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THE DEVELOPMENT OF THE MODERN AIR BRAKE.

Thesis Submitted to the Mechanical Engineering Department by

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NOTE.

Since the Westinghouse Air Brake has been accepted as the standard on the majority of the railroads both in this country and abroad, and has been the pioneer in adopting the greater number of improvements, the Westinghouse apparatus has been referred to almost exclusively. A few drawings of the New York and other types of equipment have been inserted for purposes of comparison.
The Development of the Modern Air Brake.

The air brake is now fifty three years old. In these days of miraculous development such as that of the automobile or wireless telegraphy, it is dangerous to claim that any one discovery is of unparalleled importance. It will be safest merely to state that the air brake has become an indispensable asset of our present civilization, and were it to be suddenly placed out of reach, the resulting conditions would be exactly those attending a world wide railroad tie up. Without the air brake, our modern trains could not run. The air brake is so inconspicuous and so unimpressive in its action that most people never give it a thought, unless perhaps the engineer carelessly makes an emergency application.

Fifty years ago passenger trains of three or four small cars, running at a ridiculously low rate of speed, represented the ultimate development possible in railroad transportation until some device was obtained which would insure quick and reliable stops. No scientific researches had been applied to the subject. The laws of braking were entirely unknown. The air brake first made possible longer, heavier, and faster trains, but the brake itself had to be improved at the same time, because the improvements in the trains were always just a little beyond
Simple and early types of hand-brakes.
the powers of the brake. At the same time countless experiments were made, both here and abroad, on the stopping of trains, and the air brake had to be continually modified in accordance with these tests.

As each improvement was made in the design of the brakes, common sense and economy demanded that cars fitted with the new equipment should be able to work even if coupled in the same train with the cars containing the older equipment. This was made possible at every single stage of the development.

General Principles

Nearly every brake which has ever been devised or tried, has consisted of a stationary piece or shoe which was pressed against a wheel of the moving vehicle, bringing it gradually to rest. Apparently the first users of this principle discovered that by increasing the pressure on the shoe, the stopping action was made more effective. On fig. 1 some of the earliest known brakes are illustrated, each one of which contains some simple combination of levers which multiplies the original force many times before it reaches the shoe.

There is no record that anyone of the early designers discovered the limitations of this first general principle. Even within the past few years, devices have been proposed
which would instantly lock the wheels of a train in case of an emergency. Of course the wheels would immediately begin to slide along the rails and develop flat places on their circumference. Still more surprising, however, the train would slide even further before stopping than it would have gone, provided an ordinary application of the brakes had been made. Once sliding occurs, the retarding force on the train is equal to the co-efficient of sliding friction multiplied by the weight of the train. As long as the wheel is allowed to turn, the point of contact with the rail is at rest as far as the rail is concerned, and so any tendency to slide is resisted by the weight on the wheel multiplied by the static co-efficient of friction. The relation between these co-efficients varies more or less with the condition of the rail, but the static co-efficient is usually several times greater than the sliding co-efficient. The most effective stop occurs when the force between the shoe and the rim is at all times equal to the resistance to sliding between the wheel and the rail. Put in other words, the wheel should be just on the verge of sliding from the time the brake is applied until the whole train comes to rest. Once the wheel begins to slide, however, a great deal more than half the braking power is entirely lost.
The suffixes to the letters on the above curves represent the position of the car in the train. 

1. The application of the brakes, when skidding is not produced, does not retard the rapidity of rotation of the wheels.

2. When the speed of the wheels falls below that due to the train, skidding occurs at once.

3. The resistance resulting from an application without skidding is greater than that caused by skidded wheels.

4. The pressure required to skid the wheels is much greater than that required to hold them skidded, and bears a relation to the weight on the wheels themselves as well as to their adhesion and velocity.

Figure II

General Laws Resulting from the Gollen-Westinghouse Tests

in England in 1879
In order to obtain this ideal stop, the variation of the co-efficient of friction between the shoe and the wheel must be fully understood. A great deal of the available information on this subject was obtained during the Galton-Westinghouse tests in 1878 in England. As the average of a great many trials it was found that the values of "f", (which is used as the symbol for the co-efficient of friction) varied from .062 at 60 miles per hour, to .320 at 10 miles per hour during the first 3 seconds of application. The value of "f" declined steadily, however, as the time during which the surfaces were in contact increased. The velocity of the train should decrease materially during 5 or 6 seconds and as the end of the stop approaches, the co-efficient could naturally be expected to increase very rapidly indeed, until the static value is reached. Some representative curves showing the variation in "f" are given in fig. 2.

The importance of the speed of application of the brake cannot be over estimated if a quick and effective stop is desired. The shoe should strike a hammer blow, or a considerable percentage of the available force will be lost just at the time when it is most needed. As the stop progresses, the force on the shoe must be decreased rapidly or sliding will occur. The initial force or
pressure on the shoe should vary according to the velocity of the train. These are the most important considerations in the design of an efficient brake.

Requirements of Service.

A brake is much more than an emergency device. Properly used, it becomes even more of a factor in rapid transportation than the engine itself. A steam locomotive does not attain the speed of 60 miles per hour until at least five or six minutes after the start. During this time the train has covered six or seven miles. If the brakes are applied at this speed the train is brought to a stop within about twenty seconds and the total distance passed over is about 1400 feet or very little more than its own length. When passenger trains have to make frequent stops the total time saving effected by properly working brakes is enormous.

