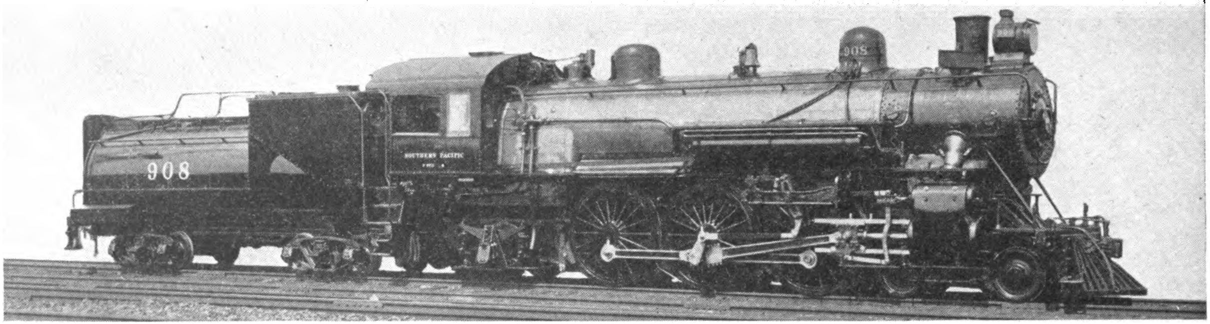
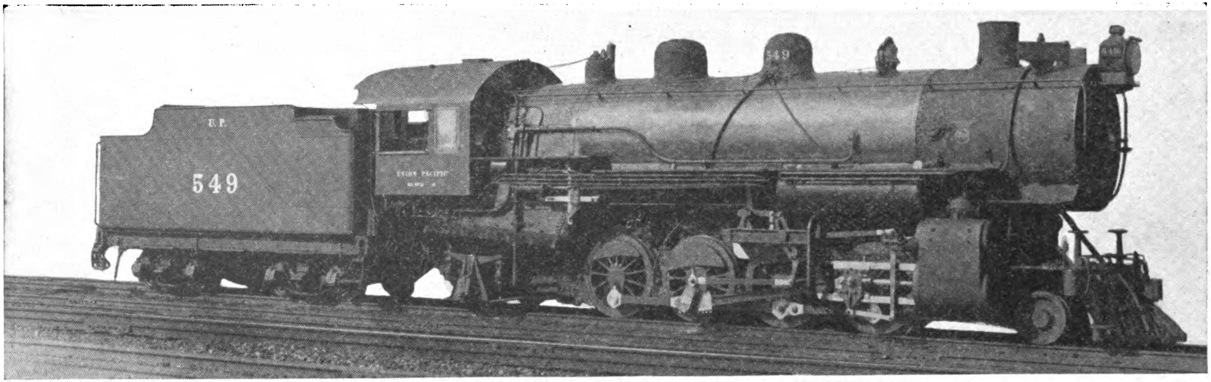


PACIFIC TYPE OIL-BURNING ENGINE EQUIPPED WITH SCHMIDT SUPERHEATER AND WALSCHAERT VALVE GEAR
Courtesy of The Baldwin Locomotive Works, Philadelphia, Pennsylvania



MIKADO TYPE LOCOMOTIVE BUILT FOR UNION PACIFIC RAILROAD COMPANY
Courtesy of The Baldwin Locomotive Works, Philadelphia, Pennsylvania

Cyclopedia

of

Engineering

A General Reference Work on

STEAM BOILERS AND PUMPS; STEAM, STATIONARY, LOCOMOTIVE, AND MARINE ENGINES; STEAM TURBINES; GAS AND OIL ENGINES; GAS-PRODUCERS; COMPRESSED AIR; REFRIGERATION; ELEVATORS; HEATING AND VENTILATION; MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY; POWER STATIONS; ETC.

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CONSULTING ENGINEERS, TECHNICAL EXPERTS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Two Thousand Engravings

SEVEN VOLUMES

AMERICAN TECHNICAL SOCIETY
CHICAGO
1919

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Grateful acknowledgment is made here also for the invaluable co-operation of the foremost engineering firms in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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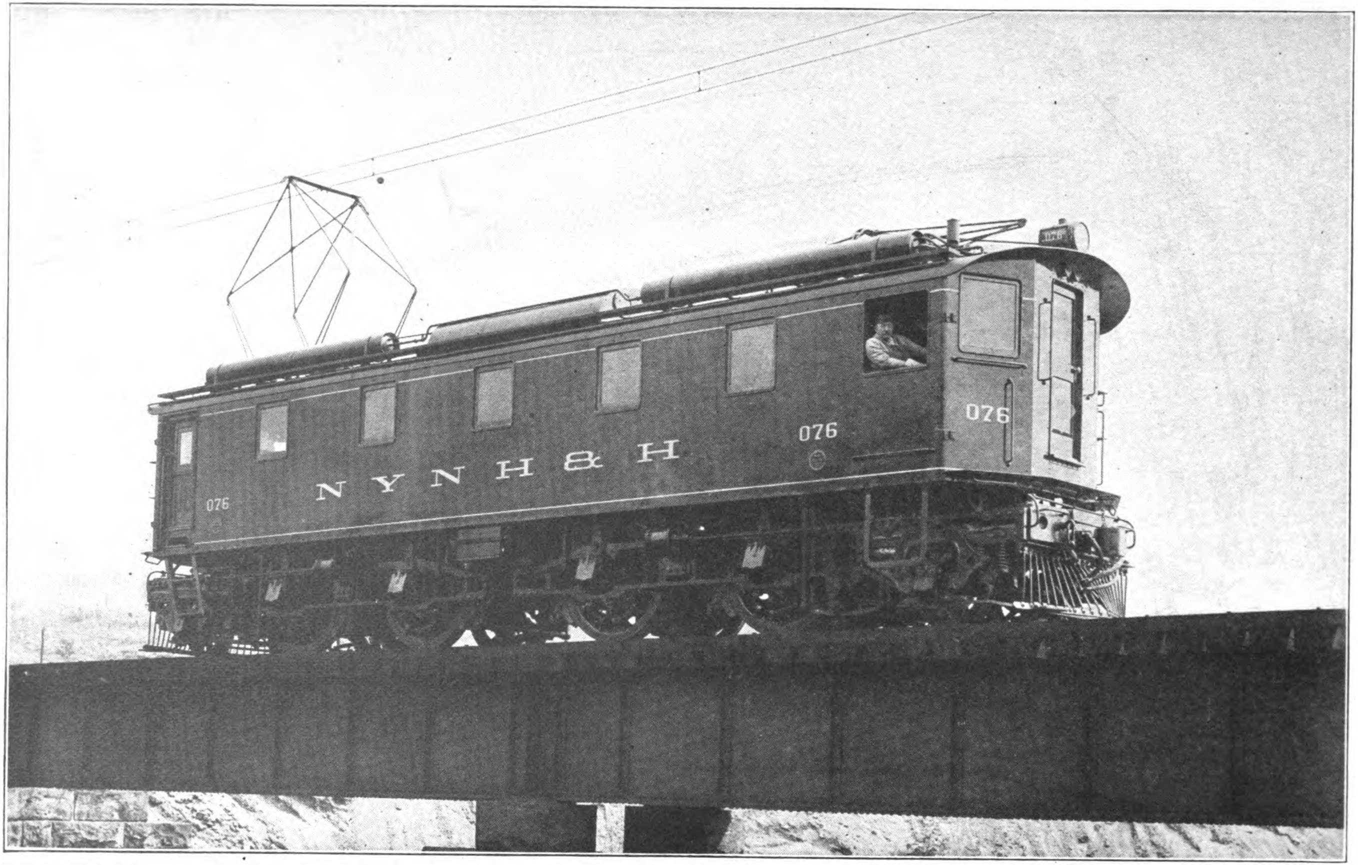

ELECTRIC PASSENGER LOCOMOTIVE IN USE ON NEW YORK, NEW HAVEN, AND HARTFORD ROADS
Courtesy of Westinghouse Electric and Manufacturing Company

Foreword

THE "prime mover", whether it be a massive, majestic Corliss, a rapidly rotating steam turbine, or an iron "greyhound" drawing the Limited, is a work of mechanical art which commands the admiration of everyone. And yet, the complicated mechanisms are so efficiently designed and everything works so noiselessly, that we lose sight of the wonderful theoretical and mechanical development which was necessary to bring these machines to their present state of perfection. Notwithstanding the genius of Watt, which was so great that his basic conception of the steam engine and many of his inventions in connection with it exist today practically as he gave them to the world over a hundred years ago, yet the mechanics of his time could not build engine cylinders nearer true than three-eighths of an inch — the error in the modern engine cylinders must not be greater than two-thousandths of an inch.

¶ But the developments did not stop with Watt. The little refinements brought about by the careful study of the theory of the heat engine; the reduction in heat losses; the use of superheated steam; the idea of compound expansion; the development of the Stephenson and Walschaert valve gears — all have contributed toward making the steam engine almost mechanically perfect and as efficient as is inherently possible.

¶ The development of the steam turbine within recent years has opened up a new field of engineering, and the adoption of this form of prime mover in so many stationary plants like the immense Fisk Station of the Commonwealth Edison Company, as well as its use on the gigantic ocean liners like the Lusitania, makes this angle of steam engineering of especial interest.

¶ Adding to this the wonderful advance in the gas engine field — not only in the automobile type where requirements of lightness, speed, and reliability under trying conditions have developed a most perfect mechanism, but in the stationary type which has so many fields of application in competition with its steam-driven brother as well as in fields where the latter can not be of service — you have a brief survey of the almost unprecedented development in this most fascinating branch of Engineering.

¶ This story has been developed in these volumes from the historical standpoint and along sound theoretical and practical lines. It is absorbingly interesting and instructive to the stationary engineer and also to all who wish to follow modern engineering development. The formulas of higher mathematics have been avoided as far as possible, and every care has been exercised to elucidate the text by abundant and appropriate illustrations.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical, yet easily comprehendible by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the publishers will feel that its mission has been accomplished.

¶ Grateful acknowledgment is due the corps of authors and collaborators — engineers and designers of wide practical experience, and teachers of well-recognized ability — without whose co-operation this work would have been impossible.

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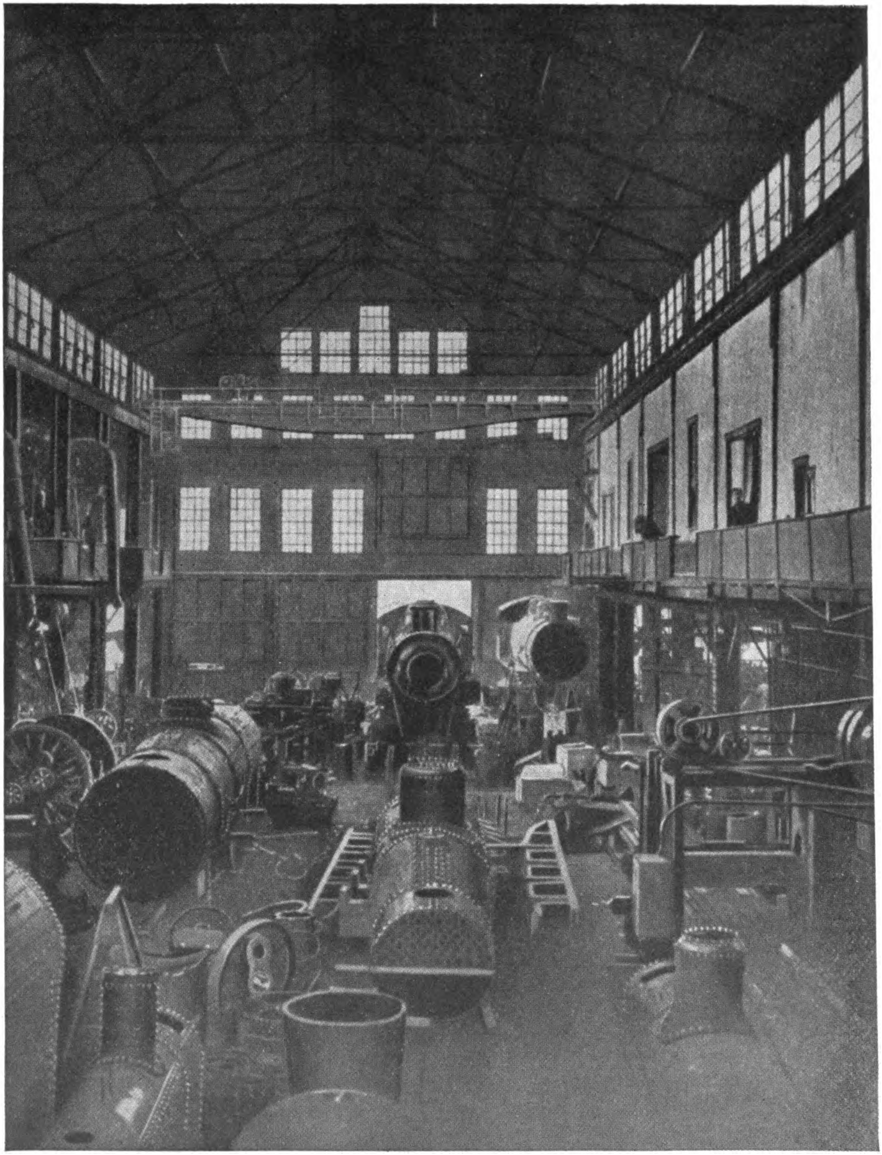
† For professional standing of authors, see list of Authors and Collaborators at front of volume.



ROD LOCOMOTIVE ERECTING ROOM
Courtesy of Lima Locomotive Corporation, Lima, Ohio

LOCOMOTIVE BOILERS AND ENGINES

PART I

HISTORICAL DEVELOPMENT OF THE LOCOMOTIVE

The first locomotive engine designed to run upon rails was constructed in 1803, under the direction of Richard Trevithick, a Cornish mine captain in South Wales. Though crudely and peculiarly made, it possessed all of the characteristics of the modern locomotive with the exception of the multi-tubular boiler. The locomotive had a return-flue boiler 60 inches long, and two pairs of driving wheels—each 52 inches in diameter. The power was furnished by

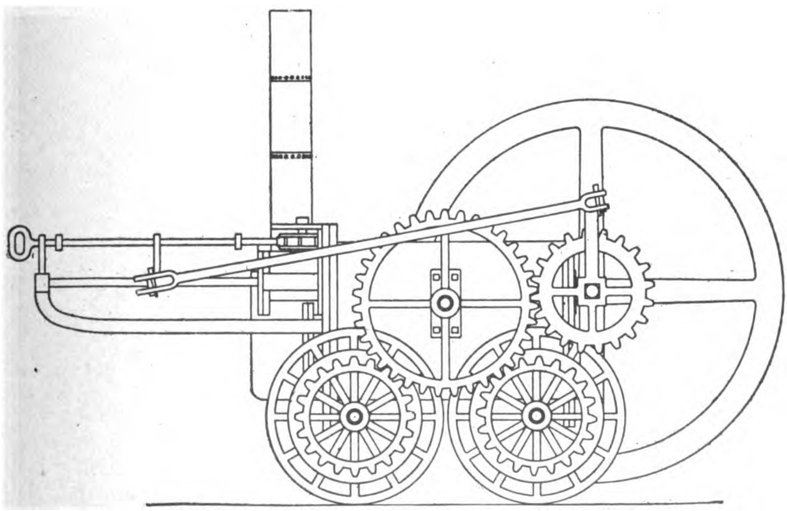


Fig. 1. Trevithick's Locomotive.

one cylinder, 54 inches long and 8 inches in diameter. The exhaust steam from the cylinder was conducted to the smoke-stack where it aided in creating a draft on the fire. This engine, shown in Fig. 1, made several trips of nine miles each, running about five miles per hour and carrying about two tons. Although the machine was a commercial failure, yet from a mechanical standpoint, it was a great success.

After the development of the Trevithick locomotive, numerous experiments were tried out and many engineers were working on a new design. As a consequence, many very crude but interesting locomotives were developed. The principal objection raised against the most of them was in reference to the complicated parts of the mechanism. Having had no previous experience to direct them, they failed to see that the fewer and simpler the parts of the machine, the better. It was not until about 1828, when the *Rocket*, as shown in Fig. 2, was built under the supervision of Robert Stephenson, that anything of note was accomplished. The Rocket, in a competition speed test, without carrying any load, ran at the rate of $29\frac{1}{2}$ miles per hour. With a car carrying thirty passengers, it attained a speed of 28 miles per hour. The construction of the Rocket was a step in the right direction, since it contained fewer and simpler parts. It had an appearance similar to the modern locomotive, having a multi-tubular boiler, induced draft by means of the exhaust steam, and a

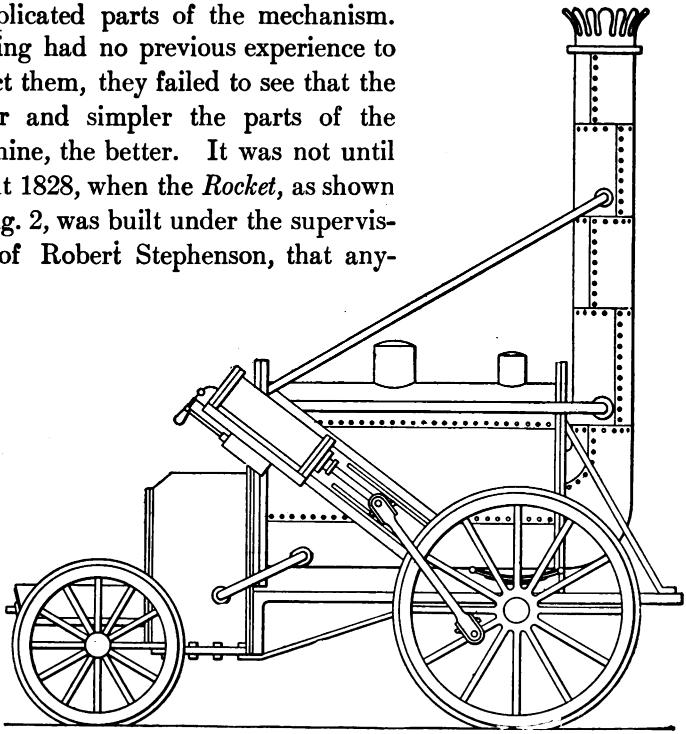


Fig. 2. The Rocket.

direct connection between the piston rod and the crank pin secured to the driving wheel. The cylinder was inclined and the proportions were very peculiar as compared with the modern locomotive, yet much had been gained by this advancement.

While these things were being accomplished in England, the fact must be noted that agitation in favor of railroad building in America was being carried on with zeal and success. Much of the machinery for operating the American railroads was being designed and built by American engineers, so it is quite generally believed that railroad and locomotive building in America would not have been very much delayed had there never been a Watt or a Stephenson.

The first railroad opened to general traffic was the Baltimore & Ohio, which was chartered in 1827, a portion being opened for business in 1830. About the same time, the South Carolina Road was built. The board of directors of this road were concerned with what kind of power to use, namely, horse-power or steam engines. After much deliberation, it was finally decided to use a steam-propelled locomotive.

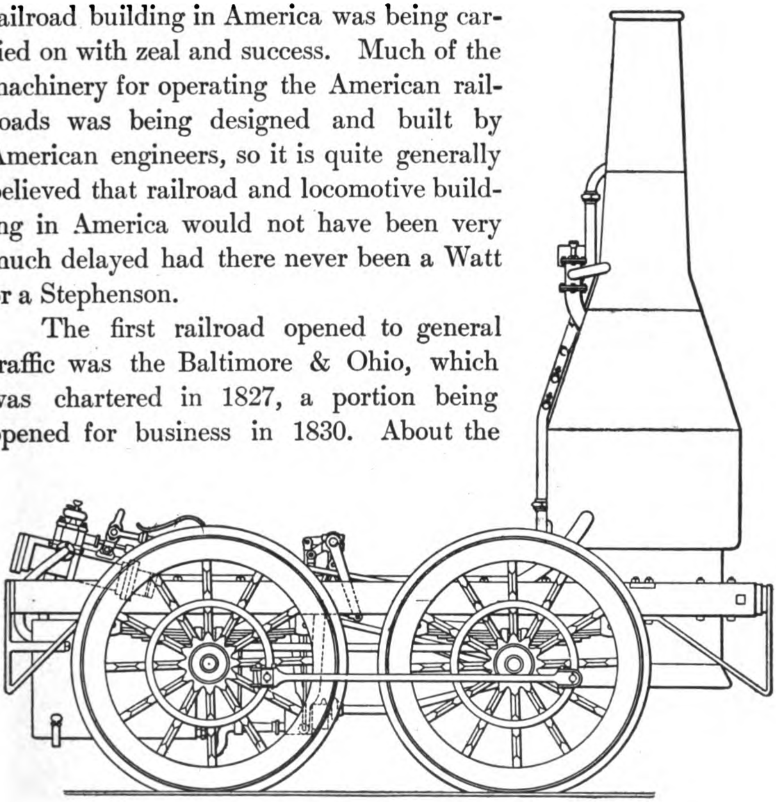


Fig. 3. The Best Friend of Charleston.

The history of this period is interesting. The first steam locomotive built in America was the *Best Friend of Charleston,* illustrated in Fig. 3. One year previous to the building of this locomotive, an

English locomotive called *Stourbridge Lion* was imported by the Delaware-Hudson Canal Co. It was tried near Homesdale. A celebrated American engineer by the name of Horatio Allen, made a number of trial trips on this locomotive and pronounced it too heavy for the American roadbeds and bridges; so it was that the Best Friend of Charleston, an American locomotive constructed in 1830, gave the first successful service in America. The Best Friend of

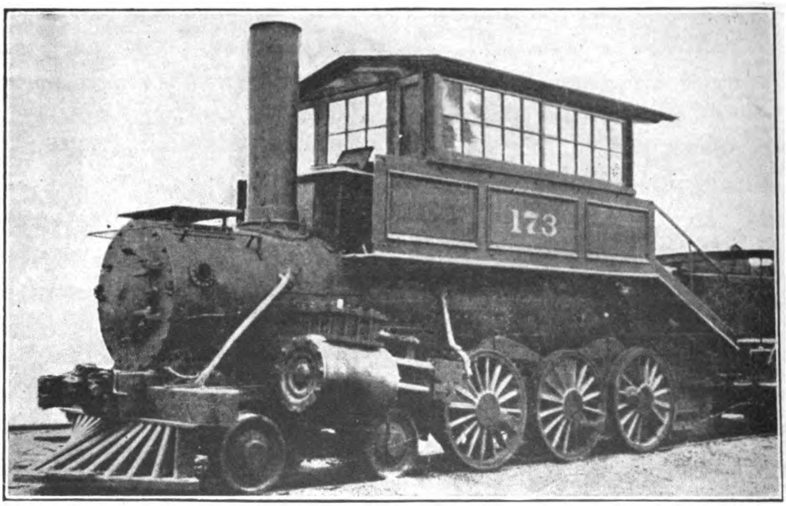


Fig. 4a. Hayes 10-Wheeler.

Charleston was a four-wheeled engine having two inclined cylinders. The wheels were constructed of iron hubs with wooden spokes and wooden fellows, having iron tires shrunk on in the usual way. A vertical boiler was employed and rested upon an extension of the frame which was placed between the four wheels. The cylinders, two in number, were each 6 inches in diameter and had a common stroke of 16 inches. The wheels were $4\frac{1}{2}$ feet in diameter. The total weight of the locomotive was about 10,000 pounds. Assuming power by present methods, it would develop about 12 horse-power while running at a speed of 20 miles per hour and using a steam pressure of 50 pounds.

The Baltimore & Ohio Railroad was the leader for a number of years in the development of the locomotive. Among the earlier designs brought out by this road was an 8-wheeled engine known as the *Camel-Back,* so-called from its appearance, and frequently spoken of as the *Winans,* as its design was developed in 1844 by Ross Winans, a prominent locomotive builder of a half century ago.

The illustration shown in Fig. 4*a* represents the *Hayes 10-Wheeler* with side rods removed, which was built after designs prepared in 1853 by Samuel J. Hayes of the B. & O. Fig. 4*b* is from an original drawing of one of the earlier types of the same engine and shows

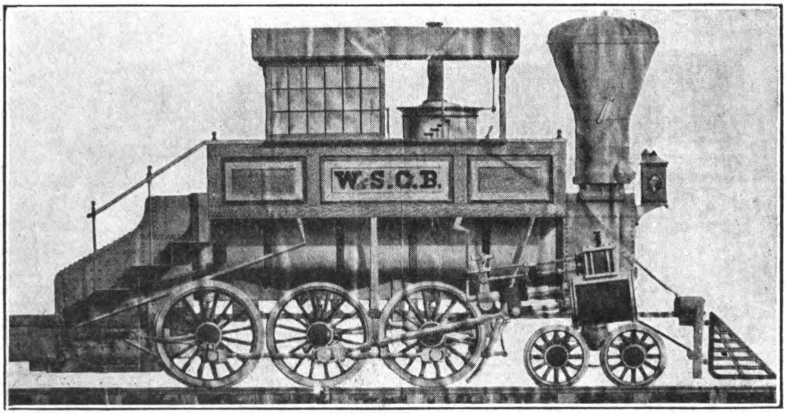


Fig. 4*b*. Hayes 10-Wheeler.

more of the details of construction. This locomotive is oftentimes improperly called the *Camel-Back* or *Winans* engine because of its close resemblance to the Winans. The name *Camel-Back,* as given to the Winans engine and also to the Hayes 10-Wheeler, was given on account of the peculiar appearance of the locomotive, which, in fact, did resemble a camel's humped back. This appearance was due to the fact that a large cab was placed on the central portion of the boiler, and also to the rapidly receding back end of the boiler. The weight of the Hayes 10-Wheeler is 77,100 pounds, of which 56,500 pounds are on the drivers and 20,060 pounds are on the front truck. The diameter of the front truck wheels is 28 inches and that of the drivers, 50 inches. The fire-box is $42\frac{1}{4}$ inches long and $59\frac{1}{4}$ inches wide. The boiler has a total heating surface of 1,176.91 square feet, 1,098 square feet of this amount being in the flues. There are 134 tubes $2\frac{1}{4}$ inches in diameter and 13 feet 11 inches long.

