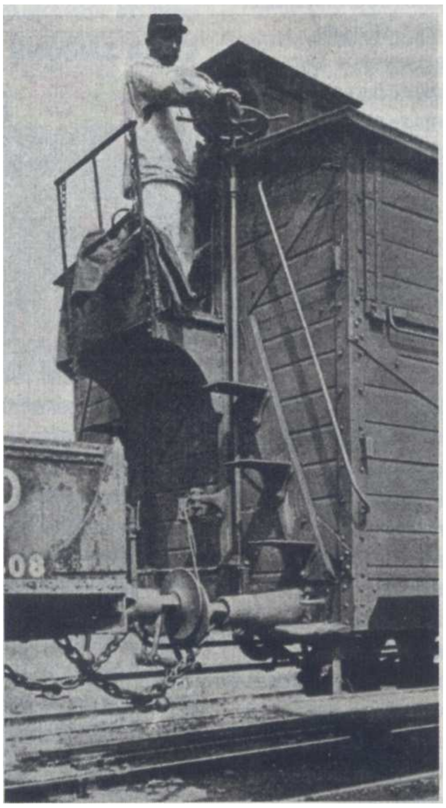


Brake system controlled by screw and rods around 1837

Anyway only part of the vehicles (generally the heaviest) are equipped with a brake system, so that "brake guards" jobs had to be created; these were specialized agents in charge of operating the brakes during train operation, but also to maintain it (greasing of mechanisms, replacement of brake shoes): they were thus considered as responsible of accidents that could be the consequence of a bad maintenance of brakes on vehicles they were in charge.

The principle was the following: the train being composed of the locomotive and cars, some of the latter being braked by "brake guards", the driver, to control the brake, launched an acoustic signal by means of the whistle of the locomotive. This signal was repeated by the first "brake guard" to the others in the train. Each "brake guard" should then actuate the brakes according to the instructions given by the driver with the whistle of the locomotive. Other orders transmission means could be used, such as bells, flags, lights, etc.

Brake guard in his guard house on a wagon built end of 19th century



Brake guard at his post, beginning of the 20th century

Some of the "brake guards" even had the responsibility of several braked vehicles, and had then to move from one vehicle to the other, whatever were the weather conditions…

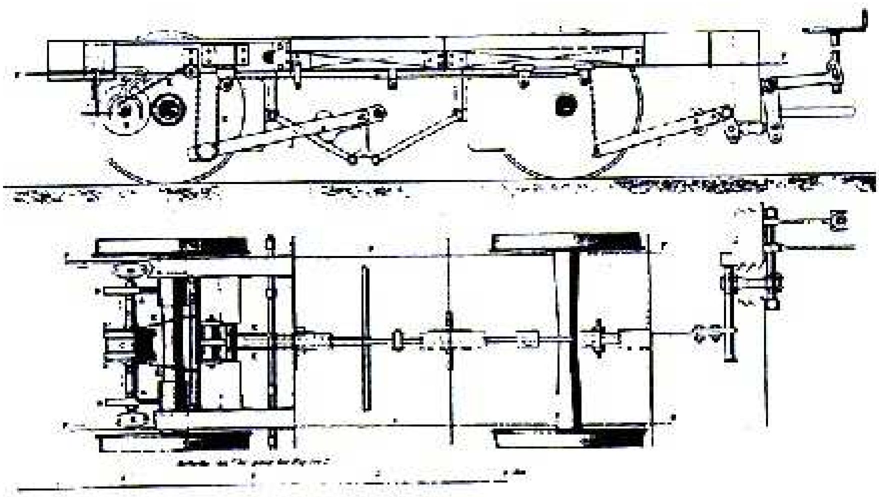
The first French patent

In 1843, Henri NOSÉDA registers in Mâcon the first French patent about a railway brake system. It concerns a brake based on a screw, gears, clutch, rods, chain, brake shoes and springs. It is tested by the Chemin de Fer d'Orléans railway company between 1843 and 1845. At the same time, a simple device based on a screw handle actuating a rigging applying the brake shoes on the wheels is spreading in France.

The year 1846 is a turning point in French railway history. On 8th of July this year, in Fampoux (surroundings of Arras), a train that left Paris in the morning and is composed of 2 locomotives and 20 cars is a little bit late. The driver accelerates more than reasonable and reaches a speed that is qualified as unusual. In a curve, a shock, due to unintended brake application required by a "brake guard", breaks the coupling chain between the fourth and fifth cars. The train end after this fifth car derails and runs into a lake, killing 14 people. The engineers at this time realized that it was necessary to think about a brake system that enable a continuous and centralized control of brakes from the locomotive. This accident also demonstrates that couplers reactions consecutive to a bad use or design of brakes can lead to train breaking.