Safety, requires that the brake shall be under instant control from any portion of the train. An accident to one of the rear coaches may be averted only by the ability of the conductor to stop the train as quickly as the engineer himself.

If the train should become separated on a grade, and either section be rendered helpless, serious consequences would ensue. In the case of such an accident therefore,
Fig. 3.

This brake was applied by a large spiral spring which was wound up by the conductor after each stop. A cord running from the engine to each car released the spring when a stop was necessary.

Creamer brake, 1853.

Fig. 5.

Loughridge chain-brake, 1855.
warning should automatically be given to the engineer and the brakes applied on each part of the train.

The train might be descending a dangerous grade which required frequent or perhaps even continuous application of the brakes. In spite of any previous drain upon it, the brake should be capable of an emergency application.

In actual operation, the emergency stop is too uncomfortable for the passengers and too damaging to the equipment to be used continually. The engineer must have at his control some means of applying the brakes more or less gently.

Although stated last, reliability is really the most important requirement. One failure nearly always means a serious accident. In the long run only the brake which gives 100% perfect service is admissible.

The Straight Air Brake

The first practicable air brake was patented by George Westinghouse in 1869. Previously, the most widely used brake was the Loughridge Chain Brake (fig. 3). When the engineer desired to stop, he pressed a friction disk against a wheel of his engine. This disk turned a drum which wound up a long chain passing from car to car. Naturally, if the train was bunched, the brakes set only on the forward cars, and if the train was extended, only
Straight air-brake.

Coupled - Check valves open

Uncoupled - Check valve closed.

Hose coupling used with Straight Air Brake.
on the rear cars. According to Mr. Westinghouse's own story, he was trying to improve on this imperfect device when the idea of the air brake came to him. He first replaced the drum and disk by a steam cylinder. The next development was to attempt to place a steam cylinder on each car. This principle had been used by Stephenson in 1833 but was a failure except on the locomotive itself because of the excessive condensation in the pipe line. The use of air instead of steam was suggested by a magazine story concerning the drilling of a mine tunnel with compressed air tools.

The apparatus as finally perfected (fig. 4) does not differ widely from that used on small street cars today. The demands made upon it did not differ greatly from those arising in ordinary street car work. The rails in use did not permit high speeds or heavy cars and so anything a shade better than the hand brake was satisfactory. On its first trial, the brake succeeded in preventing an accident because the engineer was able to control the entire train instantly. Because of this quality alone the brake was worthy of adoption, but it had other good features also.

By merely varying the time during which the valve
was kept open the engineer could obtain any brake pressure within the limitations of his compressor.

The pressure was variable during the entire time of application. It could be increased or decreased entirely at will.

There were no parts to get out of order or adjustment.

Certain disadvantages, however, rendered it obsolete in less than three years.

In order to apply the brakes, a large volume of air was obliged to pass through the valve, through great lengths of pipe and into the brake cylinder. As a consequence the rise of pressure in the cylinder was extremely slow and so the initial braking power was proportionately low.

Pressure was built up in the first cylinder an appreciable length of time before the air reached the second cylinder and so on. This serial application was so extremely marked that more than 4 or 5 cars was an impossibility.

The breaking of the air hose anywhere in the train rendered the entire system inoperative. As a corollary to this fault, if the train parted there was no warning and both sections were without brakes.
The Vacuum Brake

The straight air brake was preceded chronologically by the Vacuum brake which was quite popular in England. This brake in its simple form possesses many of the characteristics of the straight air brake, especially in the slowness of its action. For cheapness and simplicity, however, it was remarkable. An ejector was used to withdraw the air from the train line. The brake valve merely turned steam through the ejector. The cylinder was replaced by an iron bowl covered with a loose but air tight leather diaphragm to which the brake rod was fastened. The interior of the bowl communicated with the train pipe. As the train pipe pressure was lowered, the leather was pressed into the bowl, applying the brakes. Naturally the factor of safety was low since a broken coupling served to disable the entire system.

The vacuum brake was later made automatic. In order to accomplish this, an additional train pipe was required, and the new system was not any more powerful than the older one. The vacuum brake is limited to 14 pounds per square inch at most, whereas there is theoretically no limit to the intensity of pressure obtainable with the compressed air. Since the vacuum brake played no impor-
PLATE V. is a section parallel to the section shown in Plate IV., cut through the main air-body and ejectors, showing the check-valve 6, which rises and allows the passage of air into the large ejector, and closes to retain the vacuum below when the large ejector has ceased blowing. The vacuum is produced in the large ejector by the flow of steam from the steam-space O through the contracted space at the mouth of the air-tube 8. In the small ejector, the steam from pipe 12 flows through the small conical tube 13, exhausting the air from the air-space P P, and the automatic pipes and the reservoirs connected therewith.
tant part in the development of the modern air brake, no further explanation of its operation will be given.

The Plain Automatic Air Brake.

Three years after the introduction of the straight air brake, Mr. Westinghouse introduced the plain automatic air brake. Since then there have been many important improvements all of which have been vital and essential but fundamentally the apparatus is still that of 1872.

In the new apparatus the pump and main reservoir existed as before. To each car there was added an auxiliary reservoir and a "triple valve". The engineer's valve had changed so as to become unrecognizable. The principle of operation was entirely changed.