The Boston & Providence Railroad built several locomotives during the time the Winans locomotive was being developed. One of these, the *Daniel Nason,* illustrated in Fig. 5, was built in 1858. The Daniel Nason weighs 52,650 pounds, has 16 by 20 inch cylinders, 54-inch driving wheels, and 30-inch truck wheels. Steam pumps were used in feeding the boiler instead of the injectors. The top members of the frame are built up of rectangular sections, while for the bottom members, 4-inch tubes are used.

The prevailing thought in the early development of the locomotive was, that sufficient power could not be secured by depending upon the adhesion of the drivers to the rail; as a consequence many cog locomotives were developed and used. This was true on the old

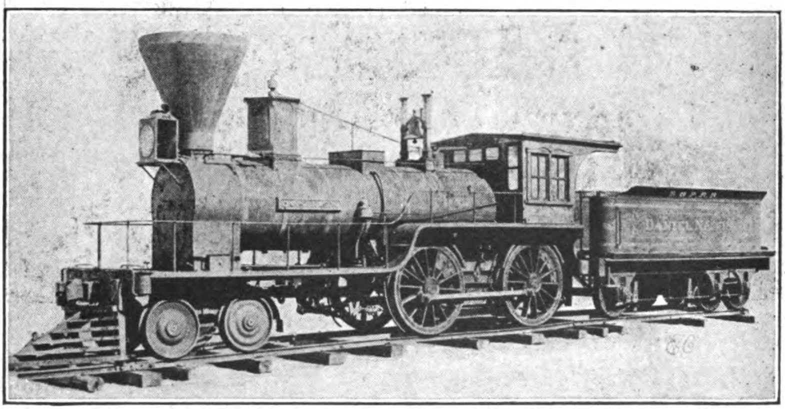


Fig. 5. The Daniel Nason.

Jeffersonville, Madison & Indianpaolis Railroad at Madison, Indiana. A portion of the road at that point included a six per cent grade three miles long. From the opening of the road in 1848 until 1858, the grade was operated by cog locomotives. On the last-named date, there appeared a locomotive named the *Reuben Wells* which was destined to have both a very interesting and successful career.

The Reuben Wells, illustrated in Fig. 6, was designed by Mr. Reuben Wells, then a master mechanic of the road. It was built in the company's shops at Jeffersonville, Indiana, in July, 1858. The Reuben Wells has cylinders 20 × 24 inches, and five pairs of drivers each 49 inches in diameter, all being coupled. No front truck is used. The boiler is 56 inches in diameter and contains

201 two-inch flues 12 feet 2 inches in length. It has a heating surface in the fire-box of 116 square feet while that in the tubes is 1,262 square feet. It is what is commonly known as a *tank locomotive*

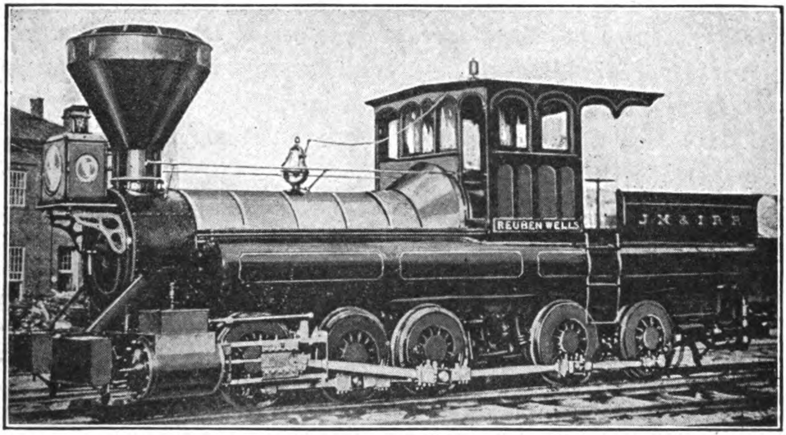


Fig. 6. The Reuben Wells.

since it carries the water and fuel upon the frame and wheels of the engine proper instead of upon a separate part, the tender. The total weight with fuel and water is 112,000 pounds. The tractive effort under a steam pressure of 100 pounds per square inch is

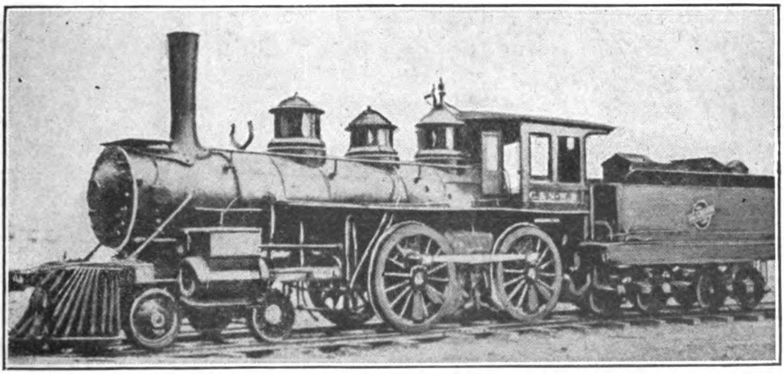


Fig. 7. American Type.

about 21,818 pounds on a level road. After having been in service for a number of years, it was rebuilt with four instead of five pair of drivers and was shortened by the cutting off of a section at the rear which had been used for coal and water. Sufficient water capacity was provided by placing a tank over the boiler.

The American type locomotive, illustrated in Fig. 7, is typical of the small sized engines of this construction which are now being rapidly replaced by other types. For a period of nearly fifty years, ending about 1895, the American type locomotive was more commonly used for passenger service than any other type.

A comparison of things with reference to size, weight, and color impresses their relative characteristics upon the mind. For this reason, the illustrations of the *Tornado* and the *Mallet* compound locomotives are given in Fig. 8 and Fig. 9, respectively, the former

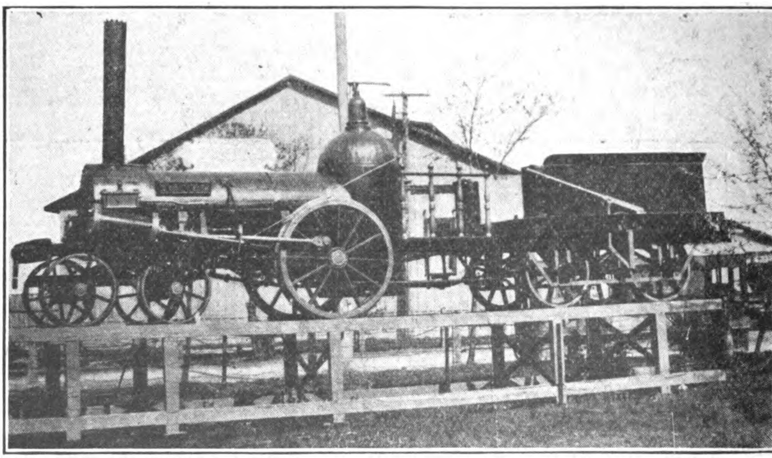


Fig. 8. The Tornado.

being an early development, and the latter the most recent heavy freight locomotive.

The Tornado was the second locomotive owned by one of the parent lines forming a part of the Seaboard Air Line Railroad. This locomotive was imported from England and put into service in March, 1840. It has two inclined cylinders 9 inches in diameter with a common stroke of 20 inches and a single pair of drivers 54 inches in diameter. The fire-box stands upright and is cylindrical in form, while the boiler proper is horizontal and but 34 inches in diameter. The steam is admitted to an exhaust from the cylinders by plain slide valves controlled by the *Hook* motion.

The Mallet compound locomotive marks one of the most successful attempts of the locomotive designer and builder. It surpasses anything thus far built in size and combination of new ideas in design. The one shown in the illustration was built for the Erie Railroad for heavy pushing service. It has a boiler diameter of 84 inches and carries a steam pressure of 215 pounds per square inch. The boiler contains 404 two and one-fourth inch flues 21 feet long. Its high-pressure and low-pressure cylinders are 25 and 39 inches in diameter, respectively, having a common stroke of 28 inches. The drivers, sixteen in number, are each 64 inches in diameter. The total weight on the drivers is 410,000 pounds. The boiler has a total heating surface of 5313.7 square feet, 4971.5 of this number being in the tubes and 342.2 in the fire-box. The fire-box is 126 inches long and 114 inches wide, giving 100 square feet of grate area. Its maximum tractive effort is 94,800 pounds.

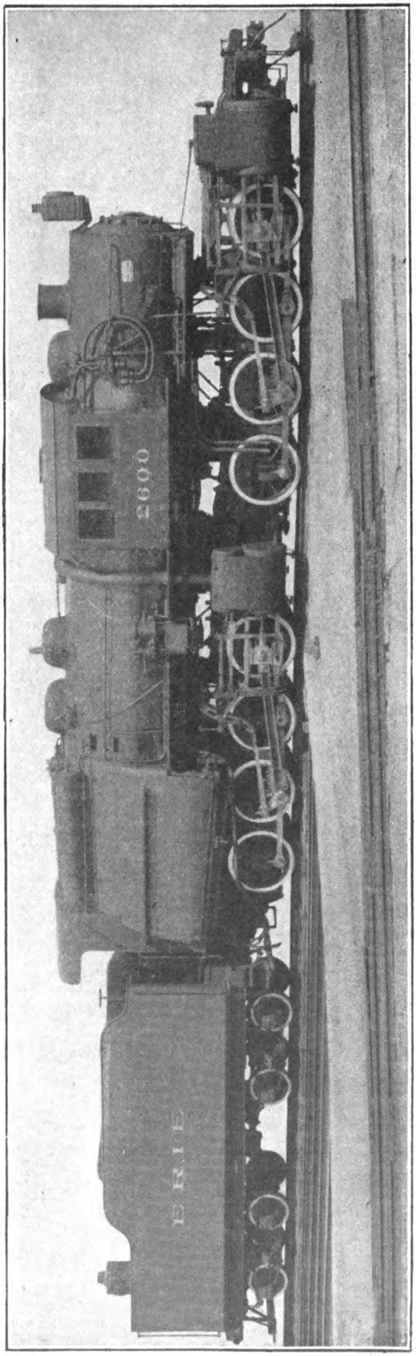


Fig. 9. Mallet Compound Locomotive.

It is of much interest to compare in a general way the developments of the locomotive in England and in America. The types differ in many respects, as shown in Table I.

TABLE I
***Comparison of English and American Locomotives**

Parts	English	American
Frames	Plate	Bar
Cylinders	Inside	Outside
Drivers	Not equalized	Equalized
Driver Centers	Wrought iron	Cast iron or steel
Fire-box	Copper	Steel
Tubes	Brass	Iron
Cab	Small	Large
Pilot	No	Yes
Reverse gear	Screw	Lever
Boiler	Small and low	Large and high

CLASSIFICATION OF LOCOMOTIVES

In order that a clear understanding may be had of the various types of locomotives, a classification is given according to wheel arrangement. In the Whyte system of classification, which is quite largely used, each set of trucks and driving wheels is grouped by number beginning at the pilot or front end of the engine. Thus, 260 means a Mogul, and 460, a 10-wheel engine. The first figure, 2, in 260 denotes that a 2-wheeled truck is used in front; the figure 6, that there are six coupled divers, three on each side; and the 0, that no trailing truck is used. This scheme gives both a convenient and easy method of classifying locomotives.

In Table II is given the classification of the locomotives used on American railroads.

The method may be further extended to include the weights of locomotives. The total weight is expressed in units of 1,000 pounds. Thus: A Pacific locomotive weighing 189,000 pounds would be classified as Type 462—189. If the locomotive is a compound, a letter C would be used instead of the dash. Thus: Type 462–C–189. If tanks are used instead of a separate tender, the letter T would be substituted for the dash. Thus: A tank locomotive having four driving wheels, a 4-wheel leading truck, and a 4-wheel rear truck, weighing 114,000 pounds would be classified as Type 444–T–114.

***The comparisons are not strictly true for every case but represent the conditions usually found.**

TABLE II

Classification of Locomotives

[WHYTE'S SYSTEM]

040	4 Wheel
060	6 Wheel
080	8 Wheel
0440	Articulated
0660	Articulated
240	4 Coupled
260	Mogul
280	Consolidation
2440	Articulated
2100	Decapod
440	8 Wheel
460	10 "
480	12 "
042	4 Coupled and Trailing
062	6 " " "
082	8 " " "
044	Forney 4 Coupled
064	" 6 "
046	" 4 "
066	" 6 "
242	Columbia
262	Prairie
282	8 Coupled
2102	10 "
244	4 "
264	6 "
284	8 "
246	4 "
266	6 "
442	Atlantic
462	Pacific
444	4 Coupled Double Ender
464	6 " " "
446	4 " " "

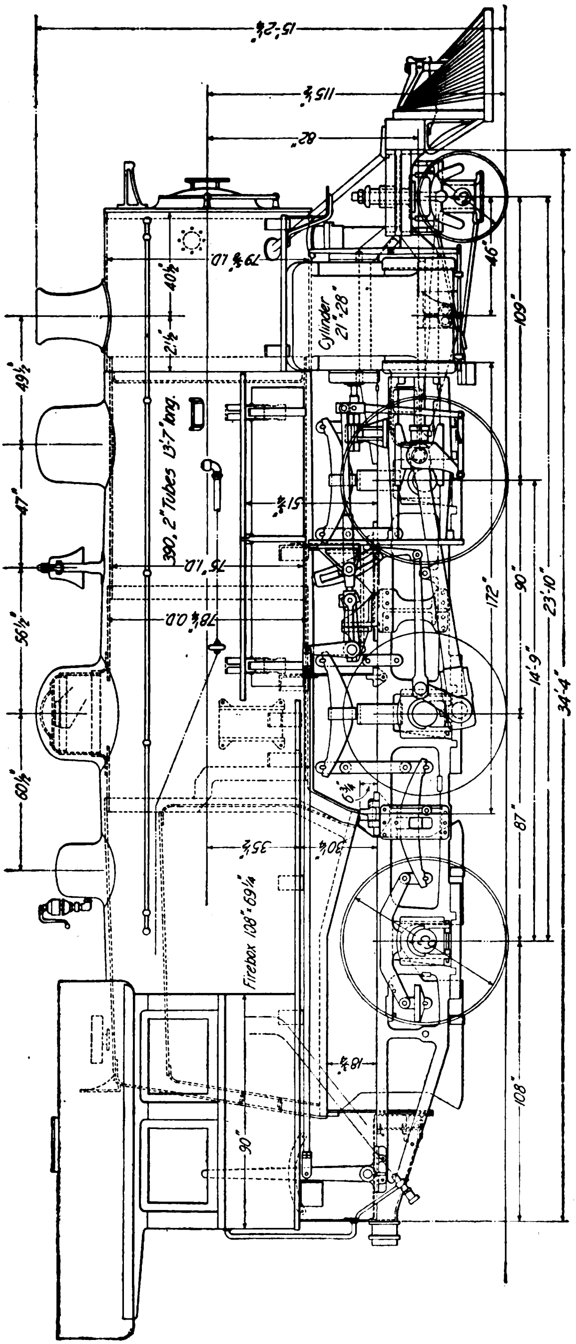


Fig 10. Modern 260, or Mogul Type of Locomotive.

From the classification table given, it is apparent that there are a great many different types of locomotives in service. Only the more commonly used types will be discussed, which are as follows: 040, 060, 080, 260, 280, 440, 442, 460, and 462. The types 040, 060, and 080 are largely used for switching service. The 040 type is of the smallest proportions and weights, being found in small yards where only light work is required. The call for heavy duty was met by the 060 type. The fact that the 060 type, being much heavier, has a greater tractive effort and a correspondingly larger steaming capacity, has caused them to be used very extensively. The following figures will aid in giving an idea of their size and capacity:

Weight on drivers (pounds)	145,000 to 170,000
Diameter of cylinders (inches)	19 to 22
Stroke of piston (inches)	24 to 26
Diameter of driving wheels (inches)	50 to 56
Working steam pressure (pounds per square inch)	180 to 200

The demand for power, steadily increasing beyond that which could be secured by locomotives of the 060 type, created a new design known as the 8-wheel, or 080 type. This type is used in switching and pushing service and has about 171,000 pounds weight on drivers, cylinders 21 inches in diameter, stroke 28 inches, drivers 51 inches in diameter, and carries 175 to 200 pounds steam pressure. The switching engines of the 060 and 080 type were converted into high-class freight engines by adding two wheel trucks to each, thus developing the 260, or Mogul, and the 280, or Consolidation types.

The Mogul was primarily intended for freight service only, but it is sometimes used in heavy passenger service. The object of the design was to obtain greater tractive force on driving wheels than is possible to obtain with four drivers, as in the 440 type. Fig. 10 illustrates a modern 260, or Mogul type, giving its principal dimensions. This type was more generally used than any other before the increasing requirements of heavy freight service resulted in the development of the 280, or Consolidation type. It is profitable from the standpoint of economy in repairs in selecting the type of locomotive for any service, to use the minimum number of drive wheels possible within the limits of the necessary tractive power, although for freight service involving the handling of heavy trains on steep grades, the 280, or Consolidation type, is required. Where the requirements are

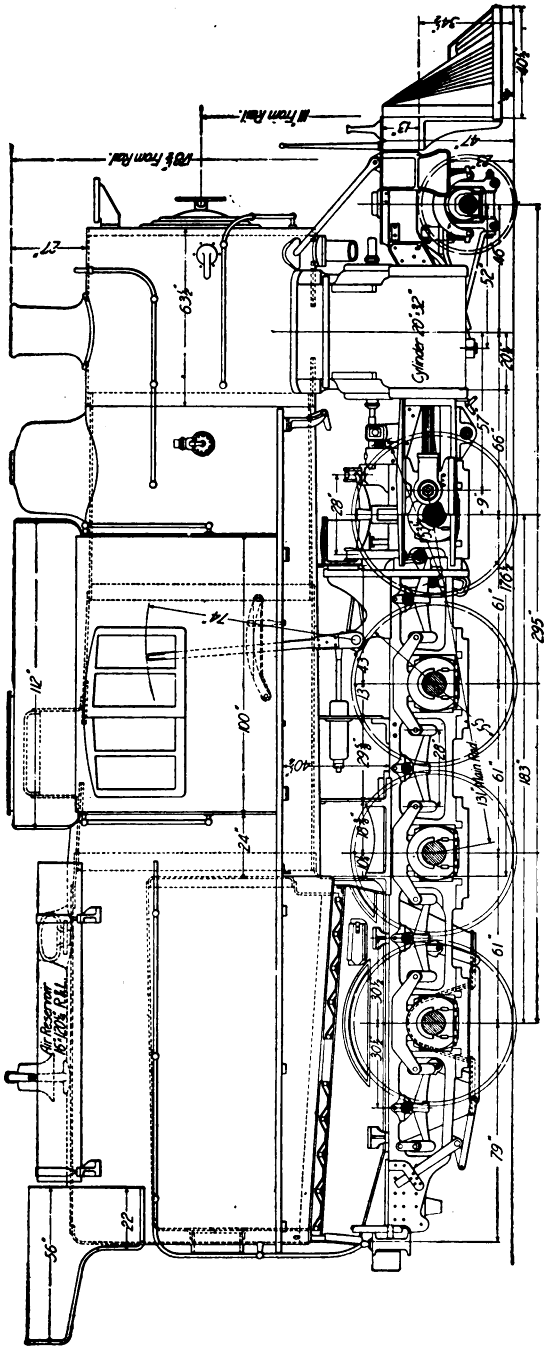


Fig. 11. A 280, or Consolidation Type of Locomotive.

not too severe, however, there is a large field for the Mogul type in freight service. Where a large axle load is permitted, the Mogul type may give sufficient hauling capacity to meet ordinary requirements in freight service on comparatively level roads. While not generally recommended for what may be called fast freight service, the 280, or Consolidation type, is sometimes used. Many Mogul locomotives are successfully handling such trains.

The 260 type provides a two-wheel leading truck with good guiding qualities and places a large percentage of the total weight on the driving wheels. A large number of locomotives of this type show an average of 87½ per cent of the total weight of the locomotive on the drivers. Boilers with sufficient capacity for moderate speed may be provided in this type; and with relatively small diameters of driving wheels, it will lend itself readily to wide variations in grates and fireboxes

The Consolidation locomotive, or 280 type, shown in Fig. 11, was designed, as has been mentioned, for hauling heavy trains over steep grades. It is perhaps more generally used as a high class freight engine than any other type so far developed. Locomotives of this type have been designed and built with total weights varying between 150,000 to 300,000 pounds.

The four most prominent types of passenger locomotives, namely, 440, 442, 460, and 462, have each been developed at different times and in successive order to meet the ever-increasing and changing demands. The 8-wheel or 440 type, commonly known as the *American type,* was for some time the favorite passenger locomotive, but as the demands for meeting the conditions of modern fast passenger service increased, a locomotive of new design was required. The conditions which were to be met were *sustained high speed* and *regular service.* This did not mean bursts of high speed under favorable conditions with a light train running as an extra or special with clear orders, but it meant rather the more exacting requirements of regular service.

Where regular train service had to be sustained day after day at a schedule of 50 miles per hour, it required reserve power to meet the unfavorable conditions of the weather and for an occasional extra car in the train. For such exacting demands, much steam is required and ample heating and grate surface must be provided. In the 440

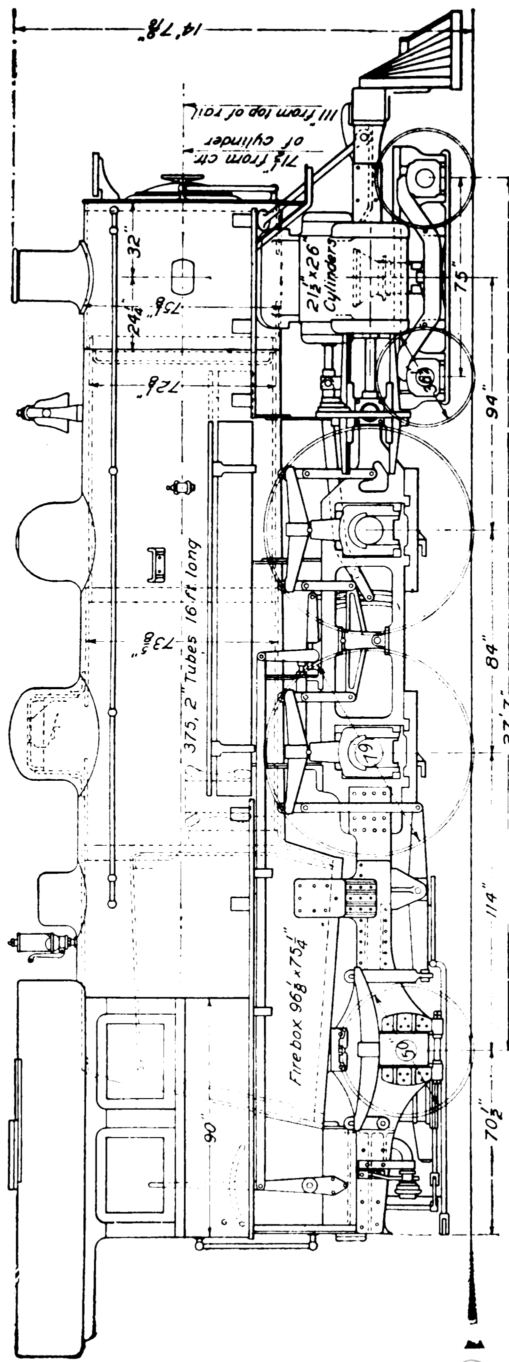


Fig. 12. A 442, or Atlantic Type of Locomotive.