The first continuous brake

Thus nine years later, in 1855, appears the first so called continuous brake, i.e. it is installed on all vehicles of a train and that is controlled by the driver. Patented on 20th of March by Auguste ACHARD, it is made of brake shoes actuated by electromagnets which bring friction rollers in contact with the axle, which in turn can transfer its rotation energy to ensure brake application by means of a chain and rigging system. Thus the first continuous brake is an electric controlled one! This brake is also, for one of its versions, automatic: in case of couplers breaking, the electric supply line is broken and, thanks to local batteries, the action of electromagnets leads to brake application on vehicles downstream the breaking point.



Brake system designed by ACHARD

This brake system, initially tested around 1860-1862 by the PLM railway company and the Compagnie des Chemins de Fer de l'Est, will remain until around 1883, but will be abandoned due to the poor reliability of electric connections between vehicles, and following the development of the pneumatic brake, that was more reliable.

Other brake systems, that can be qualified as serious, were developed at this time:

- The self-actuating brake developed by Mr GUERIN: on each vehicle, braking is controlled by means of a device actuated by the contraction of buffers, which is consecutive to a first slowing effect provided by the locomotive. If this system is continuous and is controlled only by the driver, its reliability is low and it is not automatic: in case of couplers breaking, the train end drifts without possibility to brake it.
- The counterweight based brake system developed by Mr NEWALL: a counterweight installed in the first vehicle of a group of vehicles actuates, when going down, a rigging that in turn applies brakes on all vehicles of the concerned group. This brake is automatic, as the rigging between vehicles is designed to apply brakes on the vehicles of the same group downstream the couplers breaking. Brake control is ensured by the driver, by means of a rope that enables to control several groups of vehicles simultaneously: the continuity principle can thus be fulfilled. It has been adopted by the Compgnie des Chemins de Fer du Nord in 1855.

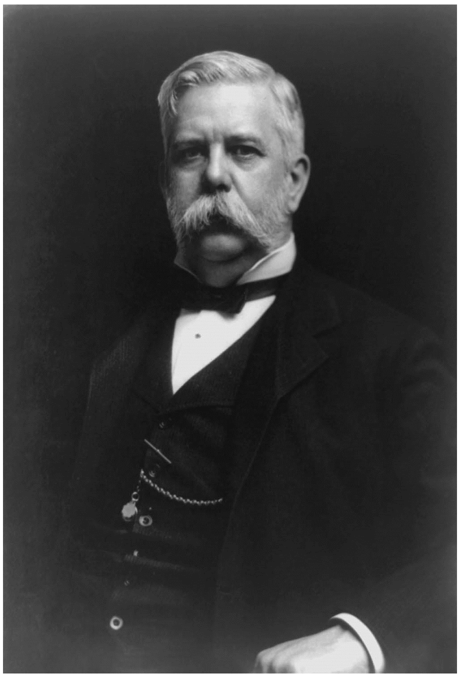
The era of air

Although the first patent for a pneumatic brake (vacuum brake) is dated 1844, it is only in 1862 that such a brake system is tested by Mr VERDAT du TREMBLAY and Mr MARTIN. In 1877, the Compagnie des Chemins de Fer du Nord is the first French railway company to use a pneumatic brake (also a vacuum brake), developed by Mr SMITH and Mr HARDY.

The principle consists in generating vacuum in a pipe installed along the train, this vacuum leading, on each vehicle, to suck a piston up into a cylinder: the piston then generates a force that applies the brake shoes on the wheels by means of a rigging. Brake release is obtained par the piston coming back to its initial position by effect of gravity (which thus required a vertical installation of the cylinder).

The great invention of George Westinghouse

In parallel, another pneumatic brake is developed, using compressed air: 1870 sees the birth of the pneumatic brake as we still know a century and a half later. In this day of November 1867, George WESTINGHOUSE seats in a train facing a passenger reading a magazine, when his attention is drawn by the title of an report: “in the tunnel under the Mont Cenis”. He asks his neighbor for permission to read the report: the WESTINGHOUSE pneumatic brake is born. Indeed, George WESTINGHOUSE will learn from the use of compressed air by the engineer SOMMEILLER – to actuate the percussion rock drilling machines in the tunnel under the Mont Cenis – to imagine the modern pneumatic brake. In France, he asks for a patent on November 9th, 1870 (during the French-Prussian war!); this patent being the base of the modern pneumatic brake. As a curiosity at this time, this patent is registered by the Minister of Agriculture and Trade (with idea to reduce the number of cows killed on tracks ?...)!