During the normal operation of the train, the main reservoir was connected to the train pipe through a small opening in the engineer's valve and maintained a predetermined pressure throughout the train line. Ordinarily 80 lb. per sq. in. was used. As long as this pressure was sustained, the "triple valve" operated in such a way as to isolate the brake cylinder and connect the auxiliary reservoir to the train pipe. The auxiliary reservoir pressure was thus always equal
to that of the train pipe.

If the train pipe pressure were suddenly reduced, either by a parting of the hose or by operating the engineer's valve in such a way as to close the connection to the main reservoir and open the pipe to the atmosphere, the unbalanced pressure in each auxiliary reservoir caused the triple valve to move to the opposite end of its seat. This movement connected the auxiliary reservoir directly with the brake cylinder, at the same time closing the small opening between the reservoir and the train pipe. The brakes were applied suddenly, with a force dependent on the size of the opening between the reservoir and the cylinder.

In order to release the brakes, air at the full pressure of the main reservoir was allowed to flow into the train pipe. This once more reversed the position of the "triple valve" and allowed the air in the cylinder to escape. The auxiliary reservoirs then recharged and were prepared for the next application.

The heart of the apparatus consisted of the triple valve shown in fig. 7. Accompanying the diagram will be found a description of the purpose of each part.

All the components of the plain automatic brake
Fig. 9—Plain Triple Valve

(New Style)
were of the simplest sort and in certain details even rather crude but the brake was considered a marvel when first introduced.

On any ordinary train the total volume of air contained in the train pipe was not large and so the necessary reduction in pressure was obtained by releasing a very small quantity of air. The last brakes on the train thus felt the reduced pressure nearly as soon as the head brakes. Many people considered that the action of all the triple valves was simultaneous, but the time factor, although small, was the most serious drawback of the brake.

In the light of present knowledge, the faults of the brake of 1872 are so glaring, that the good points are apt to be neglected. The latest electro-pneumatic brake provides not a bit more safety applied to our modern trains, than the original automatic brake provided to the passengers on the trains of 1872. As the multitude of improvements is discussed, we must bear in mind that the air brake has barely held its own as the size, speed, and weight of trains has undergone phenomenal increases.

When safety is considered from the view point of reliability, the present day brake shows a satisfactory return for the endless investigation which has been lavished upon it.
Arrangement of Brake Gear with Friction Regulating Valve

Gatton-Westinghouse Tests - 1879

Friction-Regulating Valve

Air Outlet Closed
While simplicity of maintenance has decidedly lost ground, simplicity of operation has increased in a proportionate amount.

The plain automatic brake certainly was not flexible. If a service application were made as explained in the description of the triple valve (fig. 7), one or two slight reductions of train pipe pressure permitted the auxiliary reservoir pressure and brake cylinder pressure to equalize. Once that occurred no more braking power was available until the after the brakes had been released and the auxiliaries recharged. The emergency braking power was available only with fully charged reservoir and fully released brakes. An emergency application was quite apt to skid the wheels after the first few seconds of application since no partial release was possible.

The skidding was more or less satisfactorily overcome by the regulating valve shown in figure 10. This valve was used with success during the Galton-Westinghouse tests but was later rendered unnecessary. Its chief drawback was its lack of means of adjustment and its inability to cope with the various conditions of the rails.

The plain automatic brake could be transformed
easily into a straight air brake by means of the valve 15 (figure?) and short trains were sometimes run in that way, thus gaining the flexibility of the straight air system.

Some ingenious devices are apparent in the design of the automatic brake which tended to render it more reliable. The use of the feed groove m instead of a check valve as a means for charging the auxiliary reservoir prevents the accidental application of the brakes as a result of small train pipe leaks. A similar groove in the brake cylinder allows the slow escape of air during the first three inches of the stroke and prevents the brakes from creeping on due to a leaky triple valve.

Skillful engineers were needed to properly operate the brake however. Previous to the release of the brakes a main reservoir pressure of considerably more than the normal train pipe pressure was needed in order to secure prompt release. Furthermore a large volume of air was drawn from the main reservoir in order to charge the auxiliary reservoirs. If this air was not stored in the main reservoir at the instant of release, the pump would be forced to overspeed to supply the deficiency. As this high pressure was turned into the
brake pipes, the first auxiliaries would be charged up to a pressure 10 or 15 pounds in excess of that which existed in the brake pipe as soon as all the reservoirs became charged. The head brakes would thus release for an instant and immediately re-apply. Watchfulness and skillful manipulation of the brake valve was the engineers only recourse.

With the valve handle in running position a small quantity of air was continually admitted to the train pipe in order to counteract leaks. If this supply of air was more than sufficient, a higher pressure than normal was built up in the train pipe. If the engineer noticed this by watching the black hand of his gage and attempted to reduce the pressure to normal too suddenly, the brakes would apply. If the excess pressure were allowed to continue an ordinary service application might have the same effect as an emergency application.

Beyond the control of the engineer, was the matter of uneven braking power on different cars in the train. Since all the auxiliaries were of the same capacity on similar cars, the pressure at which the auxiliary reservoir and the brake cylinder equalized depended entirely on the volume of the brake cylinder, which in turn depended on the piston travel. A cylinder having a piston travel of four inches equalized at a much higher pressure than
Fig. 26—Passenger Brake Cylinder with Automatic Slack Adjuster
Showing Lever Connections
MODERN AIR-BRAKE PRACTICE

PLATE NO. 10.—AUTOMATIC SLACK ADJUSTER.
the cylinder in which the piston travel was eight inches. If a number of cars with short piston travel happened to be bunched at the end of a train, a break in two sometimes resulted when the brakes were applied.