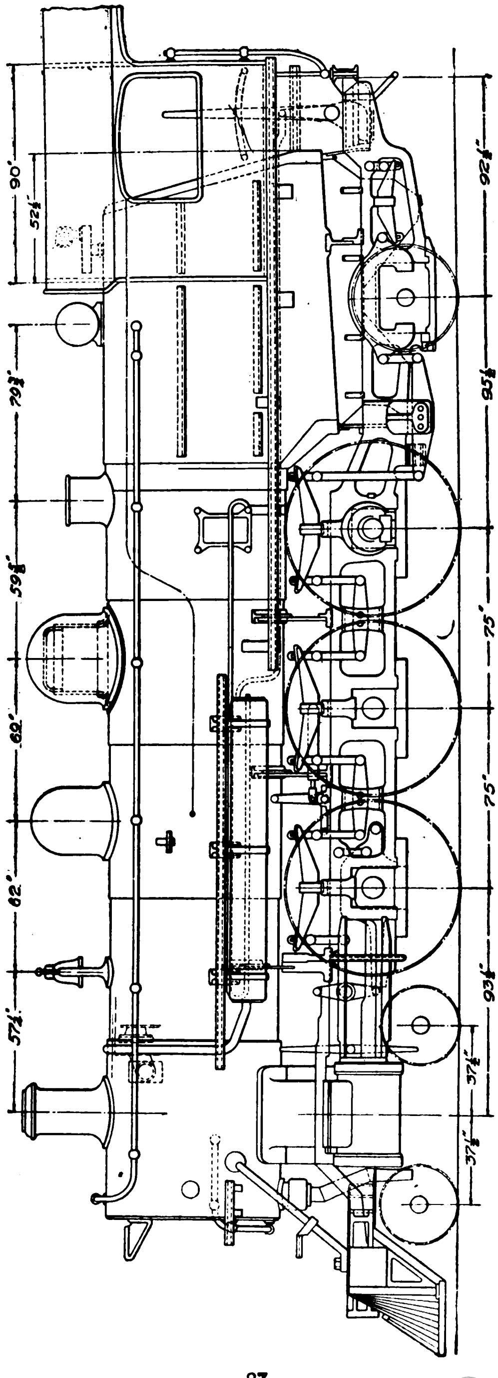
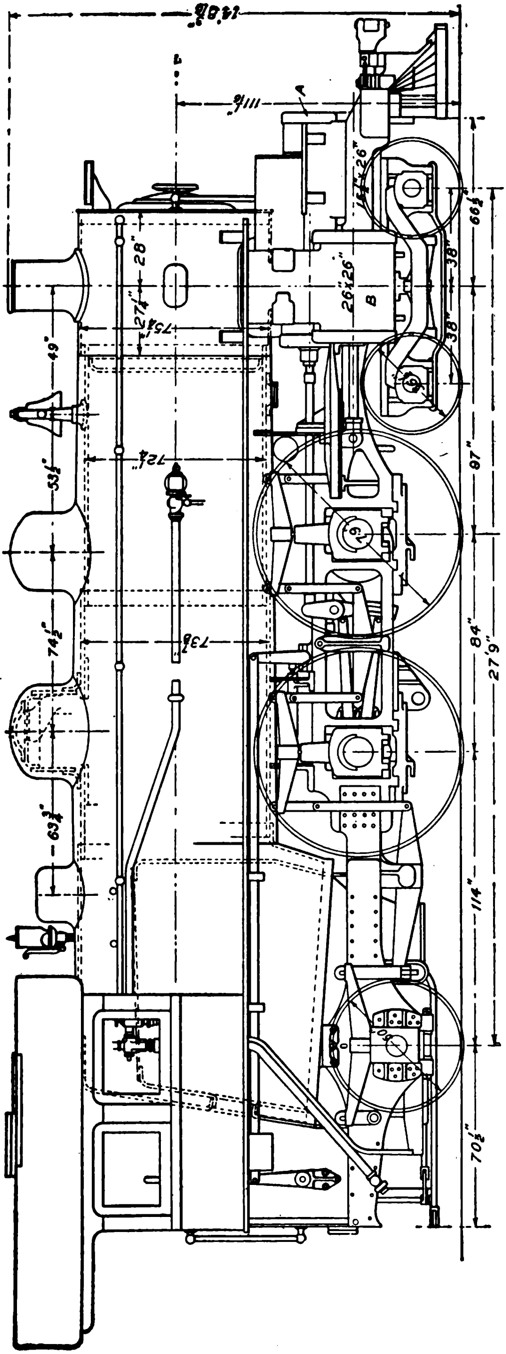


Fig. 13. A 462, or Pacific Type of Locomotive for Very Heavy Passenger Service.

type with a 4-wheel leading truck and four driving wheels without a trailing truck, the boiler capacity is limited. Not only is the heating surface also limited but the grate area as well, because the grates must be placed between the driving wheels. The desirability of larger boilers and wider grates than the distance between the wheels in the 440 type will permit, led to a ready acceptance of the 442, or Atlantic type locomotive, as shown in Fig. 12. The 442 type combines a 4-wheel leading truck, providing good guiding qualities, and four coupled driving wheels having a starting capacity sufficient for trains of moderate weight, and a trailing truck. The use of the trailing truck permits the extension of the grates beyond the driving wheels thus obtaining a much larger grate area. This wheel arrangement also permits the use of a deep as well as a wide fire-box which is especially advantageous in the burning of bituminous coal. It also gives a much greater depth at the front or throat of the fire-box, which is very important.

As modern passenger service increased and heavier trains had to be drawn, four driving wheels would not give sufficient starting power. Because of the heating surface and grate area being limited by the same factors as mentioned in the 440 type, another type, the 462, or Pacific type, came into favor. As this type was called upon to pull the heaviest passenger trains, much power was required even under very favorable conditions. For such trains, a locomotive having a combination of large cylinders, heavy tractive weight, and large boiler capacity is required. The Pacific type meets these requirements in a very successful way. From a study of Fig. 13, which illustrates such a locomotive, it is obvious that the 462 type differs from the general design of the Atlantic type only in the addition of another pair of driving wheels. This, however, makes possible a much heavier boiler; therefore, more heating surface, more grate area, and greater tractive weight are obtained. Grate areas of from 40 to 50 square feet are possible in this type which provides for the large fuel consumption that is required for the rather severe service. The heating surface is of equal importance since large cylinders require large steaming capacity. The 462 type meets this need also. A comparison of passenger locomotives shows that the Pacific type has more heating surface for a given total weight than is found in any other type of passenger locomotive.



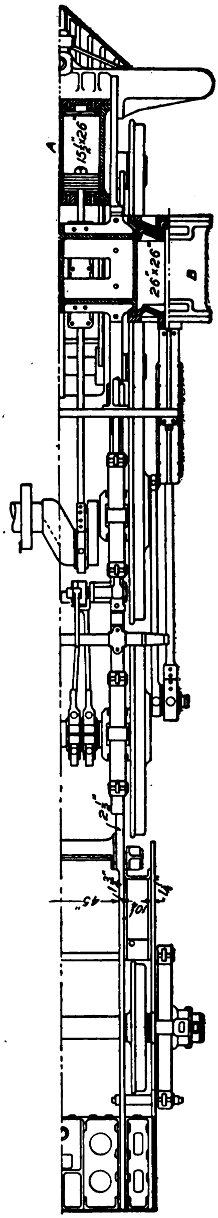


Fig. 14. Elevation of a Cole Four-Cylinder Balanced Compound Locomotive.
Fig. 15. Plan of the Same Locomotive.

Compound Locomotive. In continuation of a study of the development of the various types of locomotives, it is important to consider the compound locomotive. The compound locomotive is one in which the steam is admitted to one cylinder, called the *high-pressure cylinder,* where it partially expands. From this cylinder the steam is exhausted into the steam chest of another cylinder having larger dimensions, called the *low-pressure cylinder.* From this steam chest, the steam enters the low-pressure cylinder where it continues its work and is exhausted into the atmosphere. There have been a large number of different types of compound locomotives developed, all of which have had more or less merit. The following types have been used in America: the four-cylinder balance compound, the Mallet compound, and the tandem compound. The remarks and description which follow, of the *Cole four-cylinder compound,* are quoted from publications of the American Locomotive Company, builders of this locomotive:

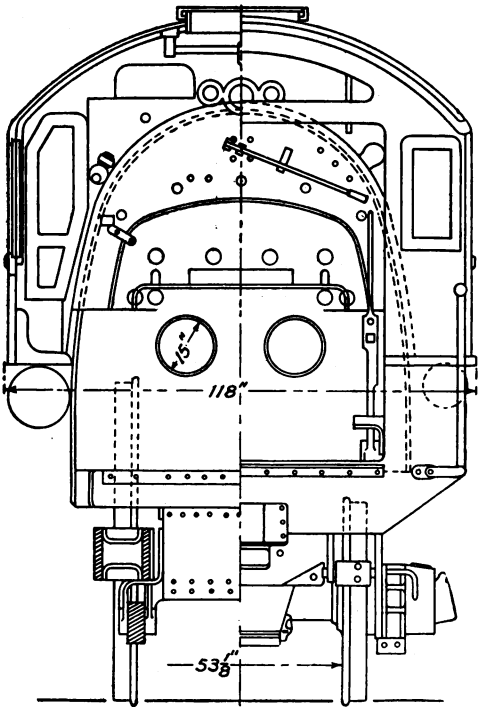


Fig. 16. Rear Elevation of the Cole Compound.

The time has arrived when merely increasing weight and size of locomotives to meet increasing weights of trains and severity of service does not suffice. To increase capacity, improve economy, and at the same time reduce injury to track, a new development is needed. Limits of size and weights have been reached in Europe and to meet analogous conditions there, the four-cylinder balanced compound has been developed into remarkably successful practice. The purpose of the Cole four-cylinder balanced compound is to advance American practice by adapting to our conditions the principles which have brought such advantageous results abroad, especially the principles of the de Glehn compound.

The Cole four-cylinder balanced compound employs the principle of subdivided power to the cylinders; the high pressure (between the frames) drives the forward or crank axle and the others; the low pressure (outside of the frames) drives the second driving axle. In order to secure a good length for connecting rods without lengthening the boiler, the high-pressure cylinders are located in advance of their usual position.

Special stress is laid on perfect balancing and the elimination of the usual unbalanced vertical component of the counterbalance stresses as a means for increasing the capacity, improving economy of operation and maintenance, and promoting good conditions of the track.

The relative positions of the high-pressure cylinder *A* and the low-pressure cylinder *B* may be seen in Fig. 14 and Fig. 15. The high-pressure guides, Fig. 15, are located under and attach to the low-pressure saddle, whereas the low-pressure guides are in the usual location outside of the frames The cranks of the driving wheels are 180 degrees apart. In order to equalize the weights of the pistons, those of the high-pressure cylinders are solid and those of the low-pressure cylinders are dished, and made as light as possible. A single valve motion, of the Stephenson type, operates a single valve stem on each side of the engine. Each valve stem carries two piston valves, one for the high- and the other for the low-pressure cylinder, as illustrated and explained later.

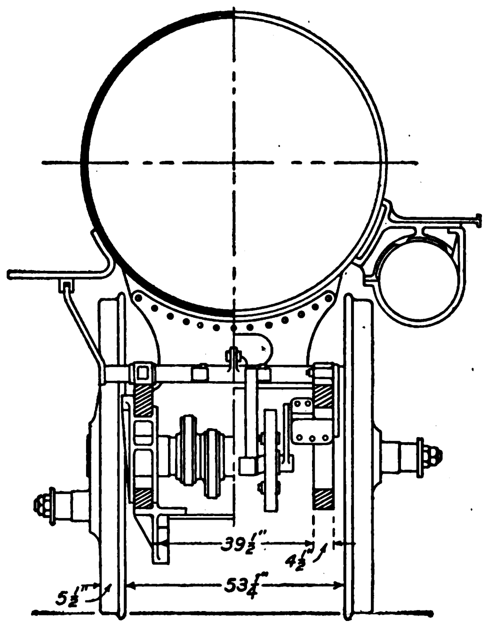


Fig. 17. Section of the Cole Compound.

The back end, Fig. 16, and the two sections, Fig. 17 and Fig. 18, resemble ordinary construction of two-cylinder locomotives but the half front elevation and half section shown in Fig. 19 disclose a number of departures. The high-pressure piston rod, crosshead, and the guides *C* are shown in position under the low-pressure saddle. The high-pressure cylinders *A* and the high-pressure section of the piston valve chamber *D* are all in one casting, Fig. 20. The sides of the cylinder casting are faced off to the exact distance between the front plate extension of the frames. The valve chambers are in exact line with the valve chambers of the low-pressure cylinder; intermediate thimble

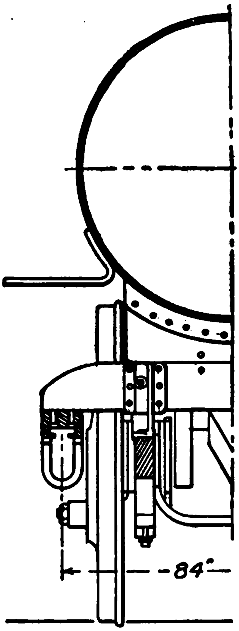


Fig. 18. Half-Section of the Cole Compound.

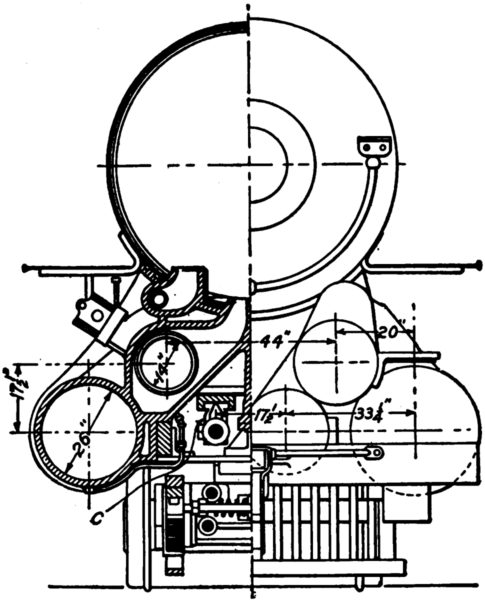


Fig. 19. Half Front Elevation and Half-Section.

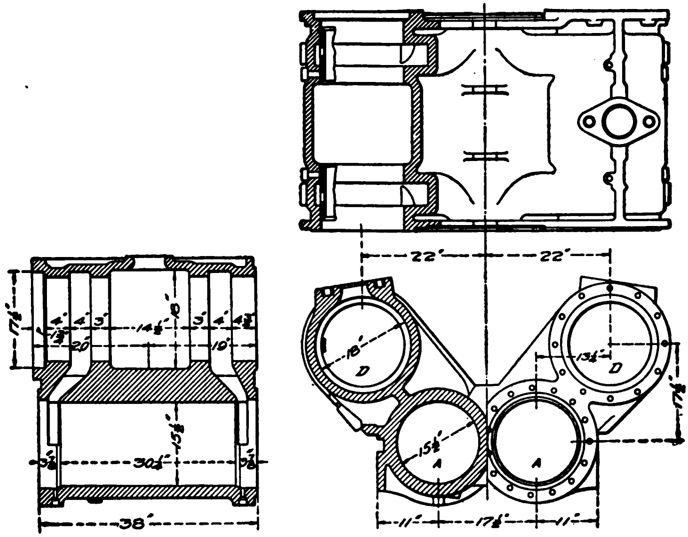


Fig. 20. Details of the Cylinders in the Cole Compound.

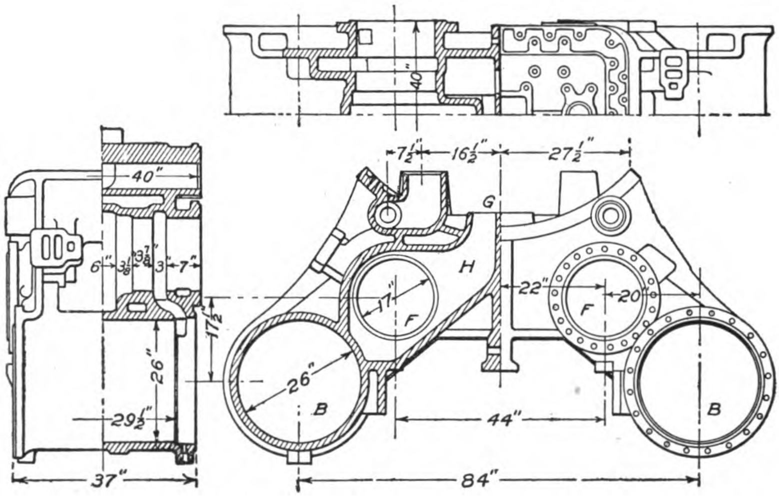


Fig. 21. Low-Pressure Cylinder Details.

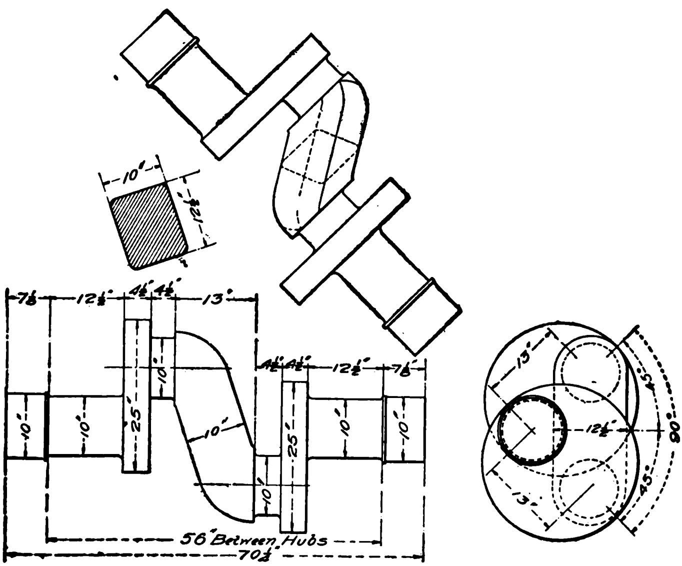


Fig. 22. The Crank Axle.

castings and packing glands being inserted between the two, form a continuous valve chamber common to both high- and low-pressure cylinders, thus providing for expansion.

Fig. 21 shows the low-pressure cylinders *B* which are cast separately and bolted together. In this case the inside of the cylinders are faced off to proper dimensions to embrace the outer faces of the bar frame. The low-pressure piston valve chamber *F* is in direct line between the cylinder and the exhaust base *G*. This view illustrates the short direct exhaust passage *H* from the low-pressure cylinders to the exhaust nozzle.

Fig. 22, the crank axle, shows that under the existing conditions it is possible to make this part exceedingly strong. Inasmuch as the cranks on this axle are 90 degrees from one another, it is possible to introduce exceedingly strong 10 by 12½ inch rectangular sections connecting the two crank pins. The whole forms an exceedingly strong and durable arrangement constructed

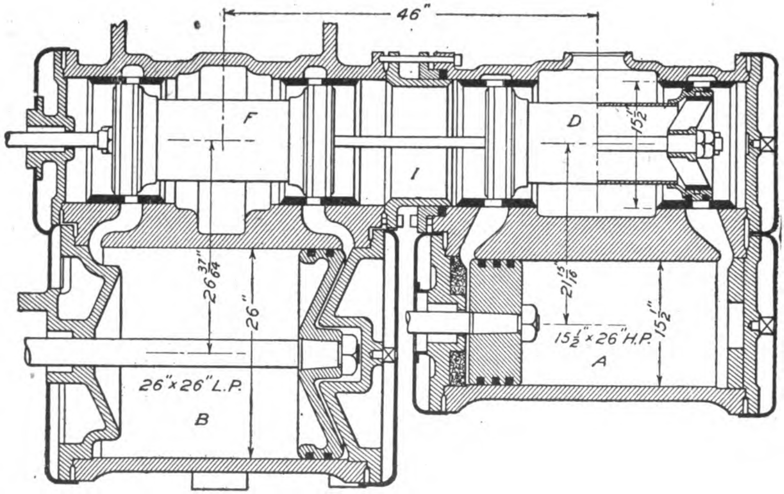


Fig. 23. Section of High- and Low-Pressure Cylinders Revolved into the Same Plane.

in accordance with the best European practice which is likely both to wear and stand up well in service. A cross-section of the central portion of the axle indicates its proportions between the crank pins.

The high- and low-pressure cylinders, *A* and *B*, are shown in Fig. 23 as they would appear in section revolved into the same plane. The high-pressure valve *D* is arranged for central admission and the low-pressure valve *F* for central exhaust, both valves being hollow. A thimble casting or round joint ring and a gland connect the two parts of the continuous valve chamber *I*.

The following advantages of the four-cylinder balanced compound are claimed by the maker:

1. The approximately perfect balance of the reciprocating parts combined with the perfect balance of the revolving masses.

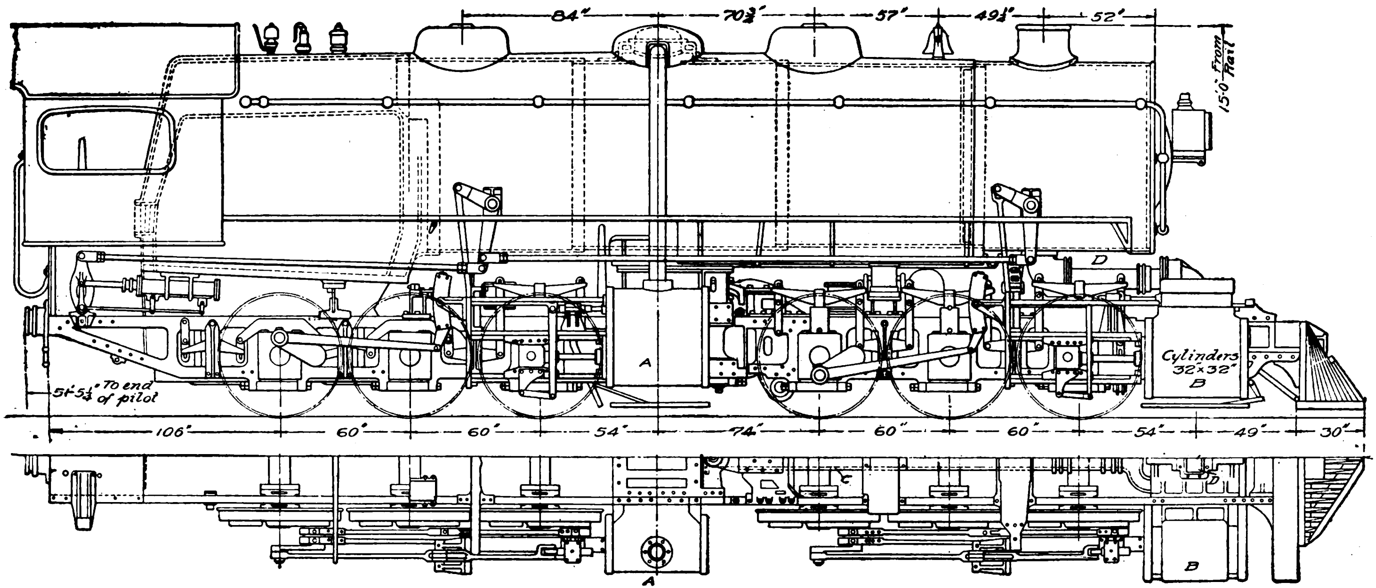


Fig. 24. Elevation of American Model of Mallet Articulated Compound.
Fig. 25. Half-Plan of the Same.

2. The permissible increase of weight on the driving wheels on account of the complete elimination of the hammer blow.

3. An increase in sustained horse-power at high speeds without modification of the boiler.

4. Economy of fuel and water.

5. The subdivision of power between the four cylinders and between the two axles, and the reduction of bending stress on the crank axle due to piston thrust because of this division of power.

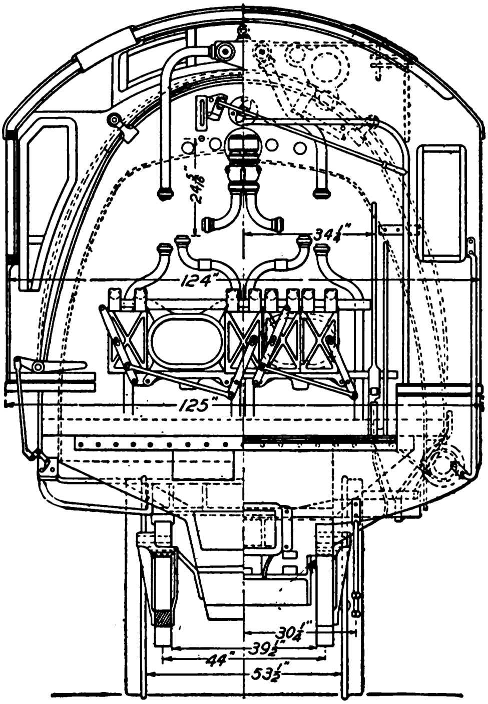


Fig. 26. Rear Elevation of the American Mallet.

6. The advantage of light moving parts which render them easily handled and which will minimize wear and repairs.

7. Simplicity of design One set of valve gears with comparatively few parts when compared with other designs which have duplicate sets of value gears for similar locomotives.

Another type of compound which is remarkable in many respects and which has had very successful usage in Europe is the *Mallet articulated compound.* It has been known and used in certain mountainous sections of Europe for several years but has recently been modified and adapted to meet American requirements. It is practically two separate locomotives combined in one, and advantage is taken of this opportunity to introduce the compound principles under the most favorable conditions. The following is a description together with dimensions of a large locomotive of this type built by the American Locomotive Company. Its enormous size is realized from Fig.