George WESTINGHOUSE (1846-1914) beginning of 20th century (Library of Congress, Washington, D.C.)

Just let George WESTINGHOUSE praise his invention by himself in 1872:

« In service on more than 50 railways in the *USA*

Approved by the headquarters of the main companies

Can stop a train within its own length...

Is always efficient...

Does not need a heavy maintenance

Places the train under the complete control of the driver

Avoids shocks and shakes during braking

Is quite and soft in its operation

Does not need the use of locomotive whistle when the train shall stop

Return of investment within one year...

Reduces wear and damages on rolling stock

Save wheels

Reduces bills to pay for shocks against livestock on tracks (editor's note: thus a validation by the Minister of Agriculture?...)

Avoids loss of human lives and accidents costs »

It's all here in this advertising, up to concerns, more than of current events today, of return on investment and of reduction of maintenance costs: really of vision!

In 1873, George WESTINGHOUSE develops the first triple valve, which is the main component of the compressed air pneumatic brake and which still equips (in more advanced versions) some of ancient vehicles still in operation (e.g. BB 6300 in SNCF…).

In France, the WESTINGHOUSE brake is introduced in operation in 1877 by the Compagnie des Chemins de Fer de l'Ouest.

In view of the importance of this innovation, a ministerial circular dated September 21st, 1880 asks the French railway companies to install within a delay of 2 years continuous and possibly automatic brakes on their express trains (speed greater than 60 kph…), recommending at this occasion the use of the WESTIGHOUSE brake…

As a result of success met by his invention, George WESTINGHOUSE cannot meet the demand, and a French man, Mr WENGER, invents in 1883 a compressed air pneumatic brake having more or less the same functions than the WESTINGHOUSE brake, and tested by the Compagnie de Paris à Orléans. These two brakes will coexist until 1897, when the WESTINGHOUSE brake will be improved (quick WESTINGHOUSE brake) and will definitively take over beginning of the 20th century. Meanwhile, the famous accident in Montparnasse station on October 22nd, 1895 reinforced the wish of authorities to impose installation on trains of a safe and reliable brake system: indeed a failure of the brake system when entering Montparnasse station impeded the stop of the train coming from Granville, which locomotive finished its run down on the Place de Rennes – an image that remains famous, and went round the world – killing a news agent in her newsstand.

Progress performed in less than half of a century have been huge, bringing safety as well as performances: around 1845, a 8 cars train equipped with the screw brake and running at 50 kph stopped on a distance of 230 meters; in 1889, the WESTINGHOUSE brake is able to stop a 50 cars train from a speed of 70 kph on a distance of 215 meters… Today, the stopping distance of a TGV from the same speeds is lower than 150 meters.

In 1911 appears a new generation of triple valve, which is designed for all vehicles (passengers and freight).

During the First World War happened the most serious railway accident in the European history. On November 9th, 1917, obeying a threat of military authority, a train for soldiers on leave coming from the Salonique front is engaged in the Maurienne 30‰ downhill gradient, although it had been reported that an insufficient number of vehicles with brakes in operation. During the run, the driver cannot master the speed of the train, the latter derailing in a curve and caught fire: there will be 700 killed.

Arrival of distributor valves

Restart of economy in the years 1920 and 1930 made it possible to develop the first distributor valves, UIC homologated: WESTINGHOUSE and KUNZE-KNORR distributor valves in 1926, then HILDEBRAND-KNORR in 1932.

Braking will then no more progress until the end of the years 1960. Indeed, the Second World War will dramatically affect the European railways, when besides the Atlantic Ocean airplanes and automobile starts to relegate the train to freight traffic only. Thus the only evolutions concern the improvement of the WESTINGHOUSE brake, with the development of modern distributor valves still in operation today in several hundred thousands of copies: CHARMILLES distributor valve in 1948, KNORR KE in 1954, WESTINGHOUSE E3 in 1957, then CHARMILLES C3W in 1972. The last distributor valves that have been developed are the OERLIKON ESG one in 1977 and the SAB WABCO SW4 in 1998.

The birth of disc brake

In parallel, the years 1960 are characterized by a major technological leap. Indeed during these years, the operator launch in race for speed, in order to remain competitive in front of the development of automobile. In Japan and in France, high speed trains (for this time!) start to be operated at speeds around 200 to 210 kph. It then appears that braking with cast iron brake shoes on the wheels – as used since a hundred years – is insufficient and inadequate, on one hand because of its low braking capacities (low friction coefficient of cast iron) and on the other hand because of unacceptable thermal solicitations generated on the wheels treads. The speed increase then requires the installation on railway vehicles of the disc brake and of the magnetic track brake. These innovations, more than the traction – what has been demonstrated with the speed record at 331 kph in 1955 – will enable daily operation at 200/210 kph within safe and acceptable cost conditions.