The automatic slack adjuster (fig. 11) was later added to the equipment and has remained practically unchanged ever since.

The oldest style of triple valve shown in fig. 12 differs from fig. 7 only in the flimsiness of its construction and the large and inconvenient brass drip cup hanging from the chamber to which the train pipe is connected. The drip cup was the first method employed to rid the brake pipe of the troublesome and excessive moisture which was deposited in all parts of the system as the air cooled in the pipes. This moisture has always been one of the chief causes of stuck or disabled brakes. As the air left the compressor it was at a high temperature and capable of holding a large amount of moisture. Many methods have tried to get rid of this moisture before it reached the triple valves and caused trouble. These methods will be explained later on because for a number of years the presence of the water was endured as a necessary evil.

For freight service a very compact form of
TRIPLE VALVE, WITH BRASS CASE.

PLATE A:3.
Fig. H—High and Low Pressure Weight Type Retaining Valve, Section

Fig. 6—Single-Pressure Weight Type Retaining Valve, Open
NOTE:—While the Weight Type Pressure Retaining Valve is regularly furnished with Freight Brake Equipments, the Spring Type, illustrated below, is in use on some roads. Among other improved features, this type includes a spring instead of a weight for retaining the pressure in the brake cylinder, and an opening tapped for gage connection whereby brake cylinder leakage may be readily tested without the necessity of disconnecting the retainer pipe at the triple valve.

Sectional Views Single Pressure Spring Type Retaining Valve

Sectional Views Double Pressure Spring Type Retaining Valve
apparatus was used. The brake cylinder was fastened directly to one end of the auxiliary reservoir and the triple valve to the other. Freight brakes were ordinarily designed to furnish a break shoe pressure equal to about 70 or 80% of the empty weight of the car. When the cars were loaded the percentage braking power became quite low and the trains were many times hard to control. In descending even a slight grade, leakage was apt to reduce the power of the brakes so considerably that the recharging of the auxiliary reservoirs was imperative. Naturally the brakes had to be released in order to accomplish this, and in a very few minutes a heavy train would have gained such a momentum that the brakes were powerless.

For use on long grades, a pressure retaining valve was devised (fig. 13). This valve is connected to the exhaust pipe leading from the triple valve. At the beginning of a descent the valves are all closed by a brakeman and allow air to exhaust from the brake cylinder only as long as the pressure is more than 10 lb. per square inch. The brakes are thus never completely released and as long a time as necessary may be taken to charge the auxiliaries.

Retaining valves are sometimes used on passenger
trains but ordinarily they are not needed in that class of service. The chief drawback to the valve is that sometimes it is left closed after the need for it has passed, and the wheels upon which the brakes are kept applied become overheated and burst.

The demands of freight service first called attention to the inadequacies of the plain automatic brake. During the Burlington trials in 1886 a series of tests was made on a train of 50 cars and every type of brake tried was unable to stop the train without causing shocks to the end cars which were as severe and damaging as a collision. This occurred simply because the air could not flow rapidly enough through the brake valve to produce a drop in pressure throughout the length of the pipe. Consequently, the first 30 or 40 brakes would set, and the rear cars would then take up the slack with unretarded velocity. Many cars were badly broken in the resulting impact.

The Quick Action Brake.

In the endeavor to overcome the slow action of the ordinary triple valve, Mr. Westinghouse produced the quick action triple in time for the last of the Burlington tests. All the characteristic features of the older form of valve were retained and in addition means was
Fig. 23—Quick-Action Triple Valve

Fig. 6—Brake Cylinder with Quick-Action Triple Valve
provided for exhausting the train pipe air directly into the brake cylinder when an emergency application was desired. The train pipe pressure was thus reduced locally at each valve in rapid succession producing a nearly instantaneous application of the brakes throughout the train. In addition, the air which was vented into the brake cylinder produced the same effect as a decrease of piston travel and caused the auxiliary pressure to equalize with the cylinder at a much higher value than before. The saving of air was also of some importance.

The service application was still the same as before and did not call the quick action feature of the valve into play. Although the brake was designed for freight service, the increased emergency power rendered it desirable for passenger trains. The constantly increasing length and speed of the passenger trains soon served to make the quick action feature indispensable.

With the 50 car train, the time of application of the brakes was reduced to one sixth of that required by the plain brake. Naturally, then, long trains and higher speeds soon became the rule and a general improvement of the whole apparatus was necessary. The old style of engineers valve had given a great deal of trouble as a result of careless handling. The pump governor was
ENGINEER'S BRAKE-VALVE.

PLATE...
connected to the train pipe in order to keep the train pipe pressure as constant as possible. If the valve should happen to be left in lap position at a time when the train pipe pressure was under 70 pounds, the pump would charge the main reservoir right up to the boiler pressure, and as soon as the valve were returned to release or running position, the entire train line would be overcharged.

In release position both the reservoir and train line were kept at 70 pounds, but as soon as running position was used, the excess pressure valve prevented any air from entering the brake pipe until the main reservoir was charged to 90 pounds. During this interval sufficient leakage might occur to set the brakes.

The quick action apparatus was furnished with a new type of brake valve containing what was known as a feed valve (fig. 19). The pump governor was connected to the main reservoir side of this valve and kept the reservoir pressure constant. The feed valve admitted air to the train pipe only when the train pipe pressure fell below a predetermined amount. Thus no excess of reservoir pressure had to be built up before leakage from the train pipe could be supplied.