24 and Fig. 25. The weight of this particular locomotive in working order is nearly 335,000 pounds and the flues are 21 feet long. The rear three pairs of drivers are carried in frames rigidly attached to the boiler. To these frames, and to the boiler as well, are attached the high-pressure cylinders. The forward three pairs of drivers, however, are carried in frames which are not rigidly connected to the barrel of the boiler but which are in fact a truck. This truck swivels radially from a center pin located in advance of the high-pressure cylinder saddles. The weight of the forward end of the boiler is transmitted to the forward truck through the medium of side bearings, illustrated in Fig. 24, between the second and third pair of drivers. In order to secure the proper distribution of weight, the back ends of the front frames are connected by vertical bolts with the front ends of the rear frames. These bolts are so arranged that they have a universal motion, top and bottom, which permits of a certain amount of play between the front and rear frames when the locomotive is rounding a curve. The low-pressure cylinders are attached to the forward truck frames.

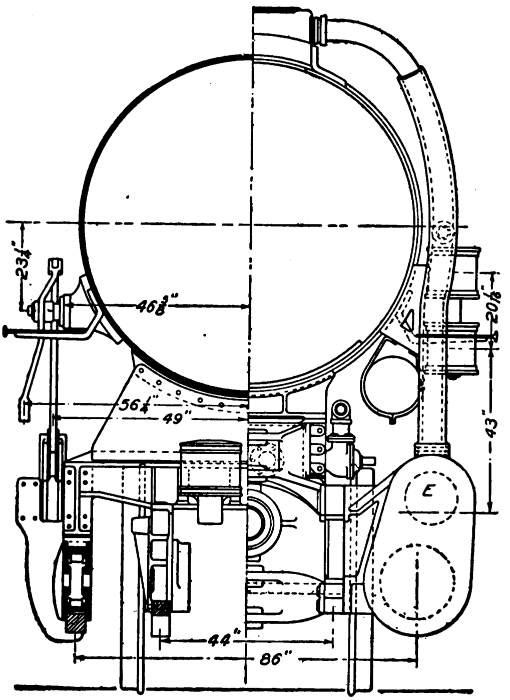


Fig. 27. Section of American Mallet Showing Method of Bringing Steam from Dome to High-Pressure Cylinder.

The steam dome is placed directly over the high-pressure cylinders *A* from which steam is conducted down the outside of the boiler on either side to the high-pressure valve chamber. The steam after being used in the high-pressure cylinders *A* passes to a jointed pipe

C between the frames and is delivered to the low-pressure cylinders *B*, whence it is exhausted by a jointed pipe *D* through the stack in the usual way. The back end, Fig. 26, presents no unusual feature other than the great size of the boiler and fire-box. The section shown in Fig. 27 illustrates the method of bringing the steam down from the steam dome to the high-pressure valve *E*. The section in Fig. 28 clearly shows the sliding support *F* between the boiler and front truck. It also shows the method of attaching the lift shafts to the boiler barrel which is made necessary by the use of the Walschaert valve gear. Fig. 29 shows that the low-pressure cylinders *B* are fitted with slide valves, and also shows the jointed exhaust pipe from the low-pressure cylinder to the bottom of the smoke-box. Fig. 30 illustrates the construction and arrangement of the flexible pipe connection *C* between the high-pressure cylinder *A* and the low-pressure cylinder *B*. This pipe connection, as well as the exhaust connection *D* between the low-pressure cylinder and the smoke stack, serves as a receiver. The ball joints are ground in, the construction being such that the gland may be tightened without gripping the ball joint.

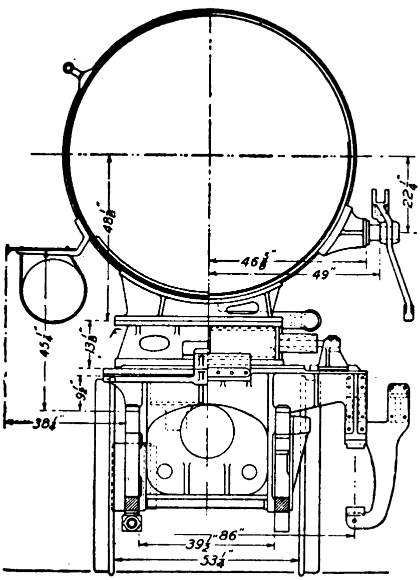


Fig. 28. Section of American Mallet.

The builders claim for this design about the same advantages over the simple engine as were enumerated in the description of the Cole four-cylinder balanced compound. It is evident that the Mallet compound is a large unit and hence can deliver more power with the same effort of the crew. A reserve power of about 20 per cent above the normal capacity of the locomotive may be obtained by turning live steam into all four cylinders and running the locomotive simple which can be done at the will of the engineer when circumstances demand it.

The diagrammatic illustration shown in Fig. 31 presents a good means of studying and comparing the four different types of compound locomotives referred to in the preceding pages. Briefly stated, the essentials in each of the four cases illustrated are as follows:

Cole. High-pressure cylinders, inside but in advance of the smoke-box, driving front axle. Low-pressure cylinders, outside in line with the smoke-box, driving rear driving axle. Two piston valves on a single stem serve the steam distribution for each pair of cylinders, and each valve stem is worked from an ordinary link motion.

Vauclain. High-pressure cylinders inside and low-pressure cylinders outside, all on the same horizontal plane, in line with the smoke-box and all driving the front driving axle. As in the von Borries, a single piston valve worked from a single link effects the steam distribution for the pair of cylinders on each side

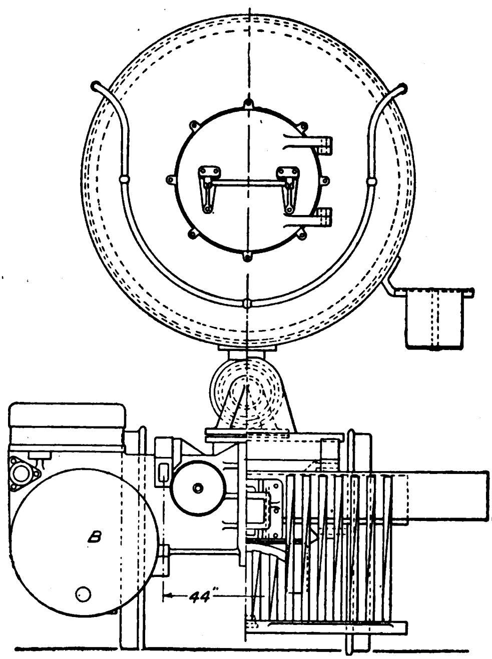


Fig. 29. Forward Half-Section Showing Slide Valves in the Low-Pressure Cylinders.

De Glehn. High-pressure cylinders, outside and behind smoke-box, driving the rear drivers. Low-pressure cylinders, inside under smoke-box, driving crank axle of front drivers. Four separate slide valves and four Walschaert valve gears allowing independent regulation of the high- and low-pressure valves.

Von Borries. High-pressure cylinders inside and low-pressure cylinders outside all on the same horizontal plane in line with the smoke-box and all driving the front driving axle. Each cylinder has its own valve but the two valves of each pair of cylinders are worked from a single valve motion of a modified Walschaert type. This

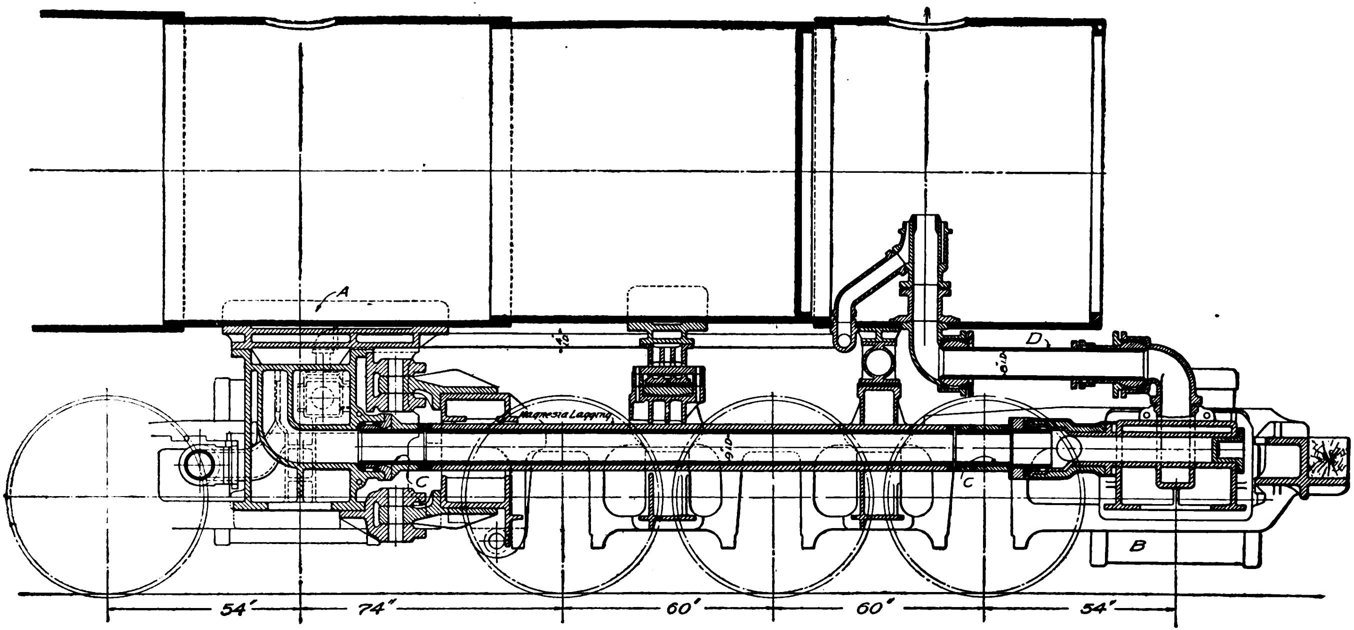


Fig. 30. Longitudinal Section of American Mallet Showing Flexible Pipe Connection Between High- and Low-Pressure Cylinders.

arrangement permits the varying of the cut-off of the two cylinders giving different ratios of expansion which cannot, however, be varied by the engine-man.

In addition to the compound locomotives already described, an early development of this type, known as the *Richmond*, or cross-compound, came into service. This engine differs from those already described in that it has only two cylinders, whereas those previously mentioned have four. In the cross-compound engine there is a high-pressure cylinder on the left side and a large or low-pressure cylinder

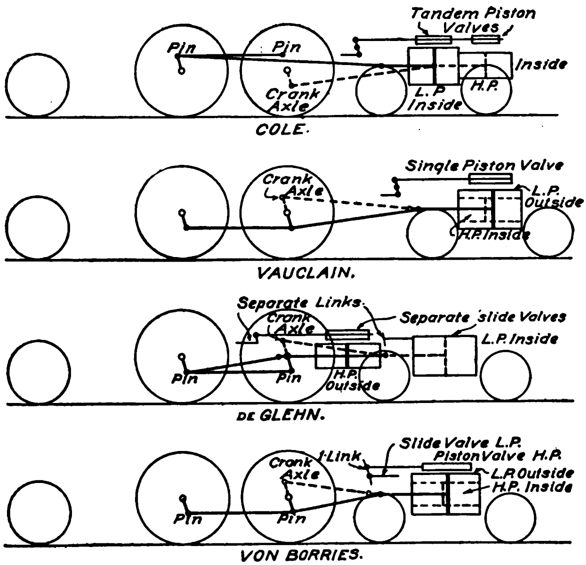


Fig. 31. Diagrams Showing Variations in the Four Principal Types of Compounds.

on the right. The live steam passes from the boiler through the head and branch pipes to the high-pressure cylinder in the usual way. It is then exhausted into a receiver or circular pipe resembling the branch pipe which conveys the steam from the high-pressure cylinder across the inside of the smoke-box into the steam chest of the low-pressure cylinder. The steam passes from the steam chest into the cylinder and exhausts out through the stack in the usual way. The construction is such that the locomotive can be worked simple when starting trains. This type was never very largely used.

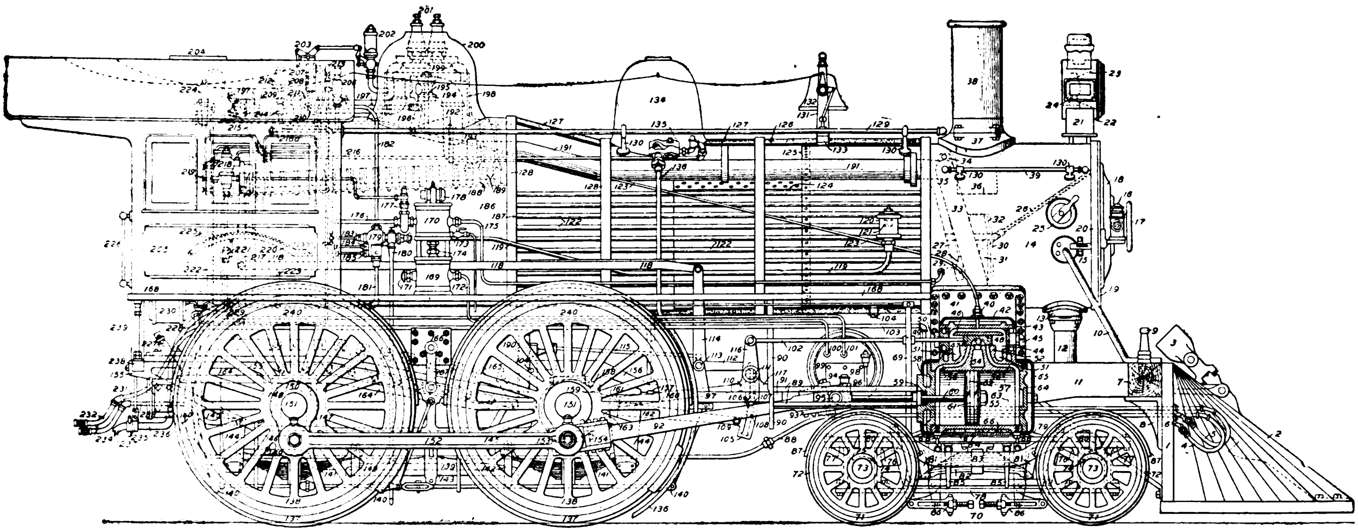


Fig. 32. Longitudinal Section of the American Locomotive.

1—Pilot. 2—Draw Head Attachment. 3—Folding Draw Head. 4—Air Signal Hose. 5—Air Brake Hose. 6—Hose Hangers. 7—Buffer Beam. 8—Pilot Bracket. 9—Flagstaff. 10—Arch Brace. 11—Front Frame. 12—Cinder Chute. 13—Cinder Chute Slide. 14—Extension Front. 15—Headlight Front. 16—Signal Lamp. 17—Number Plate. 18—Smoke Arch Door. 19—Smoke Arch Front. 20—Smoke Arch Ring. 21—Headlight Bracket. 22—Headlight Case. 23—Headlight Reflector. 24—Headlight Burner. 25—Cleaning Door. 26—Netting. 27—Deflector Plate. 28—Deflector Plate Adjuster. 29—Air Pump Exhaust Pipe. 30—Blower. 31—Nozzle Stand. 32—Nozzle Tip. 33—Steam Pipe (2). 34—T or Nigger Head. 35—Dry Pipe Joint. 36—Petticoat or Draft Pipe. 37—Stack Base. 38—Smoke Stack. 39—Arch Hand Rail. 40—Oil Pipe Plug. 41—Cylinder Saddle. 42—Steam Chest Casing Cover. 43—Steam Chest Cover. 44—Steam Chest. 45—Relief Valve. 46—Balance Plate. 47—Balanced Valve. 48—Valve Yoke. 49—Valve Stem. 50—Valve Stem Packing. 51—Steam Passages to Chest. 52—Valve Seat. 53—Bridges. 54—Exhaust Port. 55—Piston Rod Nut. 56—Steam Ports. 57—Cylinder. 58—Back Cylinder Head. 59—Piston Rod Packing. 60—Piston Rod. 61—Piston Head. 62—Piston Packing Rings. 63—Truck Center Castings. 64—Front Cylinder Head. 65—Cylinder Head Casing. 66—Cylinder Lagging. 67—Cylinder Casing. 68—Cylinder Cocks. 69—Cylinder Cock Rigging.

70—Engine Truck Wheel. 71—Engine Truck. 72—Engine Truck Tire. 73—Engine Truck Axle. 74—Engine Truck Brass. 75—Engine Truck Box. 76—Engine Truck Pedestal. 77—Engine Truck Frame. 78—Engine Truck Pedestal Brace. 79—Engine Truck Frame Brace. 80—Engine Truck Equalizer. 81—Engine Truck Spring Hanger. 82—Engine Truck Spring. 83—Engine Truck Spring Band. 84—Engine Truck Spring Pocket. 85—Safety Hanger. 86—Truck Brake. 87—Wheel Guard. 88—Signal Pipe. 89—Guides. 90—Guide Yoke. 91—Guide Block. 92—Main Rod. 93—Main Rod Front Strap. 94—Key. 95—Crosshead Pin. 96—Crosshead. 97—Main Frame. 98—Air Drum Bracket. 99—Air Drum. 100—Pump Connection. 101—Train Pipe Connection. 102—Valve Stem Rod. 103—Train Pipe. 104—Wash Out Plugs. 105—Link. 106—Suspension Stud. 107—Link Block Pin. 108—Link Block. 109—Eccentric Connection, Back Up. 110—Eccentric Connection, Go Ahead. 111—Link Hanger. 112—Tumbling Shaft Arm. 113—Tumbling Shaft. 114—Tumbling Shaft Lever. 115—Counterbalance Spring and Rig. 116—Rocker. 117—Rocker Box. 118—Reach Rod. 119—Branch Pipe. 120—Check Valve Case. 121—Check Valve. 122—Flues. 123—Oil Pipe. 124—Horizontal Boiler Seam. 125—Circumferential Seam. 126—Boiler Lagging. 127—Boiler Jacket. 128—Jacket Bands. 129—Hand Rail. 130—Hand Rail Brackets. 131—Bell Stand. 132—Bell. 133—Steam Bell Ringer. 134—Sand Box. 135—Pneumatic Sander. 136—Sand Pipe. 137—Driving Wheel Tire. 138—Driving Wheel Centers. 139—Ash Pan. 140—Driver Brakes. 141—Driver Springs. 142—Driver Spring Hangers. 143—Driver Spring Equalizers. 144—Driver Spring Hanger Brace. 145—Lower Rail of Frame. 146—Pedestal Brace. 147—Driving Box Shoe. 148—Driving Box Wedge. 149—Wedge Bolt. 150—Driving Box. 115—Driving Axle. 152—Side or Parallel Rod. 153—Rod Bush. 154—Main Rod Connection. 155—Main Frame. 156—Frame Brace. 157—Frame Splice. 158—Go Ahead Eccentric. 159—Back-Up Eccentric. 160—Go Ahead Eccentric Rod. 161—Go Ahead Eccentric Strap. 162—Back-Up Eccentric Rod. 163—Back-Up Eccentric Strap. 164—Grate Shaking Rig. 165—Rocking Grates. 166—Expansion Pad. 167—Expansion Link. 168—Running Board. 169—Air Cylinder Brake Pump. 170—Steam Cylinder Brake Pump. 171—Air Strainer. 172—Delivery to Drum. 173—Drip Cock. 174—Pump Piston Packing. 175—Pump Exhaust Connection. 176—Pump Steam Connection. 177.—Governor. 178—Pump Valve Case. 179—Injector. 180—Injector Overflow. 181—Water Pipe. 182—Steam Pipe. 183—Steam Valve. 184—Primer. 185—Water Valve. 186—Fire Box. 187—Tube Sheet. 188—Crown Bars. 189—Sling Stays. 190—Stay Bolts. 191—Dry Pipe. 192—Stand Pipe. 193—Dry Pipe Hangers. 194—Throttle Pipe. 195—Throttle Valve. 196—Throttle Bell Crank. 197—Throttle Stem. 198—Dome. 199—Dome Cap. 200—Dome Casing. 201—Safety Valves. 202—Chime Whistles. 203—Whistle Rig. 204—Ventilator. 205—Cab. 206—Air Pump Lubricator. 207—Air Gauge. 208—Steam Gauge. 209—Steam Turret. 210—Injector Throttle. 211—Blower Cock. 212—Gauge Lamp. 213—Signal Whistle. 214—Air Pump Throttle. 215—Throttle Lever. 216—Pneumatic Sander. 216*a*—Sand Lever. 217—Reverse Lever. 218—Engineer's Brake Valve. 219—Gauge Cocks. 220—Quadrant. 221—Cut Out Valve. 222—Fire Door. 223—Cylinder Cock Lever. 224—Cylinder Lubricator. 225—Oil Can Shelf. 226—Hand Hold. 227—Shake Lever Stub. 228—Ash Pan Damper Handle. 229—Whistle Signal Valve. 230—Brake Valve Reservoir. 231—Train Pipe. 232—Train Pipe Hose. 233—Signal Pipe. 234—Signal Pipe Hose. 235—Feed Pipe Hanger. 236—Feed Pipe. 237—Feed Pipe Hose. 238—Tail Piece of Frame. 239—Cab Bracket. 240—Counterbalance Weight.

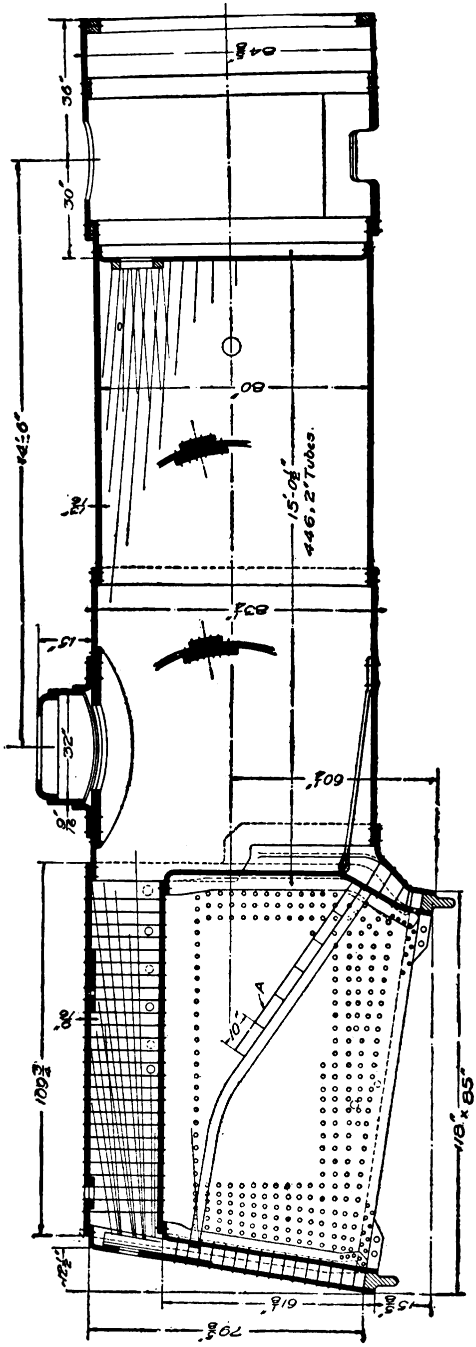


Fig. 33. Straight Top Form of Locomotive Boiler.

ACTION OF STEAM IN OPERATING LOCOMOTIVE

General Course of Steam. One of the most important features in locomotive operation is the action of the steam in transmitting the heat energy liberated in the fire-box to the driving wheels in the form of mechanical energy. It is therefore important that we should have a clear understanding, in the beginning, of the various changes which occur while the steam is passing from the boiler to the atmosphere in performing its different functions. In making this study it will prove of much assistance if reference is made to Fig. 32.

Before this is done, however, a brief statement of the characteristics of steam and the precautions which must be taken as the steam passes through the cylinder may not be out of place. At normal pressure water boils at 212°F., but with an increase of pressure the boiling temperature and the consequent temperature of the steam rises. Now if the steam formed at 212°F. and atmospheric pressure were passed into the cool steam chest and later into the cylinder, it would become cooled below 212°F., would condense, and would therefore lose its power. To avoid this possibility, the steam is generated in the boiler at a high pressure so that, when allowed to expand into the cylinder and lose some of its energy by virtue of the work it has done on the piston, the temperature is still *above* the condensation temperature for the pressure under which it is acting.

With this in mind let us follow the steam in its path and note the changes to which it is subject and the direct results of its action. When the throttle is opened the steam, which is generated in the boiler and there held at high pressure, enters the dry pipe at a point near the top of the dome and flows forward to the smoke-box, where it enters the T-head and is conducted downward on either side into the steam chest and ultimately through the cylinders and out through the exhaust to the atmosphere.

