Introduction

The vacuum brake was, for many years, used in place of the air brake as the standard, fail-safe, train brake on railways in the UK and countries whose railway systems were based on UK practice. Here is a simplified description of the vacuum system.

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Basics

A moving train contains energy, known as kinetic energy, which needs to be removed from the train in order to cause it to stop. The simplest way of doing this is to convert the energy into heat. This is usually done by applying a contact material to the rotating wheels or to discs attached to the axles. This material creates friction and converts the kinetic energy into heat. The wheels slow down and eventually the train stops. The material used for braking is normally in the form of a block or pad.

The vast majority of the world's trains are equipped with braking systems which use compressed air as the force used to push blocks on to wheels or pads on to discs. These systems are known as "pneumatic brakes". The compressed air is transmitted along the train through a "brake pipe". A change in the level of air pressure in the pipe causes a change in the state of the brake on each vehicle. It can apply the brake, release it or hold it "on" after a partial application. The system is in widespread use throughout the world. For more information, see Air Brakes.

An alternative to the air brake, known as the vacuum brake, was introduced around the same time as the air brake. Like the air brake, the vacuum brake system is controlled through connecting a brake valve in the driver's cab with braking equipment on every vehicle. The operation of the brake equipment on each vehicle depends on the condition of a vacuum created in the brake pipe by an ejector or exhauster. The ejector, using steam on a steam locomotive, or an exhauster, using electric power on other types of train, removes atmospheric pressure from the brake pipe to create the vacuum. With no vacuum, i.e. normal atmospheric pressure in the brake pipe, the brake is released. With no vacuum, i.e. normal atmospheric pressure in the brake pipe, the brake is applied.

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The pressure in the atmosphere is defined as 1 bar or about 14.5 lbs. per square inch. Reducing pressure to 0 lbs. per square inch, creates a near perfect vacuum which is measured as 30 inches of mercury, written as 30 Hg. Each 2 inches of vacuum therefore represents about 1 lb. per square inch of atmospheric pressure.

In the UK, vacuum brakes operated with the brake pipe at 21 Hg, except on the Great Western Railway which operated at 25 Hg.

The vacuum in the brake pipe is created and maintained by a motor-driven exhauster with two speeds, high speed and low speed. The high speed is switched in to create a vacuum and thus release the brakes. The slow speed is used to keep the vacuum at the required level to maintain the vacuum against small leaks in the brake pipe. The vacuum in the brake pipe is prevented from exceeding its nominated level (normally 21 Hg) by a relief valve, which opens at the set pressure and allows air into the brake pipe to prevent further increase.

**Principal Parts of the Vacuum Brake System**

This diagram shows the principal parts of the vacuum brake system as applied to an electric or diesel train. The systems used on steam locomotives were somewhat different.

[Block Diagram of Basic Vacuum Brake Equipment](http://www.railway-technical.com/vacuum.shtml#Other-Vacuum-Operated-Equipment)
Driver's Brake Valve

The means by which the driver controls the brake. The brake valve will have (at least) the positions "Release", "Running", "Lap" and "Brake On". There may also be a "Neutral" or "Shut Down" position, which locks the valve out of use. The "Release" position connects the exhauster to the brake pipe, switching the exhauster to full speed. This raises the vacuum in the brake pipe as quickly as possible to get a release.

In the "Running" position, the exhauster keeps running but at its slow speed. This ensures that vacuum is maintained against any small leaks or losses in the brake pipe, connections and hoses.

"Lap" is used to shut off the connection between the exhauster and the brake pipe to close off the connection to atmosphere after a brake application has been made. It can be used to provide a partial release or a partial application, something not possible with the original forms of air brake.

"Brake On" closes off the connection to the exhauster and opens the brake pipe to atmosphere. The vacuum is reduced as air rushes in.

Some brake valves were fitted with an "Emergency" position. Its operation was the same as the "Brake On" position, except that the opening to atmosphere was larger to give a quicker application.

Exhauster

A two-speed rotary machine fitted to a train to evacuate the atmospheric pressure from the brake reservoirs and brake cylinders to effect a brake release. It is usually controlled from the driver's brake valve being switched in at full speed to get a brake release or at slow speed to maintain the vacuum level whilst the train is running. Exhausters are normally driven off an electric motor, but they can be run directly from a diesel engine. See Also Ejector.

Brake Pipe

The vacuum-carrying pipe running the length of the train, which transmits the variations in pressure to control the brake. It is connected between vehicles by flexible hoses, which can be uncoupled to allow vehicles to be separated. The use of the vacuum system makes the brake "fail safe", i.e. the loss of vacuum in the brake pipe will cause the brake to apply.