The pump governor was changed somewhat in mechanical
Fig. 14—G-6 Brake Valve, Release Position

Fig. 16—G-6 Brake Valve, Running Position
Fig. 20—C-6 Feed Valve (Diagrammatic), Closed

Fig. 21—C-6 Feed Valve (Diagrammatic), Open
Fig. 9—Type S Single Top Steam Compressor Governor, Closed
details. The old style (fig. 20) was not sufficiently positive in its action on account of the relatively small size of the air piston in relation to the surface acted upon by the steam pressure. The form shown in (fig. 20) has been practically unchanged since it was brought out.

The High Speed Brake.

The decrease of the coefficient of friction of the brake shoes as the speed increased, was clearly demonstrated during the Galton - Westinghouse tests. This phenomenon made possible the so called "high speed brake" which replaced the quick action brake on very fast trains.

The high speed brake required a train pipe pressure of 110 pounds which naturally produced a very high initial brake shoe pressure. In order to prevent sliding the wheels, a special valve was attached to the brake cylinder which automatically reduced the pressure to the normal 60 pounds during the first few seconds of application. Otherwise the equipment (fig. 22) did not differ from the quick action type. When cars fitted with the old model brakes were used in the same train with cars having high speed brakes, a special safety valve had to be added to old brake cylinders in order to keep the pressure within
Fig. 1351—Empty and Load Freight Brake Equipment.

Fig. 1352—Arrangement of High Speed Brake Under Passenger Train Car.

Fig. 1353—Main Reservoir.

Fig. 1354—Arrangement of Train Air Signal on Passenger Train Car.

Fig. 1355—Diagram of Apparatus for High Speed Brake on Passenger Train Car.
Fig. 1369—High Speed Reducing Valve, Service Position.

Fig. 1370—High Speed Reducing Valve, Emergency Position.

Fig. 1371—Vertical Section Through High Speed Reducing Valve, Figs. 1369-1373.

1. Body
2. Spring Box
3. Piston
4. Piston Ring
5. Piston Stem
6. Piston Nut
7. Slide Valve
8. Slide Valve Spring
9. Cap Nut
10. Regulating Spring
11. Regulating Nut
12. Check Nut
13. Union Stud
14. Union Nut
15. Air Strainer
16. Union Gasket
17. Bolt and Nut
18. Piston Seal
19. Piston Disc
20. Spring Abutment
21. Cotter
22. 3/4 in. Street Elbow
23. 3/4 in. Pipe Plug

Westinghouse Air Brake Company.

Fig. 1372—High Speed Reducing Valve, Release Position.

Fig. 1373—Horizontal Section Through High Speed Reducing Valve.
Fig. 11—Type SD Duplex Steam Compressor Governor
Fig. 12—Type SF Duplex Steam Compressor Governor
the proper working amount.

Since only very fast trains used the high speed brakes, the engine equipment was changed so that either the high or low pressure could be employed at will. Two feed valves and two pressure heads on the pump were used to accomplish this and two valves were turned by the engineer in order to make the change.

The modern practice is to use a standard reservoir pressure of either 110 or 120 pounds rather than change from one pressure to another and the duplex governor is used in a much different manner as shown in fig. 25. Two types of duplex governor are used. Both tend to improve the equipment by reducing the strain on the pump rather than by improving the actual operation of the brakes. The governor shown in figure 23 keeps the main reservoir pressure practically equal to the brake pipe pressure as long as the valve handle is in the running position. While the brakes are applied, the low pressure head is automatically cut out by the brake valve and the high pressure head allows the main reservoir to accumulate the high pressure needed for an efficient release of the brakes. The pump is thus working against maximum reservoir pressure only as long as the brakes are applied. The newer type of governor (fig. 24) only in
the substitution of an excess pressure head for the low-pressure head. This head preserves a fixed excess of pressure in the reservoir above that in the brake pipe, no matter what the brake pipe pressure happens to be. This governor thus automatically adjusts itself to the feed valve and never conflicts with it.

**Locomotive Equipment.**

For a long time, due no doubt to the slowness with which the vital factors governing train braking were appreciated, no special attention was devoted to the engine and tender brakes. Sometimes one or two pairs of wheels on the locomotive were braked, the tender was usually disregarded. The advantages to be gained from proper driver brakes are obvious. The weight of the locomotive is so tremendous that brake shoe pressures which would be out of question on a car can be safely used. The engine could easily hold a train on a slight grade and thus add both to economy of operation and safety. The demands of freight service first demonstrated the actual need of powerful driver brakes. Even with the quick action equipment a freight could not slow down safely under the action of the brakes, and then regain its speed once more. Just as soon as the engineer
TRIPLE VALVE WITH DOUBLE CHECK.

Plate A27.
PLATE 35

GENERAL ARRANGEMENT AND METHOD OF PIPING THE NEW YORK COMBINED AUTOMATIC AND STRAIGHT AIR BRAKE.
attempted to release the brakes, the forward cars would release at once, but the cars beyond the 30th, or 40th, would still be braked at full power. This condition inevitably caused the train to part at a coupling. An engine whose brakes could be applied independently of those on the train, could be used to effect any required retardations in speed. Smoother stops were possible also by using the locomotive brakes to bunch the train before applying the car brakes.