Steam Enters Steam Chest. At the very outset when the throttle valve is opened and steam enters the dry pipe, a change takes place. This change is a loss in pressure; for when the steam reaches the steam chest its pressure is reduced several pounds per square inch, as evidenced by gages placed on the boiler and steam chest or by steam chest diagrams taken simultaneously with the regular cylinder diagrams. This pressure drop would not appear were it not for the fact that the locomotive is set into motion at the opening of the throttle. Consequently, motion is transmitted to the steam in the various pipes and passages, and the frictional resistance offered retards its flow, with the result that a pressure less than that in the boiler is maintained. The exact amount of this pressure drop depends upon the throttle opening and the rate at which steam is drawn off. This latter feature is a function of the engine speed, which in a measure depends upon the opening of the throttle. Under all conditions, so long as the locomotive is in motion, the pressure in the steam chest will be less than that in the boiler.

Steam Enters Cylinder. The steam, after reaching the steam chest, is admitted alternately to first one end of the cylinder then the other through the action of the valve. The opening and closing of the valve is a continuous process, the amount of opening increasing from zero to a maximum and then decreasing to zero. Because of this fact there will be two periods of wire drawing during each admission, independent of the fact that there may or may not be wire drawing during the period of maximum opening. This action causes a further drop in pressure when the steam finally gets into the cylinder, which loss increases with the speed of the engine.

Steam in Cylinder. After the steam reaches the cylinder it experiences a still further loss caused by condensation due to the comparatively cool cylinder walls, heads, and piston. This loss can be minimized to a limited extent by the use of an efficient lagging but it can never be entirely eliminated. Even if there were no loss in the cylinder due to radiation, there still would be a loss because of the exhaust, which occurs at a temperature much lower than that of the entering steam and which would cool the cylinder walls and parts to at least the average temperature of the steam in the cylinder during the stroke.

When the steam expands in the cylinder in the performance of its work still another drop in pressure occurs, the amount depending upon the point of cut-off. As this can be varied at the will of the operator, it can be seen that the pressure drop can be very great or very small. During this portion of its travel the steam does its first useful work since leaving the boiler. The steam while in the steam chest exerts a pressure on the valve which causes friction and thereby absorbs a portion of the useful work generated by the action of the steam on the piston.

The steam acting on the piston and causing it to move produces rotation of the driving wheels through the medium of the connecting rod, crank-pin, and various other parts, with an effort which varies throughout the stroke owing to the expansion of the steam, the exhaust and compression, which is taking place on the opposite side of the piston, and the angularity of the connecting rod. The pressure on the guides, due to the angularity of the connecting rod, causes friction which reduces the effectiveness of the work done on the piston. The effect of the inertia of the parts at high rotative speeds affects the thrust on the crank-pin to a marked degree. These points and many others which might be mentioned are of much importance in the study of the locomotive and its ability to do useful work in hauling trains.

Steam after Leaving Cylinder. The steam having pushed the piston to the end of its stroke is exhausted on the return stroke, but at a slight back pressure, which opposes the effectiveness of the return stroke and results in a direct loss. The closing of the valve before the completion of the return stroke causes an additional resistance in compressing the steam remaining in the cylinder, but this is not without some advantage. The steam in being exhausted from the cylinder is discharged into the exhaust cavity in the cylinder and from thence into the exhaust passage in the cylinder saddle and out through the exhaust nozzle into the smoke-box. At this point the steam is very much reduced in pressure but, owing to its relatively high velocity, as it leaves the exhaust nozzle and enters the stack, it is still able to do useful work by producing a slight vacuum in the smoke-box in an ejector-like action. The useful work performed is not in the way of moving the machine but in increasing the rate of combustion in the fire-box. The action is such as to cause a rate of combustion unequaled in any other form of steam power plant with the exception, perhaps, of the steam fire engine which a few years ago was so popular.

LOCOMOTIVE BOILERS

Before entering into the details of the various elements comprising a locomotive, it is thought advisable to give them some study in order to become familiar with the names of the various parts and their relation to each other. Fig. 32 is given for this purpose and represents a longitudinal section of a 440 type locomotive with all parts numbered and named. This figure should be carefully studied in order that the future work of the text may be clearly understood.

A *locomotive boiler* may be defined as a steel shell containing water which is converted into steam, by the heat of the fire in the fire-box, to furnish energy to move the locomotive.

Locomotive boilers are of the internal fire-box, straight fire-tube type having a cylindrical shell containing the flues and an enlarged back-end for the fire-box, and an extension front-end or smoke-box leading out from which is the stack.

Classification of Boilers as to Form. Locomotive boilers are classified as to form as follows:

Straight top, Fig. 33, which has a cylindrical shell of uniform diameter from the fire-box to the smoke-box.

Wagon top, Fig. 34, which has a conical or sloping course of plates next to the fire-box and tapering down to the circular courses.

Extended wagon top, Fig. 35, which has one or more circular courses between the fire-box and the sloping courses which taper to the diameter of the main shell.

Classification of Boilers as to Fire-Box Used. Boilers are frequently referred to also and designated by the type of fire-box contained, such as *Belpaire, Wooten,* and *Vanderbilt.* This designation does not in any way conflict with the classification of different types of boilers already given but refers to the general character of the fire-box; that is, the boiler may be classified as a straight top boiler and at the same time a Wooten fire-box. Since this is true it is necessary to know the distinction between the Belpaire, the Wooten, and the Vanderbilt types of fire-box.

The *Belpaire boiler,* as illustrated in Fig. 36, has a fire-box with a flat crown sheet *A* jointed to the side sheets *B* by a curve of short radius. The outside sheet *C* and the upper part of the outside sheets *D* are flat and parallel to those of the fire-box. These flat parallel

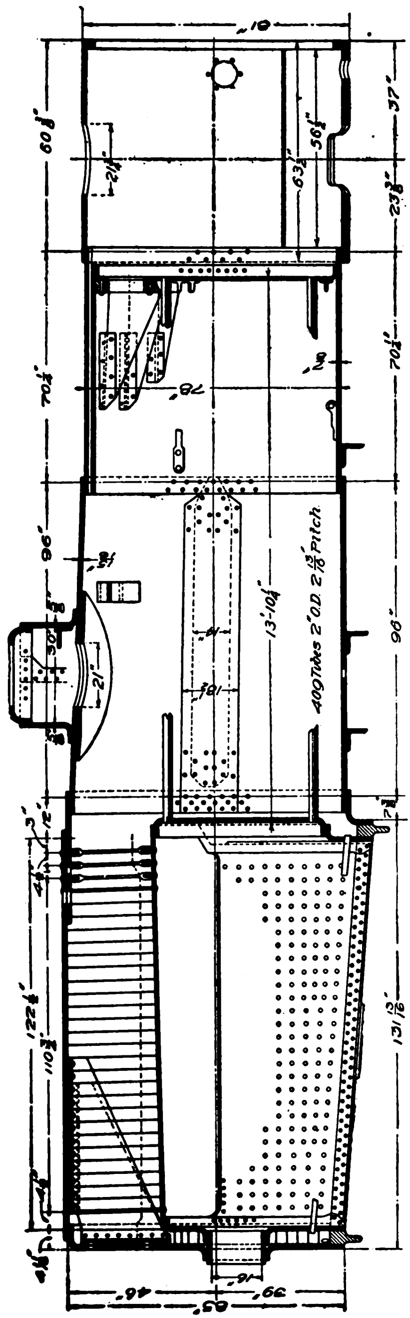


Fig. 34. Wagon Top Form of Locomotive Boiler.

plates are stayed by vertical and transverse stays and obviate the necessity of crown bars to support and strengthen the crown sheet. The advantage gained is that the stay bolts holding the crown and side sheets can be placed at right angles to the sheets into which they are screwed.

The *Vanderbilt fire-box* is built of corrugated forms, as illustrated in Fig. 37. The principal object in the design of this fire-box is to eliminate stay bolts which are a source of much trouble and expense in keeping up repairs. Only a few locomotives fitted with this type of fire-box have been used.

The *Wooten fire-box*, so-called, obtained its name from the designer. This form of fire-box extends out over the frames and driving wheels, as may be seen from Fig. 38. It was designed for the purpose of burning fine anthracite coal but soon after its introduction it found favor with a few railroads using bituminous coal. The drawing shown in Fig. 39 illustrates its general construction. It has rendered good service in certain localities but has never been very extensively used.

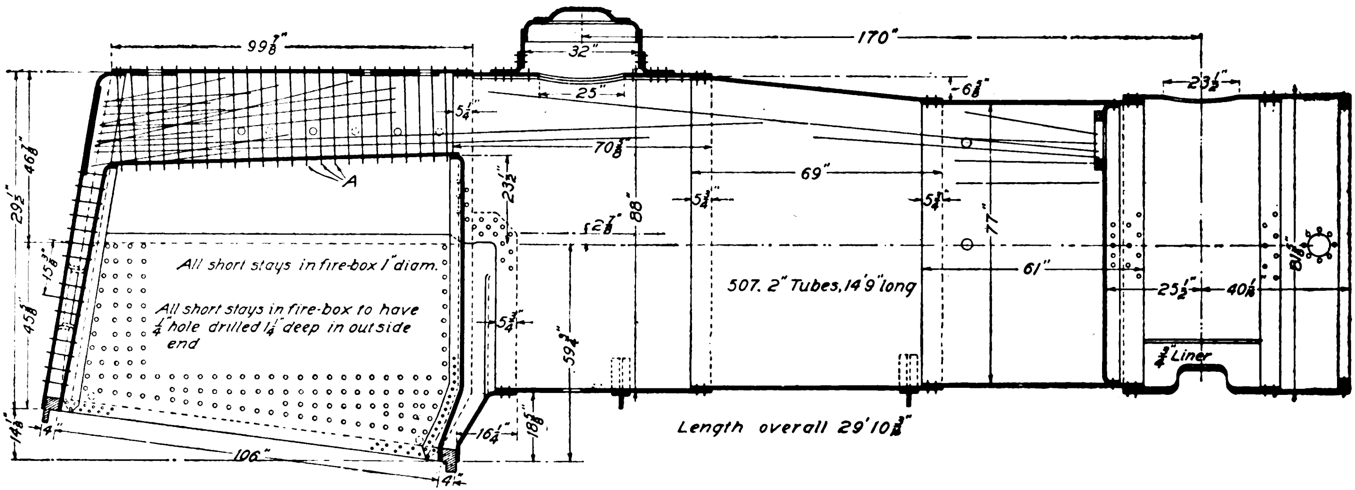


Fig. 35. Extended Wagon Top Form of Locomotive Boiler.

In addition to the designations given the various boilers already mentioned, they are frequently spoken of as narrow or wide fire-box locomotives. A *narrow fire-box* is one which is placed between the frames or may rest on the frames between the driving wheels. These conditions limited the width of the fire-box from 34 to 42 inches. *Wide fire-boxes* are those which extend out over the wheels, as is the case in the Wooten, their width only being limited by road clearances. The dimensions commonly used are as follows: width 66, 76, 85, 103,

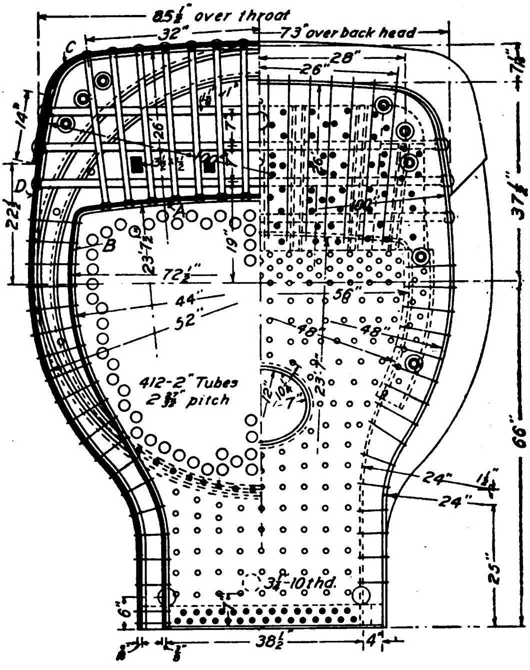


Fig. 36. Belpaire Boiler.

and 109 inches; length 85, 97, 103, 115, and 121 inches, all dimensions being taken inside of the fire-box ring. Variations above and below these figures are often found which are made necessary by existing conditions.

In locomotives where the fire-box is placed between the axles, the length of the fire-box is limited by the distance between the axles and is rarely more than 6 or 9 feet, from which the front and back legs must be deducted. Placing the fire-box on top of the frames

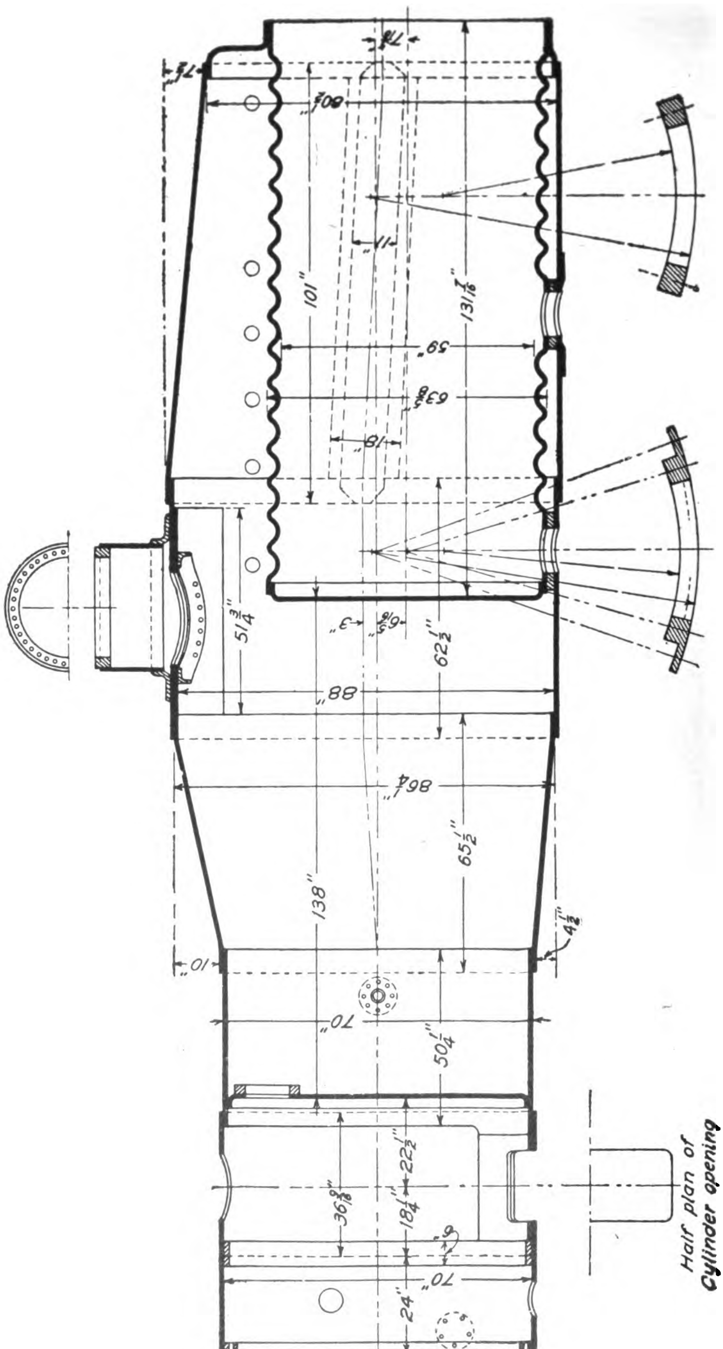


Fig. 37. Vanderbilt Fire-Box.

makes any length possible, the length being governed by the capability of the fireman to throw the coal to the front end of the fire-box.

Flues. From the sectional view of the boiler illustrated in Fig. 32 and Fig. 44, it is evident that a large part of the boiler is composed of flues or tubes. The flues give to the boiler the largest part of its heating surface. It is the flues which largely affect the life of the boiler and, therefore, the life of the locomotive, for this reason it is quite necessary to properly install and maintain them. A large amount of the repair costs is directly traceable to the flues. This is especially true in localities where water is found which causes scale to form on the flues from $\frac{1}{16}$ to $\frac{1}{2}$ inch in thickness, thus causing unequal expansion and contraction and overheating. These conditions cause the joints to break at the flue sheets. Cold air entering the fire-box door is another source of flue trouble. It is to these details that careful attention must be given in order to alleviate flue failures. Flues should be made of the best quality of charcoal iron, lap-welded, and subjected to severe tests before being used. They must be accurately made, perfectly round and smooth, must fill standard gauges perfectly, must be free from defects such as cracks, blisters, pits, welds, etc., and must be uniform in thickness throughout except at the weld where $\frac{2}{100}$ of an inch additional thickness may be allowed. The present practice is to use tubes of from 2 to $2\frac{1}{4}$ inches in diameter. They vary in length from about 15 to 20 feet, the length depending on the construction of the boiler and locomotive as a whole. The tubes

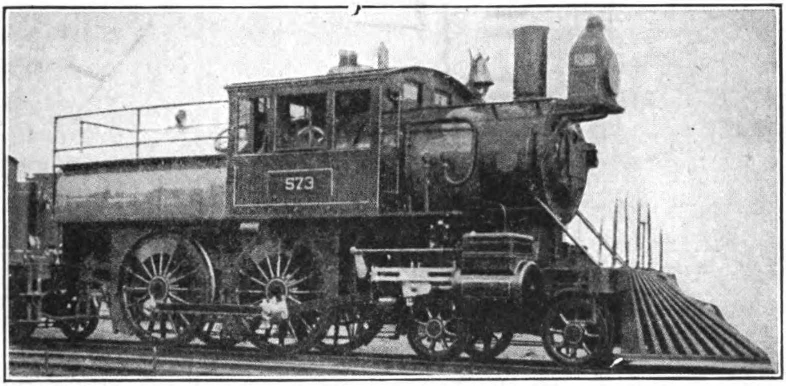


Fig. 38. Engine with Wooten Fire-Box.

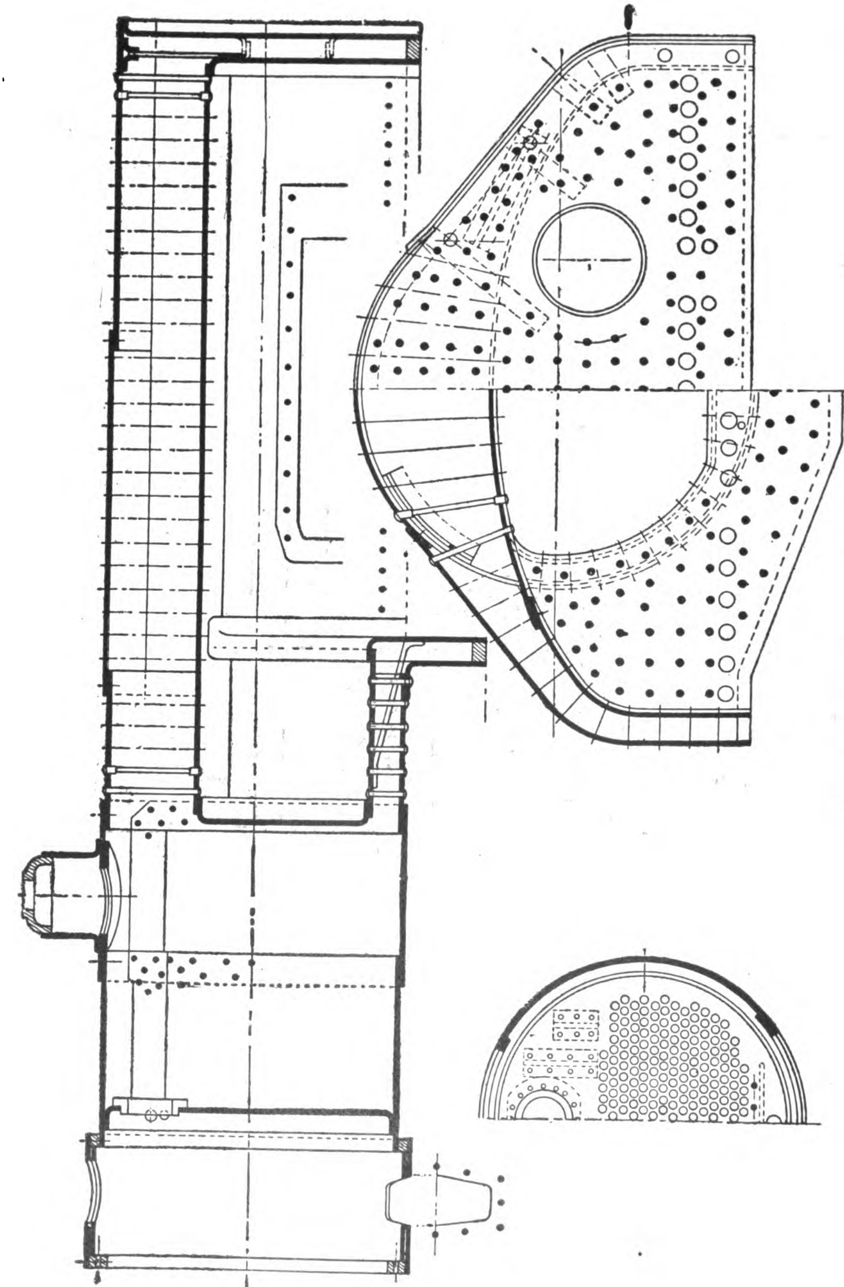


Fig. 39. Details of Wooten Fire-Box.

are supported at each end by letting them extend through the tube sheets. It is in the setting of the tubes that great care should be exercised. The tube sheets must be carefully aligned and the hole drilled through and reamed. These holes are usually made $\frac{1}{16}$ of an inch larger in diameter than the outside diameter of the tubes. The tubes should be made not less than $\frac{1}{4}$ nor more than $\frac{3}{8}$ inch longer than the gauge distance over the front and back flue sheets. All back ends of tubes should be turned and beaded, and at least ten per cent of those in the front end. The number of tubes used varies according to the type and size of the locomotive but usually from 300 to 500 are employed. The flue sheets are made thicker than the other sheets of the boiler in order to give as wide a bearing surface for the tubes as possible. They are usually $\frac{5}{8}$ inch thick. The flue sheets are braced or stayed by the flues and by diagonal braces fastened to the cylindrical shell. The bridges or metal in the flue sheets between two adjacent flues are usually made from $\frac{3}{4}$ to 1 inch in width. The greater the width of the bridges, the greater the space between the flues; therefore, better circulation will be obtained.

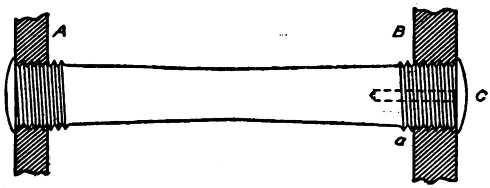


Fig. 40. Screw Stay-Bolt.

Stay-Bolts. The universal method of staying flat surfaces of the fire-box at the sides and front is by the use of stay-bolts. These stay-bolts are screwed through the two sheets of the fire-box and are riveted over on both ends. Fig. 40 illustrates a stay-bolt screwed into position and represents a strong and serviceable form. The stay-bolt is cut away between the sheets and only sufficient thread is cut at the ends to give it a hold in the metal. In Fig. 40, *A* represents the inside sheet or the one next to the fire, and *B* represents the outside sheet. A small hole *C* is drilled into the outside end of the stay-bolt. This is known as the *tell-tale hole* and will permit the escape of water and steam should the bolt become broken. This tell-tale hole is usually $\frac{3}{16}$ of an inch in diameter and $1\frac{1}{4}$ inches deep and is drilled at the outer end of the stay-bolt, since almost invariably the fracture occurs near the outer sheet. All boiler stay-bolts, including radial stays, have 12 Whitworth standard threads per inch. The most common cause of stay-bolts breaking is the bending at the point *B*, Fig. 40, due to the expansion of the sheets *A* and *B*. The sheet *A*, being next to the fire, is kept at a much higher temperature while the boiler is at work than the sheet *B*, which is subjected to the comparatively cool temperature of the atmosphere. This causes the plates *A* and *B* to have a movement relative to each other due to unequal expansion. The breakage is greatest at points where the greatest amount of movement takes place. As the two sheets are rigidly fastened to the mud ring, it is evident that the variation of expansion must start from that point; hence, the greatest vertical variation will be found at the top of the fire-box. In like manner, the back heads are securely fastened by stay-bolts so that horizontal variation must start at the back end; consequently the greatest horizontal variation will be found at the front end of the fire-box. The result of these two expansions will, therefore, be greatest at the upper portion of the front end. It is there that the greatest number of staybolt breakages occur.

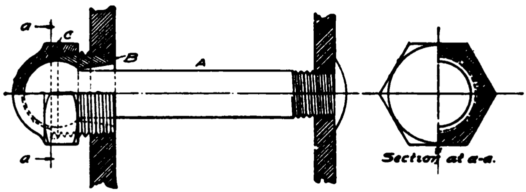


Fig. 41. Flexible Stay-Bolt.