From the years 1960 to today, progress have been essentially concentrated on the dissipation of kinetic energy of trains – which is always greater with the increase of speed – the brake control (pneumatic brake) making slow progresses. Only the development of the electric assistance of the WESTINGHOUSE brake (so called E.P. brake) and progresses in the design and manufacturing of pneumatic components have sensibly improved the performances in terms of response times and controllability. But basic principles of pneumatic brake have not been changed, and the WESTINGHOUSE brake is installed on the TGV which is operated daily at 320 kph.

The electric control

However another innovation appears in the years 1960 and 1970, pushed by the metro operators. Indeed, the huge development of urban transport requires a more and more dense operation, which leads to equip lines with automatic train operation. The WESTINGHOUSE pneumatic brake then reveals its limits, the intrinsic response times of this system (even with E.P. assist) being incompatible with very precise stopping points and quick reactions. This is the reason why the direct electropneumatic control has been developed, which is different from the E.P. assist on vehicles equipped with the pneumatic brake.

The principle is to replace the pneumatic Brake Pipe by electric train lines: the idea is not new, as it brings us back to the invention of Auguste ACHARD! But technical progresses have made it possible to render reliable the use of this technology, and the electric control is generalized on all urban vehicles.

For actuation, the only available technology at this time remains the pneumatic one: the brake actuation at each vehicle level will thus remain pneumatic, the local response times being sufficiently short with regard to rusticity and mainly to reliability of the pneumatic technology.

The electrohydraulic brake

A variant will anyway be developed in the years 1970 for tramcars, the requirements in terms of compactness of calipers and an additional reduction in response times on these vehicles – associated to the development of industrial hydraulics – leading to the generalization of the electrohydraulic brake, for which the brake actuation is ensured by means of an hydraulic fluid instead of compressed air.

And for tomorrow ?...

As we could see, railway braking evolution is made of a succession of small steps, and can appear to be very slow in comparison to progresses made by traction. However, braking is directly linked to safety of operation, and brake engineers shall be very careful. Moreover, friction is the braking core topic, which presents very variable and nonlinear properties that render its management very difficult as its use is the only guarantee of safety: dynamic brake is easier to regulate and wear less, but its principle is not safe as it is not able to guarantee immobilization of the train when stopped.

Anyway brake engineers are condemned to permanent progress, being pulled by increasing needs in terms of operation speed and lines debit generated by the increased competition of the different transportation means. Diverse innovations appear beginning of the 21st century, which could bring revolution in railway braking:

- In the frame of friction, new materials appear (ceramics, reinforced aluminum, carbon, performing composite, etc.), some of them being possibly used for railway braking to increase energy dissipation capacities of brake discs in the same volume of material, and mainly for a cost that shall remain competitive. These new materials could also enable to sensibly reduce the acoustic signature of freight trains, by installation of brake shoes that do not generate squealing during braking and avoid roughening of wheels treads, which is source of noise during operation.
- In terms of brake control, electric control has supremacy in urban transport, but compressed air remains almost the only technology used for main lines and freight. The E.P. assist is certainly efficient for passenger trains, for which compositions are rarely modified and for which maintenance is more careful than for freight rolling stock. For the latter, connection problems between vehicles have up to now relegated E.P. assist to rare exceptions of almost indeformable compositions (fast freight trains, operated up to 160 kph even 200 kph). However a revolution is engaged in the USA since the middle of the years 1990, which also reached South Africa and Australia (all great users of heavy and long freight trains), and that could arrive in Europe: it concerns the electronic brake control for freight trains. Two technologies have been evaluated, one based on the use of a wired digital bus to transfer the brake demands simultaneously to data relative to each vehicle (such as load, origin, destination, etc.), the other based on radio transmission with emission of brake demands by the locomotive and repetition of these demands step by step by each equipped vehicle (with possibility to “jump” a failed or non-equipped vehicle). The radio technology has been abandoned for different reasons, and only the wired digital technology has been fully developed, followed by some operational applications.

The electronic control for freight trains should be generalized in the future, as its advantages have been demonstrated several times in the USA: stopping distances reduced by an average 30% (thus authorizing higher operation speeds), no couplers reactions in trains (thus lower risks of train breaks); better controllability of braking which leads to a lower solicitation, thus a lower wear, of friction components – wheels and brake shoes for the freight vehicles – as well as a lower consumption of energy for traction engines – which also can be multiplex controlled by means of the electronic control.

As we can see, stakes remain huge and no doubt that railway braking history is far from its end, and looks even fascinating!