The simple and logical method first employed to obtain at least semi-independent control of the engine brakes was use a combined straight air and automatic brake equipment. An old fashioned three way valve was added to the equipment by means of which air from the main reservoirs could be turned into the driver brake cylinders. A triple valve with double check valves prevented the straight and automatic systems from interfering with each other.

The Westinghouse - and New York systems had no way of releasing the engine brakes independently of the train brakes. In the Dukesmith system, this was effected in a manner similar to bleeding a defective brake, i.e., by allowing the air to escape from the auxiliary reservoir. When this is done, the air in
PLATE 28-A.

METHOD OF PIPING THE WESTINGHOUSE COMBINED AUTOMATIC AND STRAIGHT AIR BRAKE.

(For description see following page.)
the brake cylinder raises the slide valve of the triple from its seat and escapes through the exhaust port.

The combined equipment was by no means fool proof. The engineer might by accident or through carelessness fail to return one of the valves to the running position and thus cause imperfect action of the brakes. Moreover, the mess of equipment required was none too easily accommodated.
The E. T. Equipment.

The engine and tender brake equipment which is known under the trade name of the E. T. equipment, is fundamentally merely the combined automatic and straight air system. The functions of several separate parts have been combined in one valve and the auxiliary reservoirs have been discarded altogether. The valve which has been evolved to make the simplified equipment possible is known as the distributing valve and deserves special attention since many of its features have been employed to perfect the new equipment required by the fastest trains.

The E. T. equipment as a whole is praiseworthy because it is applicable to any variety of service; express, slow passenger, freight or switching. A special effort has been made to acquire the maximum economy of maintenance. With this end in view, the pipe connections have been permanently made to brackets so that any of the important parts of the apparatus may be easily removed for repairs or replaced.

As shown in the diagram, two brake valves are required. The operation has been made fool proof, however, by equipping the independent valve with a spring by means of which it is automatically returned to the running position. The flexibility of the outfit is very nearly perfect. By using the independent valve, any pressure of
application, within the necessary limits of course, may be obtained. This pressure is then automatically maintained regardless of brake cylinder leakage or piston travel. Release is likewise perfectly graduated and is quite independent of the state of the train brakes. Release of the engine brakes is also unaffected by the position of the locomotive in the train. Double heading is automatically provided for.

The distributing valve is shown in diagramatic form. Flexibility has been obtained oddly enough by postponing the actual application of the brakes until certain operations have taken place. The engineer's independent valve admits air into the application chamber at any desired pressure. This air has no other purpose than to move the large piston which in turn admits air directly from the main reservoirs to the brake cylinder until the cylinder pressure equals that in the application chamber. In order to make possible an automatic application, the triple valve section admits air from the pressure chamber into the application chamber as soon as the train pipe is exhausted. The triple does merely what the engineer's valve did during the first type of application.

The foregoing principle of indirect application has great possibilities if a uniform and constant cylinder pressure is desired in any number of cylinders.
Fig. 1365—Quick Action Triple Valve, Type P-2.

Parts of Type P-2 Triple Valve, Fig. 1365.

1. Body
2. Slide Valve
3. Main Piston
4. Main Piston Ring
5. Slide Valve Spring
6. Graduating Valve
7. Emergency Piston
8. Emergency Valve Seat
9. Emergency Valve
10. Rubber Seat
11. Check Valve Spring
12. Check Valve Case
13. Check Valve Case Gasket
14. Check Valve Case Gasket
15. Check Valve
16. Strainer

Fig. 1366—Standard Quick Action, Quick Service, Uniform Release, Uniform Recharge Freight Triple Valve, Type K-1.

Parts of Type K-1 Triple Valve, Fig. 1366.

1. Body, Complete
2. Slide Valve
3. Main Piston
4. Main Piston Ring
5. Slide Valve Spring
6. Graduating Valve
7. Emergency Piston
8. Emergency Valve Seat
9. Emergency Valve
10. Rubber Seat
11. Check Valve Spring
12. Check Valve Case
13. Check Valve Case Gasket
14. Check Valve Case Gasket
15. Check Valve
16. Strainer
17. 1 in. Union Nut
18. 1 in. Union Swivel
19. Cylinder Cap
20. Graduating Stem Nut
21. Graduating Stem
22. Spring
23. Cylinder Cap Gasket
24. Cylinder Cap Bolt and Nut
25. Cap Screw
26. 1 in. Union Gasket
27. Emergency Valve Nut
28. Retarding Device Body
29. Retarding Stem
30. Retarding Spring
31. Graduating Valve Spring

Fig. 1367—Passenger Triple Valve, Type L.

Parts of Type L Triple Valve, Fig. 1367.

1. Body
2. Slide Valve
3. Main Piston
4. Main Piston Ring
5. Slide Valve Spring
6. Graduating Valve
7. Emergency Piston
8. Emergency Valve Seat
9. Emergency Valve
10. Rubber Seat for Emergency Valve
11. Check Valve Spring
12. Check Valve Case
13. Check Valve Case Complete
14. Check Valve Case Gasket
15. Check Valve
16. Emergency Valve Nut
17. Graduating Valve Spring
18. Cylinder Cap
19. Graduating Valve Nut
20. Graduating Sleeve
21. Graduating Spring
22. Cylinder Cap Gasket
23. Cylinder Cap Bolt and Nut
24. Check Valve Case Bolt and Nut
25. By-Pass Piston
26. By-Pass Piston Ring
27. By-Pass Valve
28. Rubber Seat
29. Check Valve Case Spring
30. By-Pass Valve Cap
31. By-Pass Piston Cap
32. Strainer
33. B-7 Safety Valve
34. End Cap

Westinghouse Air Brake Company.
Modern Freight Equipment

The problems of freight service differ so widely at the present time from those of fast passenger traffic that entirely different standards of equipment are employed on each. The type K triple valve shown in fig. 33 retains the main features of the old quick action triple with the additional features of a quick action service application without obtaining the high emergency pressure, uniform release of all brakes, and uniform recharge of all auxiliaries.