In order to avoid these bending stresses, a number of different forms of flexible stay-bolts have been designed. One form of these is shown in Fig. 41. The stay-bolt proper, *A*, has a ball formed on one end and a thread cut on the other. A plug *B* sets over the ball and forms a socket in which the latter can turn. As the stay-bolt is free to revolve in the plug, there is no necessity of the thread of the stay-bolt being cut in unison with the thread on the plug. Such a stay-bolt as this permits the inner sheet of the fire-box to move to and fro relative to the outer sheet without bending the outer end of the stay-bolt. Flexible stay-bolts when used are placed in what is known as the *zone of fracture*. Fig. 42 and Fig. 43 illustrate the application of flexible stay-bolts to a wide fire-box. Fig. 42 shows five rows of flexible stay-bolts at each end of the fire-box and four rows at the bottom parallel to the mud ring. It should be remembered, however, that this is one installation only and that the arrangement in all cases may vary but this illustration is representative of good practice. Another illustration is shown in Fig. 45. Here the

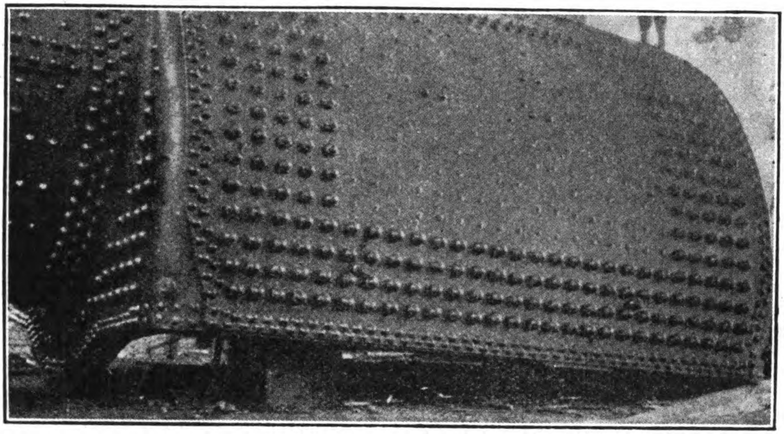


Fig. 42. Boiler, Showing Use of Flexible Stay-Bolts.

flexible stay-bolts are shown by shaded circles. It is evident from Fig. 43 that all the stays in the throat sheet are flexible, which is a

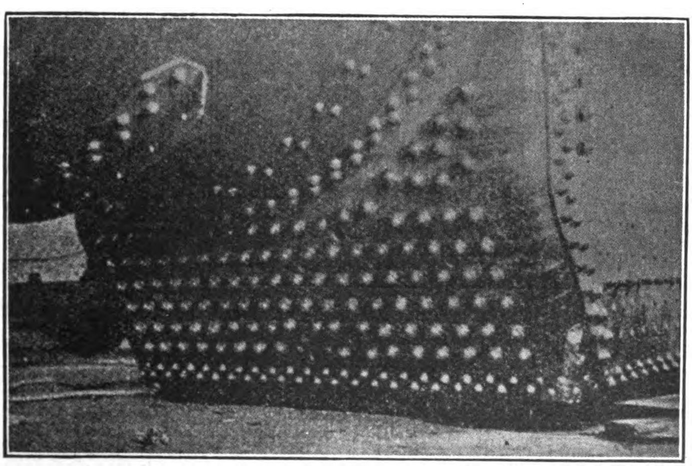


Fig. 43. Boiler, Showing Use of Flexible Stay-Bolts.

very good arrangement since the stay-bolts in the throat sheet are subjected to very severe strains. On some railroads, flexible stay-bolts are put in the fire-box door sheets but this practice varies in some details for different roads.

Stay-bolts should be made of the best quality double refined iron free from steel, having a tensile strength of not less than 48,000 pounds per square inch. The bars must be straight, smooth, free from cinder pits, blisters, seams, or other imperfections. The

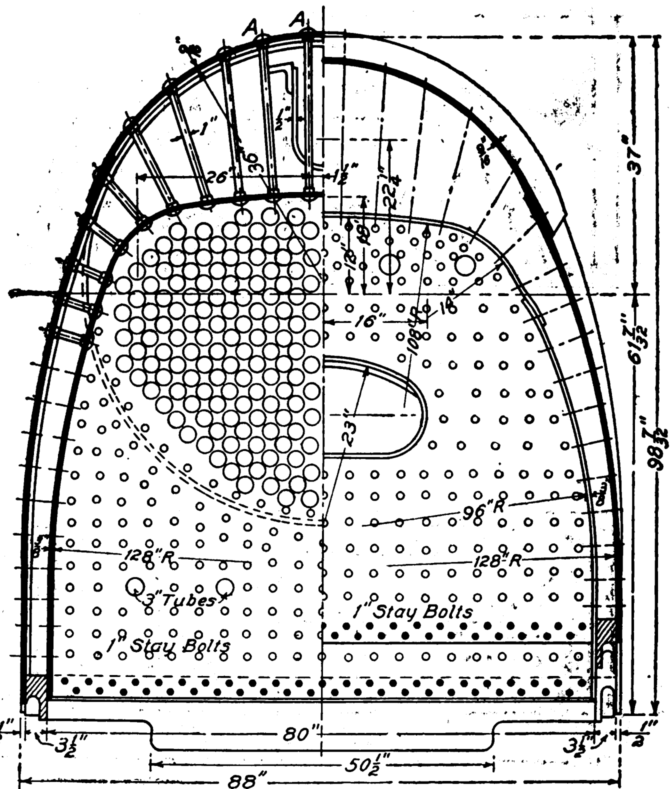


Fig. 44. Section of Boiler Having Radial Stays.

common practice is to use stay-bolts $\frac{7}{8}$ or 1 inch in diameter spaced about 4 inches from center to center.

Stay-bolt breakage is very large in bad water districts and gives a great deal of trouble on most railroads. The stay-bolt problem, therefore, is a very important one.

In addition to staying the sides and front and back ends, it is also necessary to stay the crown sheet. To accomplish this, two general methods have been used. The oldest of these, by the use of crown bars, has almost passed out of service and well it is because of the many objectionable features it possessed. In this method, a number of crown bars were used which were supported by the edges of the side sheets and which were held apart by spacers resting upon the crown sheet and to which the crown bars were tied by bolts. The crown sheet was supported by stay-bolts which were bolted to the crown bars. A great deal of the space over the crown sheet was taken up by these crown bars which greatly interferred with the circulation and made it very difficult in cleaning. The second method

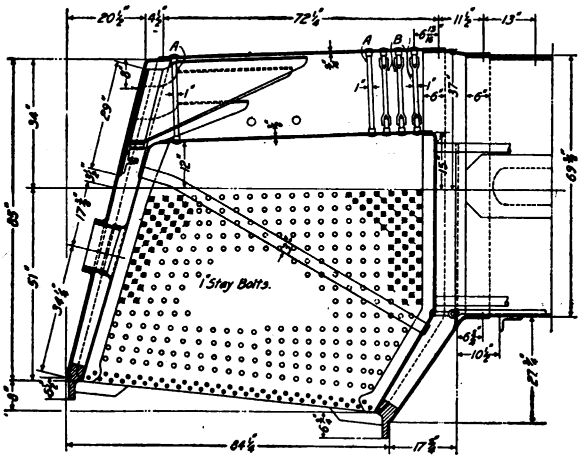


Fig. 45. Section Showing Two Types of Stays.

of staying the crown sheet is by means of radial stays. All stay-bolts over 8 inches in length are usually classified as radial stays. Radial stay-bolts are of the same general type and material as the stay-bolts already described, and are put in on radial lines; hence their name. Fig. 44 shows a section of a boiler having radial stays *A*. These stays extend around the curved surface of the fire-box from the back to within two or three rows of the front end as illustrated at *A*, Fig. 45. The stays *B* in Fig. 45 are of a different form and are frequently used in the front end to allow for expansion and contraction of the flue sheet. These extend around to the curved surface in the same manner as do the radial stays shown in Fig. 44.

All radial stays should have enlarged ends with bodies $\frac{3}{16}$ inch smaller in diameter than the outside diameter of thread. They should be made with button heads and should have threads under heads increased in diameter by giving the end a taper $\frac{1}{2}$ inch in 12 inches. Radial stays commonly used are 1 inch, $1\frac{1}{8}$ inch, and $1\frac{1}{4}$ inch in diameter at the ends. The allowable safe fiber stress is 4,500 pounds per square inch.

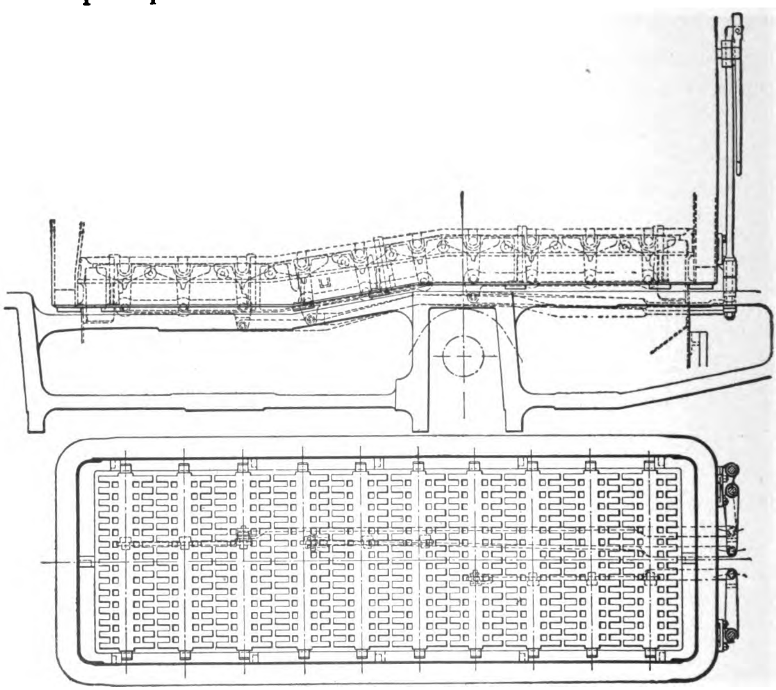


Fig. 46. Elevation and Plan of Grate.

Grates. The grate is made up of a set of parallel bars at the bottom of the fire-box, which hold the fuel. These bars are commonly made of cast iron and constructed in sections of three or four bars each. They are supported at their ends by resting upon a frame and are connected by rods to a lever which can be moved back and forth to rack the bars and shake ashes and cinders out of the fire. A drawing of such a grate is illustrated in Fig. 46. When the grates occupy the full length of the fire-box they are divided into three sections, any one of which can be moved by itself.

In the burning of anthracite coal, *water grates* are commonly used, a type of which is illustrated in Fig. 47 and Fig. 48. In Fig. 47, the grate is formed of a tube *a* expanded into the back sheets of the fire-box and inclined downward to the front in order to insure a circulation of water. Opposite the back opening, a plug is screwed into the outer sheet which affords a means whereby the tube may be cleaned and a new one inserted in position if a repair is needed. At the front end, the tube is usually screwed into the flue sheet. Water grates are rarely used alone but usually have spaced between them plain bars. These bars pass through tubes expanded into the sheets of the back water leg and by turning them, the fire may be shaken; and by withdrawing them, it may be dumped. Fig. 48 shows a cross-section of the arrangement usually employed. In this figure, *A* represents the water tube and *B*, the grate bars.

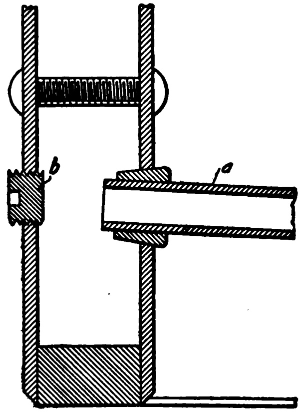


Fig. 47. Details of Water Grate for Anthracite Coal.

Ash Pans. Ash pans are suspended beneath the fire-box for the purpose of catching and carrying the ashes and coal that may drop between the grate bars. They are made of sheet steel. Fig.

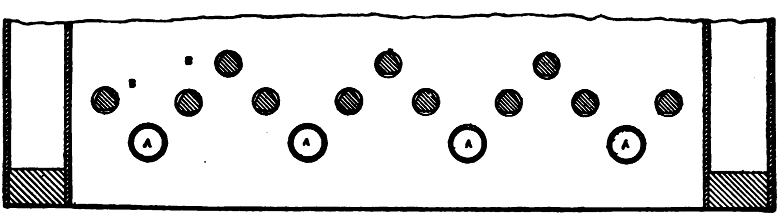


Fig. 48. Cross-Section of Water Grate.

49 illustrates a longitudinal section of an ash pan commonly used in fire-boxes placed between the axles of the engine. It is provided at each end with a damper *a* hinged at the top and which may be opened and set in any desired position in order to regulate the flow of air to the fire. It is quite important that the dampers should be in good condition in order that the admission of air to the fire may be

regulated. The total unobstructed air openings in the ash pan need not exceed the total tube area but should not be less than 75 per cent. For many years the type shown in Fig. 49 was almost universally used. More recently, however, a damper capable of better adjust-

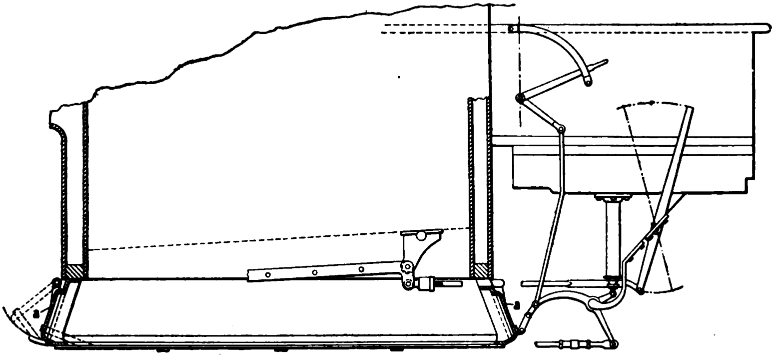


Fig. 49. Ash Pans Showing Old Lower Damper.

ment and more easily kept in condition has been developed. Such a damper is illustrated in Fig. 50. In this type the dampers are placed upon the front faces of the ash pan and are raised and lowered by the contraction of levers and bell cranks. For example, the lifting

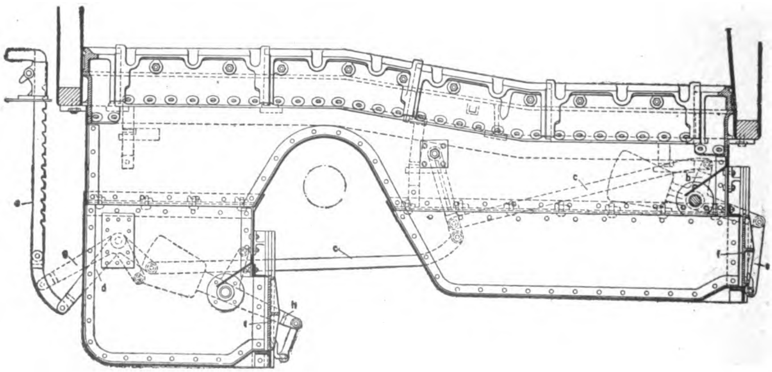


Fig. 50. New Form of Damper.

of the bar *a* turns the bell crank *d* which pulls the connection *c c* which operates the forward bell crank and opens the front damper. In a similar manner, the rear damper *i* may be operated. If these dampers were made of cast iron and work in guides, it is possible to have the construction such that when closed they will be practically air tight.

Brick Arches. A brick arch is an arrangement placed in the fire-box to effect a better combustion and to secure a more even distribution of the hot gases in their passage through the tubes. Fig. 33 illustrates a longitudinal section of the fire-box fitted with a brick arch *A*. Its method of action is very simple. It acts as a mixer of the products of combustion with the air and as a reflector of the radiant heat of the fire and the escaping gases. It is maintained at a very high temperature and in this condition meets the air and gases as they come in contact with it and turns them back to the narrow opening above. By this action it maintains a temperature sufficiently high to burn with the smallest possible quantity of air all the carbonic oxide and the hydrocarbons that arise from the coal. It thus effects a very considerable saving in the cost of running, does away to a great extent with the production of smoke, and develops a high calorific power in comparatively small fire-boxes. This is a valuable property since it is possible for the boiler to utilize the heat value of the coal to the greatest possible extent. The bricks are usually about 4 or 5 inches thick and are ordinarily supported either by water tubes, as shown in Fig. 33 and Fig. 45, or by brackets in the form of angle-irons riveted to the side sheets. The disadvantage accruing from the use of the brick arch is that it is somewhat expensive to maintain because of the rapid deterioration and burning away of the material.

Smoke-Box and Front End Arrangement. By the term *front end* is meant all that portion of the boiler beyond the front tube sheet and includes the cylindrical shell of the boiler and all the parts contained therein such as the steam or branch pipes, exhaust nozzle, netting, diaphragm, and draft or petticoat pipes. These parts referred to above are illustrated in the sectional view shown in Fig. 32.

The Steam or Branch Pipes. These pipes, 33, follow closely the contour of the shell and connect the T-head, 34, with the steam passage leading to the cylinder and conduct the steam from the dry-pipe to both the right and the left cylinders.

Exhaust Nozzle. The exhaust nozzle is the passage through which the steam escapes from the cylinders to the stack.

Netting. The netting, 26, is a coarse wire gauze placed in the front end which prevents large cinders from being thrown out by the action of the exhaust and thereby reduces the chances for fires being started along the right of way.

Diaphragm. The diaphragm or deflector plate, 27, is an iron plate placed obliquely over a portion of the front end of the flues which deflects the flue gases downward before entering the stack, thus equalizing to a great extent the draft in the different flues. This deflector plate may be adjusted to deflect the gases more or less as desired.

Draft Pipes. The petticoat or draft pipes, 36, employed to increase the draft may be used singly or in multiple and raised or lowered as desired.

Draft. The front end must be regarded as an apparatus for doing work. It receives power for doing this work from the exhaust steam from the cylinders. The work which it performs consists in drawing air through the ash pan, grates, fire, fire door, and other openings, then continues its work by drawing the gases of combustion through the flues of the boiler into the front end, then forcing them out through the stack into the atmosphere. In order that this work may be accomplished, a pressure less than the atmosphere must be maintained in the smoke-box. This is accomplished through the action of the exhaust jet in the stack. The difference in pressure between the atmosphere and the smoke-box is called *draft.*

Under the conditions of common practice, the exhaust jet does not fill the stack at or near the bottom but touches the stack only when it is very near the top. The action of the exhaust jet is to entrain the gases of the smoke-box. A jet of steam flowing steadily from the exhaust tip when the engine is at rest produces a draft that is in every way similar to that obtained with the engine running. The jet acts to induce motion in the particles of gas which immediately surround it and also to enfold and to entrain the gases which are thus made to mingle with the substance of the jet itself.

The induced action, illustrated in Fig. 51, is by far the most important. The arrows in this figure represent the direction of the currents surrounding the jet. It will be seen that the smoke-box gases tend to move toward the jet and not toward the base of the stack; that is, the jet by the virtue of its high velocity and by its contact with certain surrounding gases gives motion to the particles close about it and these moving on with the jet make room for other

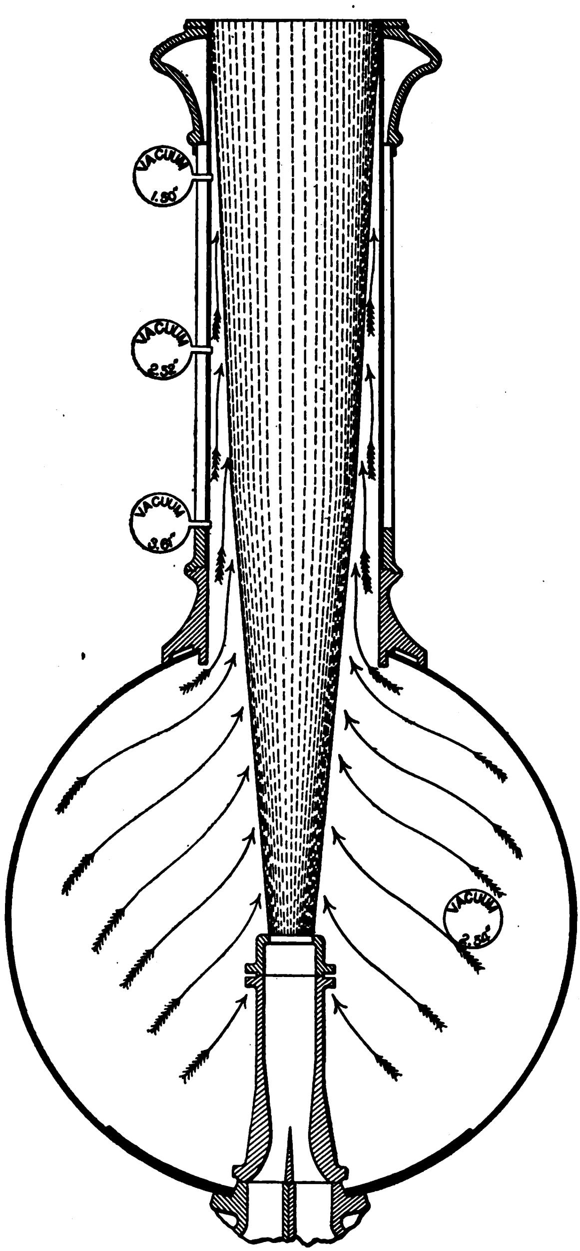


Fig. 51. Section of Exhaust Outlet into Stack, Showing Best Form to Produce Greatest Draft.

particles farther away. As the enveloping stream of gas approaches the top of the stack its velocity increases and it becomes thinner. The vacuum in the stack decreases towards the top. Thus the jet in the upper portion of the stack introduces a vacuum in the lower portion just as the jet as a whole induces a vacuum in the smoke-box.

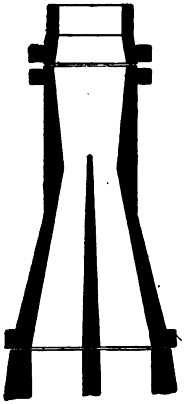


Fig. 52. Forms of Exhaust Nozzles.

It will be found that the highest vacuum is near the base of the stack. It is higher than the smoke-box on account of the large volume of gas in the latter and it grows less toward the top of the stack. This is illustrated by the different gauges shown in Fig. 51.

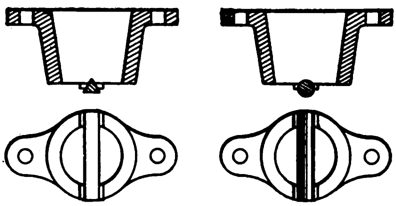


Fig. 53. Bridges Placed Across Exhaust Nozzles.

Exhaust Nozzles. It has been determined by experiment that the most efficient form of exhaust nozzle is that which keeps the jet in the densest and most compact form. Tests indicate that the nozzle giving the jet the least spread is the most efficient. Of the three forms of exhaust nozzles shown in Fig. 52, the spread of the jet is least for *a* and most for *c*. Nozzle *a* ends in a plain cylindrical portion 2 inches in length. Nozzle *c* is contracted in the form of a plain cylinder ending in an abrupt cylindrical contraction. It has been common practice, in cases where engines refuse to steam properly, to put across the exhaust nozzles round or knife-shaped bridges as indicated in Fig. 53. The use of bridges accomplishes the desired result but experiments have shown that this method materially affects the efficiency of the engine because of the increase of back pressure in the cylinders. It is, therefore, best not to split up the jet by using a bridge in cases where the draft is unsatisfactory, as the desired results may be obtained by reducing the diameter of the exhaust nozzle.

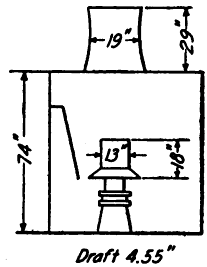


Fig. 54. Best Proportions for Single Draft Pipe and Stack.

As previously stated, draft or petticoat pipes are used for the purpose of increasing the draft or vacuum in the front end and in the tubes. A great many tests have been made under the supervision of the Master Mechanics' Association to determine the proper proportions of the petticoat pipes and their best relative position with reference to the stack and exhaust nozzle.

The report of the committee of the Master Mechanics' Association with reference to single draft pipes states "that for the best results, the presence of a draft pipe requires a smaller stack than would be used without it but that no best combination of single draft pipe and stack could be found which gave a better draft than could be obtained by the use of a properly proportioned stack without the draft pipe. While the presence of a draft pipe will improve the draft when the stack is small it will not do so when the stack is sufficiently large to serve without it. The best proportion and adjustment of a single draft pipe and stack are shown in Fig. 54."

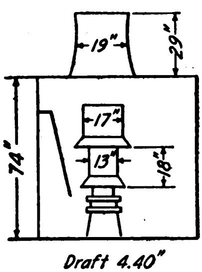


Fig. 55. Best Proportions for Double Draft Pipe and Stack.

The finding of the same committee with reference to the use of the double draft pipes is as follows: "Double draft pipes of various diameters and lengths and having many different positions within the front ends all in combination with stacks of different diameters, were included in the experiments with results which justify a conclusion similar to that reached with reference to single draft pipes. Double draft pipes make a small stack workable. They cannot serve to give a draft equal to that which may be obtained without them provided the plain stack is suitably proportioned. The arrangements and proportions giving the best results are illustrated in Fig. 55."