Dummy Coupling

At the ends of each vehicle, a dummy coupling point is provided to allow the ends of the brake pipe to be sealed when the vehicle is uncoupled. The sealed dummy couplings prevent the vacuum in the brake pipe from escaping.
Coupled Hoses
The brake pipe is carried between adjacent vehicles through flexible hoses. The hoses can be sealed at the outer ends of the train by connecting them to dummy couplings.

Brake Cylinder (shown in blue)
Each vehicle has at least one brake cylinder. Sometimes two or more are provided. The movement of the piston contained inside the cylinder operates the brakes through links called "rigging". The rigging applies to the brake blocks to the wheels. I do not know of a vacuum brake system which uses disc brakes. The brake cylinder moves in accordance with the change in vacuum pressure in the brake pipes connected to it. When the vacuum pressure falls, the brake cylinder applies the brakes, restoration of the vacuum releases the brakes.

Vacuum Reservoir
The operation of the vacuum brake relies on the difference in pressure between one side of the brake cylinder piston and the other. In order to ensure there is always a source of vacuum available to the brake, a vacuum reservoir is provided, or connected to the upper side of the piston. In the simplest version of the brake, shown above, the brake cylinder is integral with the vacuum reservoir. Some versions of the brake have a separate reservoir and a piped connection to the upper side of the piston.

Brake Block
This is the friction material which is pressed against the surface of the wheel tread by the upward movement of the brake cylinder piston. Often made of cast iron or some composition material, it is the main source of wear in the brake system and require regular inspection to see that they are changed when required.

Brake Rigging
This is the system by which the movement of the brake cylinder piston transmits pressure to the brake blocks on each wheel. Rigging can often be complex, especially under a passenger car with two brake blocks to each wheel, making a total of sixteen. Rigging requires careful adjustment to ensure all the brake blocks operated from one cylinder provide an even rate of application to each wheel. If you change one block, you have to check and adjust all the blocks on that axle.

Ball Valve
The ball valve is needed to ensure that the vacuum in the vacuum reservoir is maintained at the required level, i.e. the same as the brake pipe, during brake release but that the connection to the brake pipe is closed.
during a brake application. It is necessary to close the connection as soon as the brake pipe vacuum is reduced so that a difference in pressure is created between the upper and lower sides of the piston. See the next paragraph - Operation on Each Vehicle.

Operation on Each Vehicle

Brake Release

This diagram shows the condition of the brake cylinder, ball valve and vacuum reservoir in the release position. The piston is at the bottom of the brake cylinder. Note how the brake cylinder is open at the top so that it is in direct connection with the vacuum reservoir.

A vacuum has been created in the brake pipe, the vacuum reservoir and underneath the piston in the brake cylinder. The removal of air from the system has caused the ball valve to open the connection between the vacuum reservoir and the brake pipe. The fall of the piston to the bottom of the brake cylinder causes the brake blocks to be released from the wheels.

Brake Application

This diagram shows the condition of the brake cylinder, ball valve and vacuum reservoir in the application position. The vacuum has been reduced by admitting atmospheric pressure into the brake pipe. This has forced the piston upwards in the brake cylinder. By way of the connection to the brake rigging, the upward movement of the piston has caused the brake blocks to be applied to the wheels.

The movement of the piston in the brake cylinder relies on the fact that there is a pressure difference between the underside of the piston and the upper side. During the brake application, the vacuum in the brake pipe is reduced by admitting air from the atmosphere. As the air enters the ball valve, it forces the ball valve (in red in the diagram above) upwards to close the connection to the vacuum reservoir. This ensures that the vacuum in the reservoir will not be reduced. At the same time, the air entering the underside of the brake cylinder creates an imbalance in the pressure compared with the pressure above the piston. This forces the piston upwards to apply the brakes.

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Additional Features of the Vacuum Brake
Accelerators

The vacuum brake had one major advantage over the original air brake system. It could provide a partial release, which the air brake could not. However, it is slower in operation than the air brake, particularly over a long train. This eventually led to the adoption of accelerator valves, which helped speed up the operation on each vehicle. The accelerator valve is fitted to each vehicle on the connection between the brake pipe and the brake cylinder. It detects the loss of vacuum when the pressure rises in the brake pipe and opens the pipe to atmosphere on the vehicle. This helps to reduce the vacuum in the brake pipe and cylinder of each vehicle and therefore increases the propagation rate along the brake pipe. In the more sophisticated versions fitted to EMUs accelerators valves were electrically operated by the movement of the driver's brake valve to the "brake on" position.

Two Pipe Systems

Another version of the vacuum brake used two train pipes. The usual brake pipe operated in the conventional way but the second pipe was provided to give an additional supply to speed up the brake release. The second pipe is called the reservoir pipe. The diagram below shows a schematic of the two-pipe system with the reservoir pipe shown in grey.