The quick action service is obtained by providing a small passage from the quick action chamber to some point below the slide valve as soon as the valve moves slightly; this part is uncovered allowing a small quantity of air to escape into the brake cylinder thus reducing the brake pipe pressure locally on each car.

Uniform release and recharge are both obtained by means of the same valve, which is shown in the part which leads to the brake cylinder. Any excess of pressure such as occurs near the head of the train during release forces the triple valve piston against this valve and partially prevents the escape of air from the cylinder. At the same time the entrance to the reservoir is partly obstructed, thus avoiding overcharging.
20

Passenger Equipment

Until the electro-pneumatic equipment was introduced, all the improvements in the apparatus were secured by adding various parts to the quick action triple. These efforts culminated in the type L equipment. Increased safety is perhaps the most noteworthy feature of this valve since a remarkable number of service applications may be rapidly made without seriously depleting the supply of air or preventing the making of an effective emergency application.

This valve is illustrated in fig.33. More than a single view would be needed however to show the relationship between the working parts. The principle of operation is nevertheless quite simple. Two auxiliary reservoirs are employed and are charged simultaneously when the brake valve is in the running position. During a service application, air is drawn from only one. Release is then effected by closing the port to the brake cylinder and allowing the pressure to equalize between the two reservoirs. If a supplementary reservoir of large capacity is employed, the auxiliary reservoir can be recharged almost instantaneously to very nearly its original pressure. The complete recharge is accomplished very quickly by admitting train pipe air to the reservoirs through small ports leading from the quick action chamber. The supplementary reservoir makes possible a graduated release of the brakes after a service application. When only a small amount of air is admitted to the train pipe, the triple moves to the release position whereupon air from the supplementary reservoir is admitted to the slide valve chamber. As
Fig. 1359—Piping Diagram of Westinghouse Universal Common Standard Electro-Pneumatic Brake Equipment, Schedule UCE, Complete for Engine, Tender and Car.

Parts of Triple Valve, Fig. 1360.

2 Body
3 Slide Valve
4 Main Piston
5 Main Piston Ring
6 Main Slide Valve Spring
7 Graduating Valve
8 Emergency Piston
9 Emergency Valve Seat
10 Emergency Valve
11 Rubber Seat
12 Check Valve Spring
13 Check Valve Case
14 Check Valve Case Gasket
15 Check Valve
16 Strainer
17 Union Gasket
18 Union Nut
19 Cylinder Cap
20 Graduating Nut
21 Graduating Sleeve
22 Graduating Spring
23 Cylinder Cap Gasket
24 Tee Head Bolt and Nut
25 Hexagon Head Bolt and Nut for Check Valve Case
26 Union Gasket
27 Emergency Valve Nut
28 Cap
29 Stop
30 Spring
31 Graduating Valve Spring
32 Take-up Reservoir Check Valve
33 Take-up Reservoir Check Valve Cap Nut
soon as enough air has been admitted to build up a pressure exceeding that in the train pipe, the triple moves far enough toward the application position to stop the escape of air from the brake cylinder but not far enough to re-admit any air. The release can thus be accomplished in as many stages as desired. The quick action service application mentioned in connection with the type K freight brake is accomplished in a similar way with this valve.

The emergency application is very powerful. Air from both reservoirs simultaneously is turned into the brake cylinder and the high pressure held until reduced by the engineer. During service applications, the brake cylinder is connected through the triple valve with a large capacity safety valve which acts like a high speed reducing valve and prevents wheel sliding in case too large a pressure should be employed at moderate speeds. During the emergency application, however, the port leading to the safety valve is closed.

The type L triple possessed nearly all the features which could reasonably be expected of an efficient braking apparatus, including flexibility, quick action, high emergency pressure, and undiminished braking power after a rapid series of service applications. A further advantage was that the high emergency pressure was obtained without any increase in train pipe pressure.
Comparative train stops, control valve and high-speed brake equipments.

Graphical Results of Absecon Tests - P.R.R.
Although the type L equipment produced very satisfactory results as far as the operation of the brakes was concerned, the increase in weight and speed of certain trains made more powerful brakes a necessity. The 18" brake cylinder which had been in use for some little time was from a mechanical point of view the largest size practicable. The multiplying effect of the levers could not be increased without increasing piston travel and thus losing the high brake pressure which is wanted. Increased train pipe pressure is also impracticable on account of the increased difficulty of maintenance which would ensue.

The problem finally resolves itself into two possibilities: either to use two complete sets of apparatus on each car or devise a valve which would satisfactorily control two or more brake cylinders. The distributing valve such as used with the E.T. equipment supplied air to three or four cylinders and kept the pressure constant regardless of leakage or piston travel. This valve in a somewhat modified form is the basis of the new passenger equipment such as the PC, the UC and the electro-pneumatic equipment [fig. 26].