Stack. The stack is one of the most important features of the front end. Many different forms and proportions of stacks have been employed but at the present time only two general types are found in use to any great extent, namely, the *straight* and *tapered stacks.*

In connection with tests conducted in the Locomotive Testing Laboratory at Purdue University, it has been found that the tapered stack gives much better draft values than the straight stack. It was also found that the effect on the draft due to minor changes of proportion, both of the stack itself and the surrounding mechanism, was least noticeable when the tapered stack was used than was the case with the straight stack. A variation of one or two inches in the diameter of the tapered stack or height of the exhaust nozzle affected the draft less than similar changes with a straight stack. For these reasons, the tapered stack was recommended in preference to the straight stack. By the term *tapered stack* as herein referred to, is meant a stack having its least diameter or choke $16\frac{1}{2}$ inches from the bottom, and a diameter above this point increasing at the rate of two inches for each additional foot.

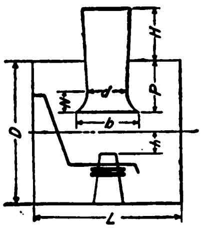


Fig. 56. Arrangement of Nozzle and Stack.

The diameter of any stack designed for best results is affected by the height of the exhaust nozzle. As the nozzle is raised, the diameter of the stack must be reduced and as the nozzle is lowered, the diameter of the stack must be increased. From the facts mentioned above, it can be seen there exists a close relation between the exhaust nozzle, petticoat pipe, stack, and the diaphragm; hence a standard front end arrangement has been recommended and is presented herewith.

The best arrangement of front end apparatus is shown in Fig. 56, in which

H = height of stack above boiler shell in inches
D = diameter of shell in inches
L = length of the front end in inches
P = the distance in inches stack extends into the smoke-box

N = distance in inches from base of stack to choke
b = width of stack in inches at the base
d = diameter of stack in inches at the choke
h = distance in inches of the nozzle below the center line of smoke-box

In order to obtain the best results, H and h should be made as great as possible while the other principal dimensions should be as follows:

$d = .21\ D + .16\ h$
$b = 2\ d$ or $.5\ D$
$P = .32\ D$
$N = .22\ D$

Rate of Combustion. It is a well-known fact that each pound of fuel is capable of giving out a certain definite amount of heat. Therefore, the more rapid the combustion, the greater the amount of heat produced in a given time. In stationary boilers, where the grate is practically unlimited, the rate of combustion per square foot of grate area per hour varies from 15 to 25 pounds. In locomotives, however, where the grate area is limited, the fuel consumption is much greater, rising at times as high as 200 pounds per square foot of grate area per hour. This rapid combustion results in a great loss of heat and a reduction in the amount of water evaporated per pound of coal. It has been shown that when coal is burned at the rate of 50 pounds per square foot of grate area per hour, 8¼ pounds of water may be evaporated for each pound of coal. While if the rate of combustion is increased to 180 pounds per square foot of grate area per hour, the evaporation will fall off to about five pounds, a loss of water evaporated per pound of coal of nearly 40 per cent. This loss may be due to a failure of the heating surface to absorb properly the increased volume of heat passing over them, or to the imperfect combustion of the fuel on the grate, or it may be due to a combination of these causes.

The results of experiments show that the lower the rate of combustion the higher will be the efficiency of the furnace, the conclusion being that very high rates of combustion are not desirable and consequently that the grate of a locomotive should be made as large as possible so that exceptionally high rates of combustion will not be necessary.

With high rates of combustion, the loss by sparks is very serious and may equal in value all of the losses occurring at the grate. Fig. 57 is a diagram representing the losses that occur, due to an increase in the rate of combustion. The line *a b* illustrates graphically the amount of water evaporated per pound of coal for the various rates of combustion. Thus, with a rate of 50 pounds per square foot of grate area per hour, 8¼ pounds of water are evaporated. When the rate of combustion is raised to 175 pounds, only about 5⅓ pounds of water are evaporated. It is thus seen that the efficiency of the locomotive from the standpoint of water evaporated per pound of

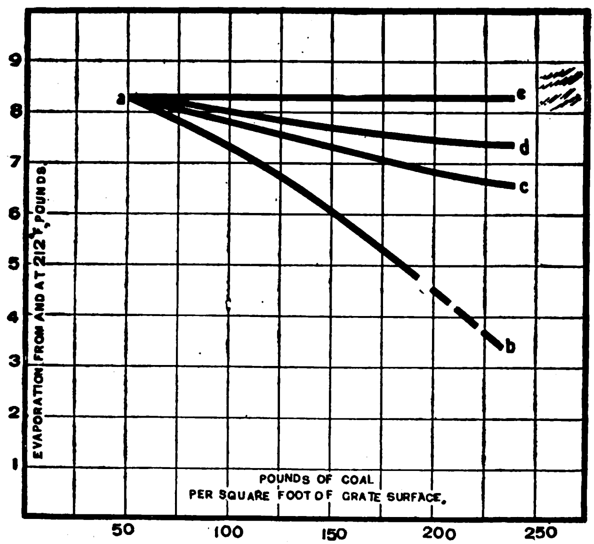


Fig. 57. Curves Showing Losses Due to Increases in Rate of Combustion.

coal decreases as the rate of combustion per square foot of grate area increases. If it could be assumed that the heat developed in the furnace would be absorbed with the same degree of completeness for all rates of combustion, the evaporation would rise to the line *a c*. If, in addition to this, it could be assumed that there were no spark losses, the evaporation would rise to the line *a d*. Finally, if in addition to these, it could be assumed that there were no losses by the excess admission of air or by incomplete combustion, then the evaporation would remain constant for all rates of combustion and would be represented by the line *a e*. That is, with the boiler under normal conditions, the area *a b c* represents the loss occasioned by deficient heating surface; the area *a c d* represents that caused by spark losses; and the area *a d e* represents that due to excessive amounts of air and by imperfect combustion.

Spark Losses. From the diagram shown in Fig. 57, it is evident that one of the principal heat losses is that of sparks. By the term *sparks* is meant the small particles of partially burned coal which are drawn through the flues and ejected through the stack by the action of the exhaust. In the operation of a locomotive, it has been demonstrated that the weight of sparks or cinders increases with the rate of combustion and may reach a value of from 10 to 15 per cent of the total weight of coal fired. Damage suits frequently arise, due to fires started by cinders thrown from the stack of the locomotive. Experiments have shown, however, that sparks from a locomotive will not be likely to start fires beyond the right of way.

High Steam Pressures. With the development of high-power locomotives came the use of high steam pressures. At first, only very low pressures were carried but soon 200 pounds pressure per square inch became very common and 220 and 225 not unusual. But with the increase of pressure there came an increase in trouble due to bad water, leaky flues, and an increase in incidental leaks in the boiler. All of these factors affected the performance of the locomotive. To determine to what extent the economic performance of the boiler was affected by an increase of steam pressure and also the most economical steam pressure to use, a series of tests were carried out at Purdue University. The following are the conclusive results as read before the Western Railway Club by Dean W. F. M. Goss:

THE EFFECT OF DIFFERENT PRESSURES UPON BOILER PERFORMANCE

1. The evaporative efficiency of a locomotive boiler is but slightly affected by changes in pressure between the limits of 120 pounds and 240 pounds.

2. Changes in steam pressure between the limits of 120 pounds and 240 pounds will produce an effect upon the efficiency of the boiler which will be less than one-half pound of water per pound of coal.

3. It is safe to conclude that changes of no more than 40 or 50 pounds in pressure will produce no measurable effect upon the evaporative efficiency of the modern locomotive boiler.

THE EFFECT OF DIFFERENT PRESSURES UPON SMOKE-BOX TEMPERATURES

1. The smoke-box temperature falls between the limits of 590 degrees F. and 850 degrees F., the lower limit agreeing with the rate of evaporation of 4 pounds per foot of heating surface per hour and the higher with a rate of evaporation of 14 pounds per square foot of heating surface per hour.

2. The smoke-box temperature is so slightly affected by changes in steam pressure as to make negligible the influence of such changes in pressure for all ordinary ranges.

CONCLUSIONS

1. The steam consumption under normal conditions of running has been established as follows:

Boiler Pressure	Steam per Horse-Power Hour
120	29.1
140	27.7
160	26.6
180	26.0
200	25.5
220	25.1
240	24.7

2. The results show that the higher the pressure, the smaller the possible gain resulting from a given increment of pressure. An increase of pressure from 160 to 200 pounds results in a saving of 1.1 pounds of steam per horse-power per hour while a similar change from 200 pounds to 240 pounds improves the performance only to the extent of .8 of a pound per horse-power hour.

3. The coal consumption under normal conditions of running has been established as follows:

Boiler Pressure	Coal per Horse-Power Hour
120	3.84
140	3.67
160	3.53
180	3.46
200	3.40
220	3.35
240	3.31

4. An increase of pressure from 160 to 200 pounds results in a saving of 0.13 pounds of coal per horse-power hour while a similar change from 200 to 240 results in a saving of but 0.09 pounds.

5. Under service conditions, the improvement in performance with increase of pressure will depend upon the degree of perfection attending the maintenance of the locomotive. The values quoted in the preceding paragraphs assume a high order of maintenance. If this is lacking, it may easily

happen that the saving which is anticipated through the adoption of higher pressures will entirely disappear.

6. The difficulties to be met in the maintenance both of boiler and cylinders increase with increase of pressure.

7. The results supply an accurate measure by which to determine the advantage of increasing the capacity of a boiler. For the development of a given power, any increase in boiler capacity brings its return in improved performance without adding to the cost of maintenance or opening any new avenues for incidental losses. As a means of improvement it is more certain than that which is offered by increase of pressure.

8. As the scale of pressure is ascended an opportunity to further increase the weight of a locomotive should in many cases find expression in the design of a boiler of increased capacity rather than in one of higher pressures.

9. Assuming 180 pounds pressure to have been accepted as standard and assuming the maintenance to be of the highest order, it will be found good practice to utilize any allowable increase in weight by providing a larger boiler rather than by providing a stronger boiler to permit higher pressures.

10. Whenever the maintenance is not of the highest order, the standard running pressures should be below 180 pounds.

11. Where the water which must be used in boilers contains foaming or scale-making admixtures, best results are likely to be secured by fixing the pressure below the limit of 180 pounds.

12. A simple locomotive using saturated steam will render good and efficient service when the running pressure is as low as 160 pounds. Under most favorable conditions, no argument is to be found in the economical performance of a machine which can justify the use of pressures greater than 200 pounds.

Heating Surface. While the points thus far considered are more or less important in their bearing in the generation of steam, yet the amount of heating surface is, as a rule, the most important. As previously stated, the lower the rate of combustion per square foot of heating surface, the higher will be the rate of evaporation per pound of coal. The ratio of the heating surface of the flues to that of the firebox varies greatly, in some cases being only 9 to 1 while in others it is found as great as 18 to 1. There is perhaps a correct value for this ratio, but at the present time it is unknown. The relation existing between the total heating surface and the grate area varies between wide limits for different cases. Table III, taken from the Proceedings of the Master Mechanics' Association for 1902, gives the ratio of heating surface to grate area in passenger and freight locomotives burning various kinds of fuel.

TABLE III

Ratio of Heating Surface to Grate Area

Fuel	Passenger Locomotive		Freight Locomotive	
	Simple	Compound	Simple	Compound
Free Burning Bituminous	65 to 90	75 to 95	70 to 85	65 to 85
Average Bituminous	50 to 65	60 to 75	45 to 70	50 to 65
Slow Burning Bituminous	40 to 50	35 to 60	35 to 45	45 to 50
Bituminous, Slack, and Free Burning Anthracite	35 to 40	30 to 35	30 to 35	40 to 45
Low Grade Bituminous, Lignite, and Slack	28 to 35	24 to 30	25 to 30	30 to 40

From the foregoing, it is evident that it is exceedingly difficult to determine just how much heating surface a locomotive boiler should have to give the best results. As a rule, they are made as large as possible so long as the total allowable weight of the locomotive is not exceeded. This is not, however, a scientific rule to follow but it is safe to say that the value of no locomotive has ever been impaired by having too much heating surface. The greater the boiler power, the higher will be the speed which can be maintained. It is important that the boiler be covered with a good lagging in order to prevent loss of heat due to radiation.

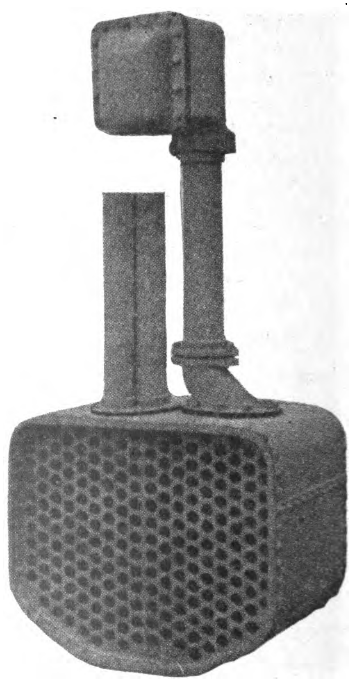


Fig. 58. Pielock Superheater.

Superheaters. When steam is admitted to the cylinder it meets the cylinder walls, the temperature of which is less than that of the entering steam, and there results an interchange of heat.

The fact that the steam gives up a part of its heat to the cylinder, causes some of the steam to condense. As the piston proceeds on its stroke and expansion occurs, some of the steam initially condensed will be re-evaporated. The cylinder, therefore, goes through a process of alternately cooling and reheating, resulting in condensation and re-evaporation; this is the principal loss occurring in the process.

In order to assist in reducing this loss to a minimum, superheated steam is being used on locomotives, to a certain limited extent in the United States, by the addition of a superheater. A superheater consists of a series of tubes and headers usually placed in the smoke-box, through which steam passes on its way to the cylinders, thus raising its temperature. It has now secured a certain amount of heat energy from the waste gases which pass out of the stack,thus improving the economy of the locomotive.

Pielock Superheater. The Pielock superheater, illustrations of which are shown in Fig. 58 and Fig: 59, is found in use on a number of railways in Germany and in Italy, and also on the Hungarian State Railways. Its construction consists of a box containing tube plates corresponding to those of the boiler, the box being set in the boiler barrel so that the flues pass through it. It is placed at such a distance from the fire-box as will prevent the tubes from becoming overheated. The vertical baffle plates *G* between the rows of tubes cause the steam to follow a circuitous path passing up and down between the tubes. The steam from the dome passes down the open pipe *A*, Fig. 59, to the left-hand chamber *B*, then transversely to the several chambers as shown by arrows until it reaches the right-hand chamber *C*. From the chamber *C* it passes up through the pipe *D* to the chamber enclosing a throttle valve from which it enters the steam pipe *E*.

In installing the superheater, the boiler tubes are first set in place in the superheater and then placed in the boiler, the smoke-box tube plate being left off for this purpose. The tubes are first expanded into the fire-box or back flue-sheet, then in the superheater plates (for which a special mandrel is used), and finally in the front flue-sheet. A blow-off cock extends from the bottom of the superheater through the boiler by means of which any leaks in the superheater may be detected. A gauge at the bottom indicates the degree of superheat of the steam in the throttle valve chamber.

This type of superheater can be applied to a locomotive without

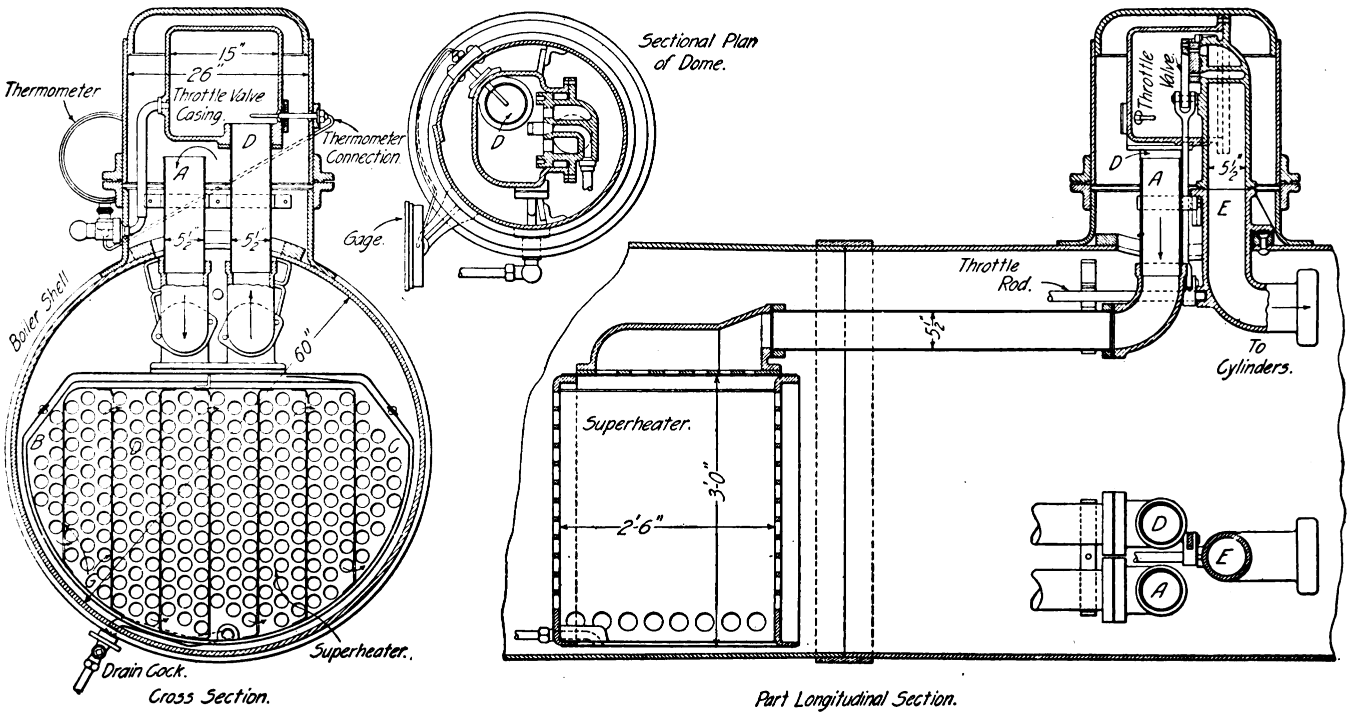


Fig. 59 Details of Pielock Superheater.

making any alteration since the superheater is built to fit the boiler in which it is to be used. It does not interfere with the cleaning of the flues or the washing out of the boiler. It is reported that by the use of this superheater a saving in coal of about 15 to 18 per cent and in water of about 20 per cent, is effected.

Schmidt Superheater. The Schmidt superheater is another type which is largely used on German railroads. Its construction is based on entirely different principles from those of the Pielock superheater. It differs from the Schenectady or Cole superheater in details only.

Schenectady or Cole Superheater. The Schenectady superheater was developed by the American Locomotive Company. It has had a large application in recent years and good results are being obtained. The general arrangement and construction of this superheater is shown in Fig. 60 and Fig. 61.

The use of bent tubes and the necessity for dismantling the whole apparatus in order to repair a single leaky boiler tube gave rise to many objections to the use of superheaters. In the construction of the Schenectady superheater, many of the objectionable features have been eliminated. By reference to Fig. 60, it will be seen that steam entering the T-pipe from the dry pipe *A* is admitted to the upper compartment only. To the front side of the T-pipe are attached a number of header castings *B*, the joint being made with copper wire gaskets, as in steam chest practice. Each header casting is subdivided into two compartments by a vertical partition shown in cross-section at *C*. Five tubes each $1\frac{1}{16}$ inch outside diameter are inserted through holes (subsequently closed by plugs) in the front wall of each header casting. These tubes having first been expanded, special plugs are firmly screwed into the vertical partition wall and are enclosed by five $1\frac{3}{4}$-inch tubes which are expanded into the rear wall of the header casting in the usual way. Each nest of two tubes is encased by a regular 3-inch boiler tube which is expanded into the front and back tube sheets as usual. The back end of each inner tube is left open and the back end of each middle tube is closed. The back ends of the two tubes are located about 36 inches forward from the rear flue sheet. The arrangement of the three flues is shown in Fig. 61. The inner tube is allowed to drop and rest on the bottom of the middle tube while the end of the middle tube is so constructed as to support both the inner and middle tubes in the upper part of the 3-inch tube, thus leaving a clear space below.

As can be seen from Fig. 60, steam from the dry pipe enters the forward compartments of each of the header castings, passes back through each of the inner tubes, thence forward through the annular space between the inner and middle tubes, through the rear compartments of each of the header castings, and thence into the lower compartment of the T-pipe, thence by the right and left steam pipe *D* and *E* to the cylinders. The steam in passing through the different channels is superheated by the smoke-box gases and products of combustion. In this particular design, fifty-five 3-inch tubes are employed, thus displacing as many of the regular smaller tubes as would occupy a similar space.

It is necessary to provide some means by which the superheater

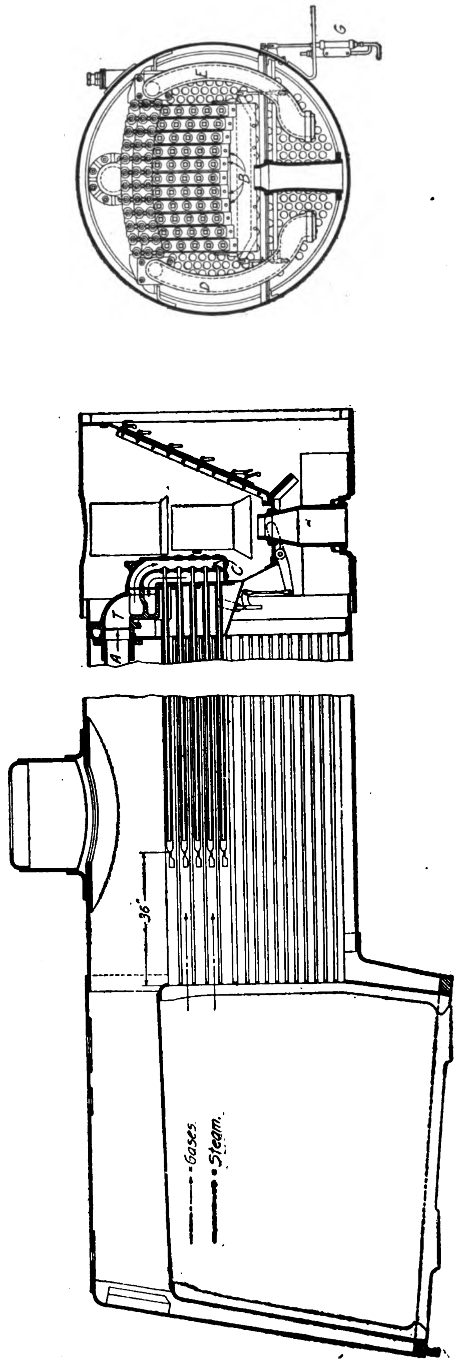


Fig. 60. Details of Schenectady or Cole Superheater.

tubes shall be protected from excessive heat when steam is not being passed through them. In this instance, this is accomplished by the automatic damper shown in Fig. 60. The entire portion of the smoke-box below the T-pipe and back of the header castings is completely enclosed by metal plates. The lower part of this enclosed box is provided with a damper which is automatic in its action. Whenever the throttle is opened and steam is admitted to the steam chest, the piston of the automatic damper cylinder *G* is

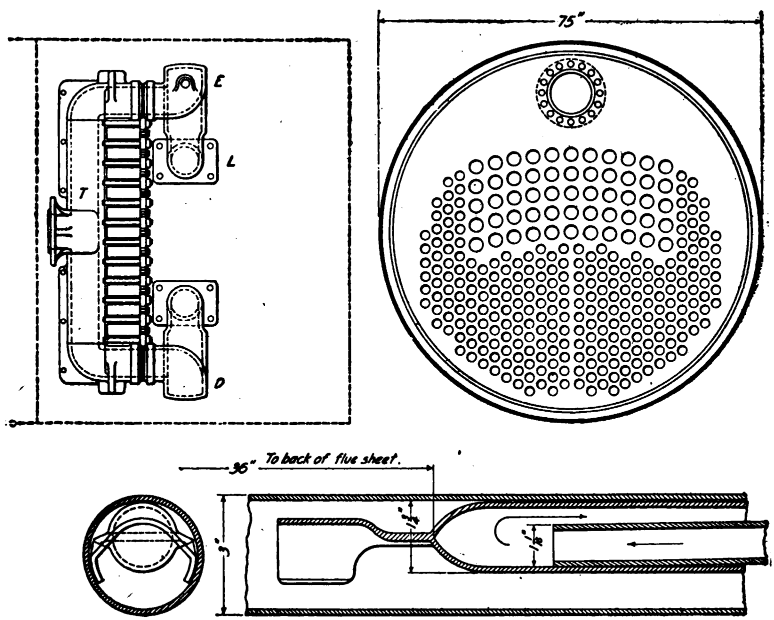


Fig. 61. Further Details of Cole Superheater.

forced upward and the damper is held open, but when the throttle is closed, the spring immediately back of the automatic damper cylinder closes the damper and no heat can be drawn through the 3-inch tubes. In this way, the superheater tubes are prevented from being burned. There is a slight loss of heating surface in introducing the group of 3-inch tubes and applying a superheater, but this loss is more than offset by the gain in economy due to the use of the superheated steam.