The two-pipe system was introduced on diesel railcars where the exhauster was driven directly off the engine. Since the engine was only idling if the train was stationary, the exhauster would only be running at slow speed. This meant that the restoration of the vacuum in the brake pipe and cylinders along the train would be very slow. To get a rapid brake release when it was needed to start the train, a "high vacuum" reservoir was provided on each car, the reservoirs being supplied from a second Train Reservoir Pipe. These additional reservoirs were characterised by their operating vacuum of 28 Hg, as opposed to the 21 Hg used in the brake pipe and brake cylinders.

While the train is moving and the driver's brake valve is in the "Running" position, the exhauster is connected to the reservoir pipe and through the driver's brake valve to the brake pipe. A automatic feed valve fitted between the reservoir pipe and the driver's brake valve limits the maximum vacuum passing to the driver's brake valve at 21 Hg. This means that the vacuum in the brake pipe and brake cylinders is limited to 21 Hg. However, the vacuum created by the exhauster in the reservoir and high vacuum reservoirs reaches 28 Hg, as shown in the diagram above in grey.

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To apply the brake, "Brake On" is selected by the driver and the brake pipe is opened by the driver's brake valve. The exhauster will continue to run and maintain the 28 Hg reservoir level. To get a partial application, "Lap" can be made by moving the handle to "Lap".

To get a release, the brake valve is moved to the "Running" position. There is no "Release" position as "Running" is selected, the connection to atmosphere is closed and the connection to the exhauster opens to start restoring the vacuum. As there is a store of "high" vacuum available in the brake pipe and reservoirs, the process is speeded up to give a rapid release.

Each reservoir has an automatic isolating valve between itself and the brake pipe. This valve is set to 19 Hg and closes if the vacuum in the reservoir falls below this level. This has the effect of preventing the reservoir from being emptied. The volume of the reservoir is such that it can restore the vacuum for several applications and releases before it drops below 19 Hg.

**Equalising Reservoir**

A problem with both air and vacuum brakes is that the driver's brake valve is at one end of a long pipe. If a partial application is required on a long train, a good deal of skill is required to estimate how much air to let in (or let out on an air braked train) to get the application wanted. To help set the brake to the right level, some vacuum brake systems have an equalising reservoir. This is fitted between the driver's brake valve and the brake pipe and it acts in conjunction with a relay valve or "air admission valve". When the driver moves the brake valve to the "Brake On" position, air is admitted into the equalising reservoir, not the brake pipe. He monitors the lowering of the vacuum using the gauge provided in the cab. As the vacuum causes the air admission valve to open the brake pipe to atmosphere. When the brake pipe has fallen to the level set in the equalising reservoir, the air admission valve closes to maintain the brake pipe vacuum at that level.

The main advantage of the equalising system is that it allows the driver to select a level using the small volume of the equalising reservoir instead of having to wait for the level along the length of brake pipe to settle before he knows what the real level is.

**Other Vacuum Operated Equipment**

On an air braked train, the compressed air supply is used to provide power for certain other functions besides braking. These include door operation, whistles, traction equipment, pantograph operation...
Some of these devices on vacuum fitted trains are operated using the vacuum supply. Some electric trains with vacuum brakes have been fitted with vacuum operated pantographs, warning horns and rail sanders.

**Vacuum Brakes on Steam Locomotives**

So far, we have concentrated on the vacuum brake equipment provided for electric and diesel operated vehicles but by far the largest number of trains fitted with vacuum brakes were steam hauled. The principle of operation was the same as for other types of train but there were some differences as described below.

**Ejectors**

For some reason, exhausters are called ejectors on steam locomotives. They are, of course, steam operated. The ejector consists of a series of cones inside a tube. Steam is allowed to pass through the cones so that a vacuum is created in the tube and thus in the brake pipe to which it is connected. There are two ejectors, large and small, which provide the brake release and vacuum maintenance functions respectively. The large ejector provides the rapid build-up of vacuum required for brake release and the small ejector provides the constant vacuum needed to keep the brake pipe and cylinder vacuum at the correct level to maintain brake release.

On some locomotives, ejectors were combined with the driver's brake valve. Most had "Running" and "Brake Off" positions and many were combined with a steam brake fitted to the tender. The more sophisticated allowed a single brake application to apply the brakes on the train while only the brakes behind the locomotive. Drivers were taught that it was best to slow the train down and then apply the brakes as the train came to a stop. This required them to restore much of the vacuum before the train was brought to a stand, allowing a quick release without having to run the large ejector for very long, thereby saving steam.

**Comment**

The vacuum brake was not widely popular outside the UK and UK inspired railways, but it was simple in design and of having the ability to get a partial release, something the air brake could not do without additional equipment. The vacuum brake was not as effective as the air brake, taking longer to apply and requiring large cylinders to provide the same brake effort as the air brake. It was also slow to release and requires additional equipment to speed up its operation.

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