In spite of its apparent complexity the electro-pneumatic brake has given reliable and satisfactory service on the New York subway for a number of years, and during a series of tests conducted by the Pennsylvania R.R. in 1913 demonstrated its superiority over any type of brake equipment which existed at that time. Any necessary future expansion is also provided for
Fig. 1361—Universal Valve, Type UE-12.

List of Parts of Universal Valve, Fig. 1361.

Equalizing Portion.

2 Equalizing Body
3 Equalizing Slide Valve
4 Equalizing Piston
5 Equalizing Piston Ring
6 Equalizing Slide Valve Spring
7 Equalizing Graduating Valve Spring
8 Graduating Valve Spring
9 Equalizing Cylinder Cap
10 Set-in Ball Check
11 Check Valve Cap Nut
12 Cylinder Cap Gasket
13 Square Head Cap Screw
14 Release Piston
15 Release Piston Ring
16 Release Piston Spring
17 Release Piston Cover
18 Application Piston Cover
19 Application Piston Cover Gasket
20 Square Head Cap Screw
21 Release Piston Cover
22 Release Piston Cover Gasket
23 Square Head Cap Screw
24 Release Piston Bush
25 Charging Valve Body
26 Graduated Release Plate
27 Graduated Release Plate Ring
28 Meshing Nut
29 Charging Valve
30 Charging Valve Piston Ring
31 Charging Valve Piston Ring
32 Charging Valve Spring

Quick Action Portion With High Pressure Cap Having Protection Valve and Safety Valve.

38 Charging Valve Cover Gasket
39 Square Head Cap Screw
40 Charging Valve Body Gasket
41 Square Head Cap Screw
42 Gasket (between Equalizing Portion and Pipe Bracket)
43 Square Head Cap Screw
44 Graduating Spring
45 Graduating Nut
46 Graduating Valve
47 Safety Valve
48 Jacket
49 Jacket Ring
50 Jacket Nut
51 Pressure Nut
52 Stop Nut
53 Spring
54 Valve Cap Nut
55 Valve Seat Nut
56 Valve Stem Nut
57 Valve Stem
58 Valve Spring
59 Valve Spring Nut
60 Valve Spring Washer
61 Valve Spring Washer Nut
62 Valve Spring Washer Nut
63 Valve Spring Washer Nut
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90 Valve Spring Washer Nut
91 Valve Spring Washer Nut
92 Valve Spring Washer Nut
93 Valve Spring Washer Nut
94 Valve Spring Washer Nut
95 Valve Spring Washer Nut
96 Valve Spring Washer Nut

98 Gasket (between Quick Action Portion and Pipe Bracket)
99 1/8-in. Ball Check
100 Ball Check Cap Nut
101 Spring to Hold Quick Action Piston against Quick Action Valve Stem

High Pressure Cap having Protection Valve and Safety Valve Cap

110 High Pressure Cap Body
111 Protection Valve Body
112 Protection Valve Seat
113 Protection Valve Nut
114 Cotter
115 Protection Valve Spring
116 Protection Valve Cap Nut
117 Intercepting Valve
118 Intercepting Valve Seat
119 Intercepting Valve Nut
120 Cotter
121 Intercepting Valve Spring
122 Intercepting Valve Cap Nut
123 High Pressure Valve
124 Piston Ring
125 High Pressure Valve Seat
126 High Pressure Valve Seat Nut
127 Cotter
128 High Pressure Valve Spring
129 Safety Valve Bracket Gasket
130 Cap Screws
131 Protection Valve Seat
132 Protection Valve Washer
133 Protection Valve Seat Nut
134 Emergency Piston Stop Nut
135 Emergency Piston Stop Ring
136 Emergency Piston Stop Spring
137 Safety Valve Bracket Body
138 Nut
139 Nut
140 Nut
141 Nut

Westinghouse Air Brake Company.
in a satisfactory manner. On a train of 12 modern passenger cars the quick action equipment required 8 seconds to attain its maximum braking power, the UC equipment required 3.5 seconds operating pneumatically and 2.25 seconds when controlled electrically. The tests further showed that shocks are due only to the non-uniform application of the brakes on different cars and never to the action of the brakes themselves. A stop was made from a speed of ten miles per hour in 42 feet with the equipment operated pneumatically and very severe shocks were felt. Operated electrically, the same train was stopped in 37 feet without a shock of any sort.

Conclusion

The development of the air brake has been traced through its five different steps, and the corresponding demands made upon it have been hinted at. The complexity of the modern equipment is convincing evidence of the struggle which has been made to maintain a constant standard of safety at any cost. It must be apparent therefore, that only men with special training could be competent to keep such a mechanism in working order. At present the demands upon our railroads are so great that no diminution of the requirements of the service is to be expected. On the contrary, electric locomotives are now in use which can cause the trains to accelerate at almost unbelievable rates, and so the braking requirements are apt to increase accordingly. Every phase of the subject needs thorough investigation unless safety is to be sacrificed.

The clasp brake is at present being investigated, since single brake shoes now exert a pressure on the journals of the car, which is much
greater than that due to the entire weight of the car.

The design of the brake shoe is of great importance when the amount of energy absorbed by the shoe is considered.

The theoretically perfect stop has not yet been attained, possibly a type of brake which will adjust itself more or less automatically to the condition of the rails or the degree of load may be one of the needed future developments.