The results of laboratory tests of the Schenectady superheater indicate a saving of from 14 to 20 per cent of water and from 5 to 12 per cent of coal.

Baldwin Superheater. The Baldwin superheater which is now being used by some railroads differs from the Schenectady and the Pielock superheaters in that it is found entirely within the smoke-box. It can be applied to any locomotive without disturbing the boiler and its application does not reduce the original heating surface.

It consists of two cast-steel headers *A*, Fig. 62, which are cored with proper passages and walls. These headers are connected by a large number of curved tubes which follow the contour of the smoke-box shell, and are expanded in tube plates bolted to the headers. The curved tubes are divided into groups, the passages in the headers being so arranged that the steam after leaving the T-head on either side passes down through the group forming the outer four rows of the rear section of superheater tubes, then crosses over in the lower header and passes up through the inner group of the next section and up through the outer group and thence down through both the inner and outer groups of the forward section and through a passage-way in the lower header to the saddle. As illustrated in Fig. 63, these tubes are heated by the gases from the fire tubes and the deflecting plates are so arranged as to compel these gases to circulate around the tubes on both sides to the front end of

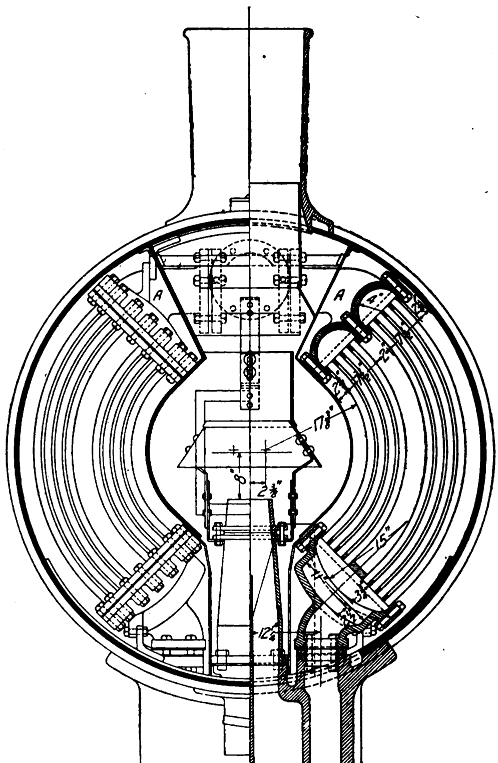


Fig. 62. Baldwin Superheater.

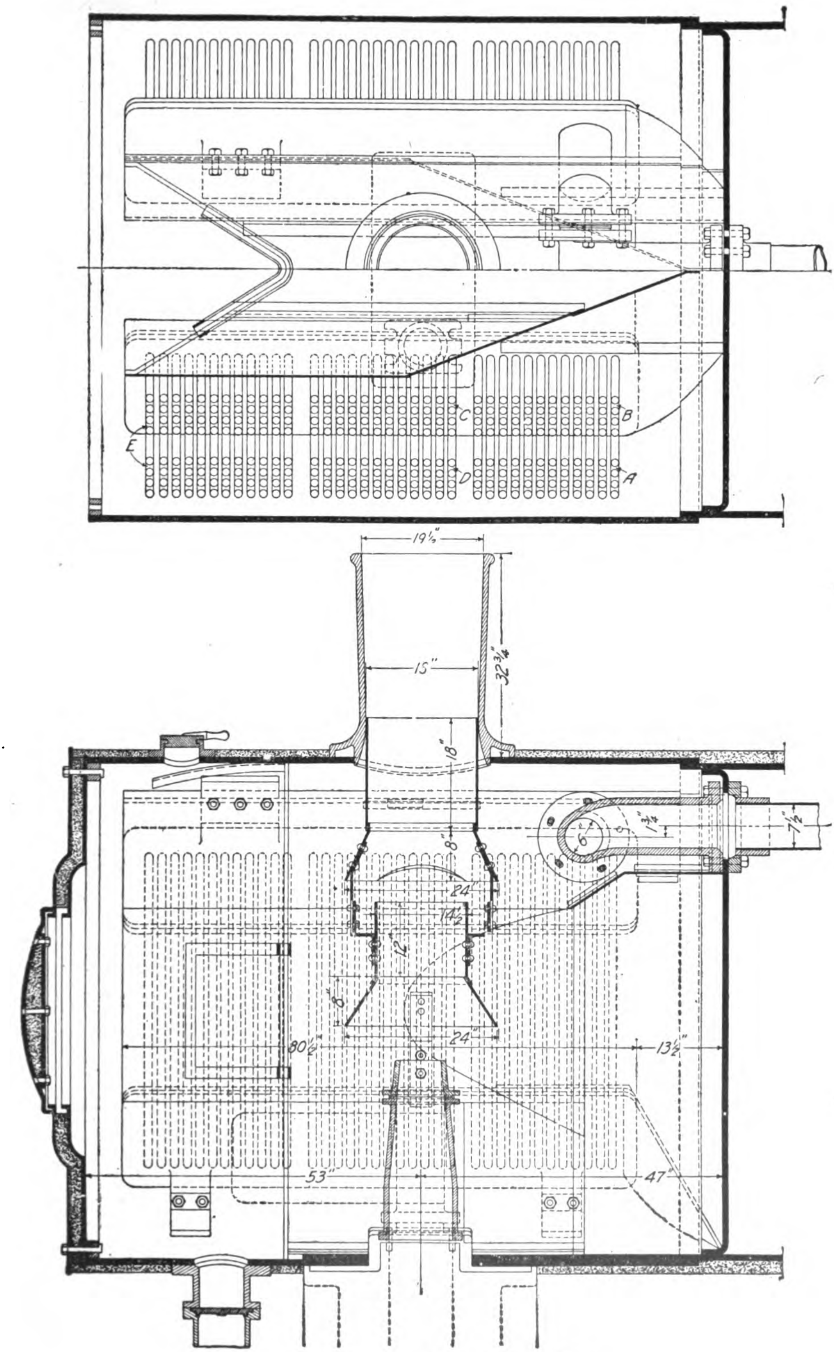


Fig. 63. Side Elevation Baldwin Superheater.

the smoke-box and thence back through the center to the stack. Thus, the superheater uses only such heat as is ordinarily wasted through the stack, and whatever gain in superheat is obtained, is clear gain.

Experiments so far made with this type of superheater show that while it is not possible to obtain a very high degree of superheat, yet enough is obtained to very decidedly increase the economy of the boiler. The front end is heavily lagged at all points to prevent as far as possible all loss of heat by radiation.

There have been several types of superheaters placed on the market in addition to those already mentioned, all having more or less merit. They differ in detail of construction but the principle embodied is covered by some one of the types described in the preceding pages.

Superheater Tests. Of recent years much experimental work has been done to ascertain the relative increase in economy obtained by the use of locomotives equipped with superheaters and to determine the increase, if any, in the maintenance of locomotives so equipped. In many instances the published data on the subject is presented in such a manner as to make comparisons rather difficult. The experiments conducted by Dr. Goss during the last few years have been of much interest to railroad men. The work was conducted on the Purdue locomotive, having a boiler designed to carry a working pressure of 250 pounds per square inch. The results obtained are very briefly summarized in Tables IV, V, VI, and VII.

TABLE IV

Steam per Indicated Horsepower per Hour
(Cole Superheater)

Boiler Pressure in Pounds per Sq. In. Gage	Superheat in Degrees F.	Pounds Steam per I.H.P. per Hour		Saving in Per Cent by Use of Superheated Steam
		Saturated Steam	Superheated Steam	
240	139.6	24.7	22.6	8.50
220	145.0	25.1	21.8	13.14
200	150.3	25.5	21.6	14.51
180	155.6	26.0	21.9	15.77
160	160.8	26.6	22.3	16.16
140	166.1	27.7	22.9	17.32
120	171.4	29.1	23.8	18.21

TABLE V

Coal per Indicated Horsepower per Hour
(Cole Superheater)

Boiler Pressure in Pounds per Sq. In. Gage	Pounds Dry Coal per I.H.P. per Hour		Saving in Per Cent by Use of Superheated Steam
	Saturated Steam	Superheated Steam	
240	3.31	3.12	5.74
220	3.37	3.00	10.98
200	3.43	2.97	13.41
180	3.50	3.01	14.00
160	3.59	3.08	14.21
140	3.77	3.17	19.51
120	4.00	3.31	17.27

TABLE VI

Steam per Indicated Horsepower per Hour
(Schmidt Superheater)

Boiler Pressure in Pounds per Sq. In. Gage	Superheat in Degrees F.	Pounds Steam per I.H.P. per Hour		Saving in Per Cent by Use of Superheated Steam
		Saturated Steam	Superheated Steam	
240	222.2*	24.7	19.5*	21.05
220	226.5*	25.1	19.0*	24.30
200	230.8	25.5	18.9	25.89
180	235.1	26.0	18.7	28.08
160	239.4	26.6	18.9	28.94
140	243.8	27.7	19.5	29.60
120	248.6	29.1	21.0	27.83

* Results estimated for making comparisons.

TABLE VII

Coal per Indicated Horsepower per Hour
(Schmidt Superheater)

Boiler Pressure in Pounds per Sq. In. Gage	Pounds Dry Coal per I.H.P. per Hour		Saving in Per Cent by Use of Superheated Steam
	Saturated Steam	Superheated Steam	
240	3.31	2.63*	20.54
220	3.37	2.57*	23.74
200	3.43	2.55	25.65
180	3.50	2.51	28.28
160	3.59	2.55	28.97
140	3.77	2.63	30.24
120	4.00	2.89	27.75

* Results estimated for making comparisons.

The results presented in Tables IV to VII were all obtained at a uniform speed of 30 miles per hour, and may be briefly stated as follows:

(a) With the locomotive equipped with a Cole superheater a saving was effected, over values obtained with saturated steam, in steam used per I.H.P. per hour of from 8.5 to 18.21 per cent, and in coal per I.H.P. per hour of from 5.74 to 17.25 per cent.

(b) With the locomotive equipped with a Schmidt superheater the saving of steam used per I.H.P. per hour varied from 21.05 to 29.60 per cent, while the saving in coal used per I.H.P. per hour varied from 20.54 to 30.24 per cent.

(c) The superheat in the branch pipe just before entering the cylinders, varied from 139.7 to 171.4 degrees F., when the Cole superheater was used, and from 222.2 to 248.6 degrees F., when the Schmidt superheater was used,

The higher efficiency obtained of the Schmidt superheater over the Cole superheater is partially accounted for by the fact that the total heating surface of the Schmidt amounted to 325 square feet, while that of the Cole was only 193 square feet.

In conclusion, it may be stated that the superheating simple locomotive will reduce the steam and coal consumption to that required by the compound locomotive. It will operate efficiently on comparatively low steam pressures, and its maximum possible power is considerably beyond that of the simple locomotive using saturated steam. Many complaints have been made by operators relative to difficulty experienced in securing proper lubrication of the valve, etc., when using superheated steam. It has been demonstrated, however, that this difficulty can be overcome by the exercise of good judgment in the use of and proper amount and grade of lubricating oil.

Locomotive Boiler Design. The design of locomotive boilers and engines is a very deep subject—one requiring much thought and study. Limited space prevents going into a discussion of the reasons for the adoption of different designs. The following formulae for the calculation of thickness of plates, spacing of rivets, etc., are given. Some of these formulae, while being semi-empirical, are based on theoretical assumptions and represent modern practice in the design of parts mentioned. In figuring the thickness of the boiler shell, the following formula is given:

$$t = \frac{P D f}{2 T E}$$

where

t = thickness of shell in inches
P = steam pressure, pounds per square inch
D = inside diameter of shell in inches
f = factor of safety, usually taken not less than $4\frac{1}{2}$
T = tensional strength of plate in pounds per square inch, usually taken as 55,000
E = efficiency of longitudinal joint expressed as a decimal fraction which may be taken as .85

Example. In a given locomotive boiler, the first ring is 60 inches in diameter; the steam pressure is 200 pounds Required the thickness of the plate.

SOLUTION.

$$t = \frac{200 \times 60 \times 4.5}{2 \times 55000 \times .85}$$
$$= .57 \text{ inches}$$

The efficiency of the joint is expressed as follows:

$$E = \frac{\text{Tearing resistance of joint}}{\text{Tearing resistance of solid plate of same dimensions}}$$

or

$$E = \frac{\text{Shearing resistance of joint}}{\text{Shearing resistance of solid plate of same dimensions}}$$

NOTE: Use whichever value is the least.

In computing the thickness of the conical connection in a boiler shell use the formula

$$t = \frac{P D f}{2 T E}$$

the inside diameter at the large end being considered.

In calculating the thickness of the fire-box side and fire-door sheets, the following formula may be used:

$$t = \sqrt{\frac{2\ a^2\ P}{49500}}$$

where a = the pitch of stay-bolts in inches.

The pitch of the stay-bolts may be taken as

$$a = \sqrt{\frac{49500\ t^2}{2\ P}}$$

Example. Determine the thickness of the side sheets when the steam pressure employed is 200 pounds per square inch and the stay-bolts are spaced 4 inches from center to center.

SOLUTION.

$$t = \sqrt{\frac{2 \times 4^2 \times 200}{49500}}$$

$$= .36 \text{ inches}$$

The safe tensile strength of stay-bolts should be taken not to exceed 5,500 pounds per square inch.

The diameter of rivets may be determined by the following formula:

$$d = 1.2 \sqrt{t}$$

The following standard thicknesses of plates are used in locomotive boiler construction: Crown sheet, side sheet, and back fire-box sheet, $\frac{3}{8}$ inch in thickness; for boiler pressures not exceeding 200 pounds, the boiler head, roof, sides, and dome, $\frac{1}{2}$ inch thick, while for boilers with steam pressures between 200 and 240 pounds, these plates are $\frac{9}{16}$ inch thick.

In designing the riveted joints, their strength must be considered from several different standpoints. It must be sufficiently strong to withstand the tensional stress on the metal contained in the plate between the rivets. The plates must be of such thickness as will safely carry the compressional stresses behind the rivets and the rivets must be placed in rows sufficiently far apart and far enough from the edge of the plate to insure against shearing or tearing out of the metal. In the formulae for the design of a riveted joint, the following notation will be used:

d = diameter of rivet hole in inches
p = pitch or distance in inches between center to center of rivets
t = thickness of plate in inches
h = distance in inches from edge of plate to center of first rivet hole
T = tensile strength of plate in pounds per square inch, usually taken as 55,000
S = shearing strength of rivets in pounds per square inch, usually taken as 55,000
R = shearing strength of plate in pounds per square inch, usually taken as 45,000 pounds per square inch
C = crushing strength of plate in pounds per square inch, usually taken as 50,000 pounds per square inch
f = factor of safety usually taken not less than 4½

The safe resistance in pounds per square inch offered by one rivet to shear

$$= .7854\, d^2 \frac{S}{f}$$

The safe resistance in pounds per square inch offered to tearing of plate between rivet holes

$$= (p-d)\, t\, \frac{T}{f}$$

The safe resistance to crushing in pounds per square inch of the portion of the plate in front of rivet

$$= \frac{t\, d\, C}{f}$$

The safe resistance to shearing out in pounds per square inch of that portion of the plate in front of the rivet

$$= \frac{2\, h\, t\, R}{f}$$

Boiler Capacity. *Importance.* In the early days of the locomotive very little attention was given to the size of the boiler. If the cylinders were large enough to pull a train of reasonable size up the maximum grade and the driving wheels were loaded sufficiently to prevent slipping, the results secured were generally considered satisfactory. Today, however, conditions are changed. Now the capacity of the locomotive boiler for the generation of steam is looked upon as the most important feature in connection with the design of a locomotive and, as a rule, the boiler is made as large as possible, consistent with total weight desired. Wherever possible the weight of parts is reduced in order to favor the boiler. It is now known that no locomotive was ever impaired in any way by having a boiler that steamed too freely, for the greater the boiler capacity the greater the speed that can be maintained. As the demand for speed and the loads hauled increased, it was soon discovered that the speed of a train of a given length and weight was limited by the capacity of the boiler. Complaints were made of the boiler "not steaming", and, although the insufficient supply of steam might have been attributed to an inferior grade of fuel, improper firing, bad adjustment, "front end" arrangement, flues in bad condition, or negligence in the manipulation of the engine, it soon became recognized that, with all boiler conditions in perfect order and the locomotive operated by experienced men, it was impossible to make a small boiler supply a sufficient amount of steam for large cylinders operating at high rates of speed. As a result the boiler gradually grew in size, and with it a desire to arrive at a rational proportioning of its various parts, such as heating surface, grate area, length of tubes, etc., necessary to maintain a definite tractive effort at a definite speed.

Effect of Area of Heating Surface. All the various dimensions of the different parts of the boiler are more or less important in their relation to the question of steam generation. Perhaps the most important of these are the dimensions of the heating surface. The area of the grate surface limits the amount of coal that can be burned in a given time, but the amount of coal burned per unit of heating surface governs, to a great extent, the rate of evaporation. Concerning the rate of combustion per square foot of heating surface, it is found that the same condition exists as in stationary boiler practice, namely, that the lower the rate of combustion the greater the evaporation per pound of coal.

Effect of Tube Length. The capacity of the boiler is also affected to a certain extent by the length of the tubes. It was found in a series of extensive experiments conducted in Europe a number of years ago that the most economical length of tubes was 14 feet. This length was found with a draft in the fire-box of 3 inches of water. In the United States a much higher draft is employed and for this reason much longer tubes can be used. Tubes over 20 feet in length are now quite common. As long as the temperature of the gases in the smoke-box is above that corresponding to the pressure of steam in the boiler there will be heat transferred from the front end of the tubes to the water in the boiler. Increasing the length of the tubes will, of course, reduce the draft in the fire-box and, as a result, the amount of coal burned will be reduced. For this reason the tubes should be of a definite length for maximum efficiency.

Effect of Scale. The transmission of heat through the tubes and fire-box sheets is dependent to a large extent on the condition of the inner surfaces. If they are covered with a thin layer of scale, the heat transmitted will be materially reduced. Experiments conducted in 1898 on the Illinois Central Railroad gave some very interesting results on the effect of scale on the steaming capacity of a locomotive boiler. Tests were first made on a locomotive which had been in service 21 months. After the test the engine was sent to the shops and received new tubes and a thorough cleaning. The total weight of scale removed from the boiler was 485 pounds and it had an average thickness on the principal heating surfaces of $\frac{3}{64}$ inch. After the engine had received the cleaning and new tubes, a second test was conducted in which the same coal per square foot of heating surface was burned as in the first test. The result of the second test showed the steam-making capacity of the boiler to have been increased 13 per cent.

Effect of Radiation. The loss of heat from the outer surface of a locomotive boiler by radiation and the ultimate effect on its capacity are items worthy of consideration. The heat lost in this manner is so great with an unprotected boiler shell that it is necessary to use some form of insulating material to minimize the loss. Covering a boiler with insulating material is more necessary with high pressure than with low pressure because of the greater temperature difference. Results of tests of boiler covering reported to the Master Mechanics' Association in 1898 show that a loss of 0.34 B.t.u. per square foot of radiating surface per hour per degree difference in temperature was obtained by the use of mineral wool, while under the same conditions with a lagging of wood and sheet iron the loss was increased to 1.10 heat units. In both cases the temperature difference was reckoned between the temperature of the steam in the boiler and that of the surrounding air. The results show a saving of 0.76 B.t.u. in favor of the mineral wool lagging. Let us consider a boiler carrying steam at 200 pounds per square inch gage pressure, which represents a temperature of 388° F. Assuming the temperature of the atmosphere to be 32° F., this represents a temperature difference of 356 degrees. Assume further a locomotive boiler having an outside surface of 600 square feet. The heat of vaporization per pound of steam at 200 pounds per square inch gage pressure is 838 B.t.u. The pounds of steam condensed in the boiler per hour due to radiation in case a wood lagging is used, in excess of the amount that would be condensed if mineral wool were used, is equal to

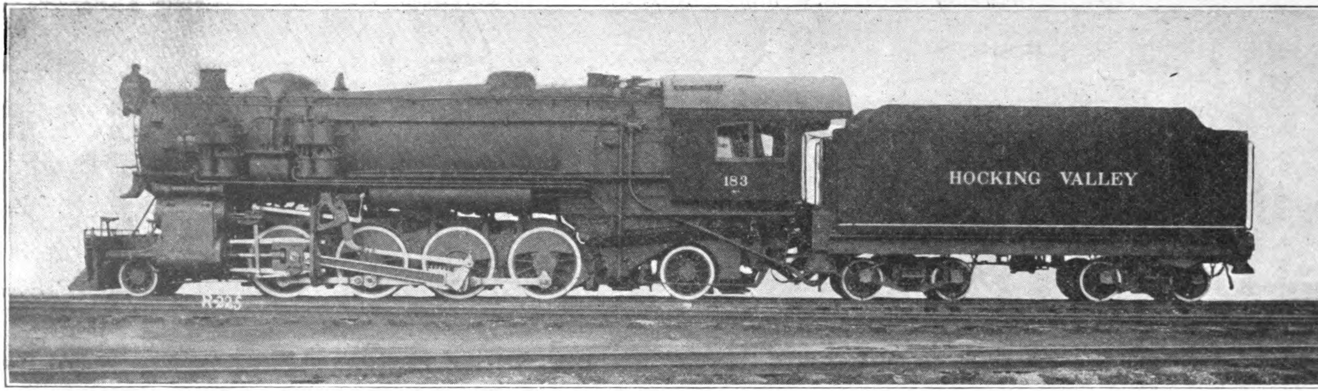
$$\frac{0.76 \times 600 \times 356}{833} = 193$$

Assuming that the steam consumption per i.h.p.hr. is 20 pounds, the above figure represents 9.6 horsepower.

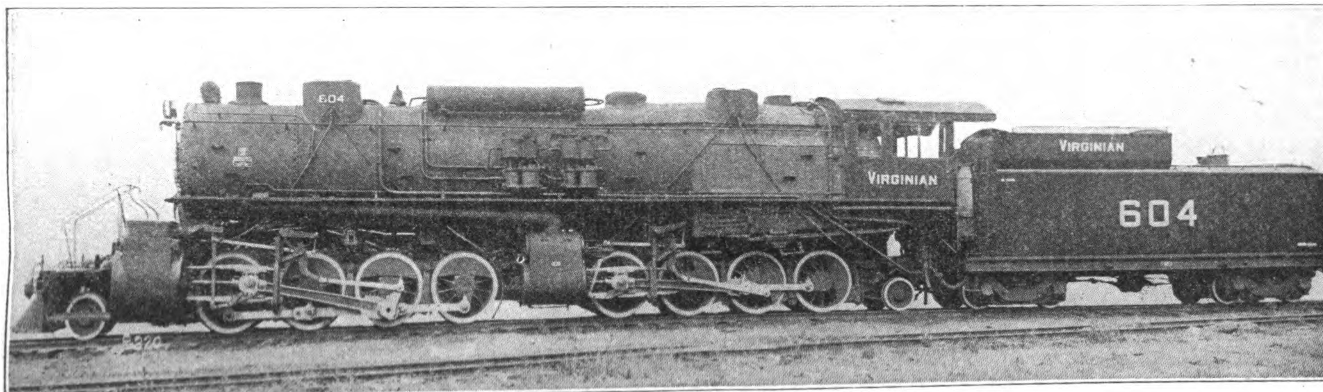
The foregoing figures represent results obtained in still air. The radiation losses are increased very much when the locomotive is in service. This fact is demonstrated by the results of tests conducted on the Chicago and Northwestern Railway in 1899. The locomotive employed had 219 square feet of covered boiler surface and 139 square feet uncovered. Assuming, for this type of engine, the steam consumption per i.h.p.hr. to be 26 pounds, the results of the tests showed a condensation representing a horsepower of 4.5 when at rest and 9 when being pushed at a rate of 28 miles per hour.

Boiler Horsepower. In the foregoing we have considered the determination of the greatest amount of steam which a locomotive boiler can produce and it is evident that the boiler capacity limits the work that can be performed by the engine. Under some circumstances it is more convenient to express the boiler capacity in terms of an evaporative unit. The term "boiler horsepower" is such a unit, but the use of this expression is sometimes misleading in speaking of the capacity of a locomotive, for a given boiler will produce a greater horsepower with a compound than with a simple engine and with an early and economical cut-off than with a later and more wasteful one.

A *boiler horsepower*, as defined by the American Society of Mechanical Engineers, is the production of 30 pounds of steam per hour at a gage pressure of 70 pounds per square inch evaporated from a feed-water temperature of 100° F. This is considered equivalent to the evaporation of 34½ pounds of water per hour from a temperature of 212° F. into steam at the same temperature.



FREIGHT ENGINE, 2-8-2 TYPE BUILT FOR THE HOCKING VALLEY RAILROAD
Courtesy of American Locomotive Company, New York City



MALLETT ARTICULATED COMPOUND LOCOMOTIVE
Courtesy of American Locomotive Company, New York City

LOCOMOTIVE BOILERS AND ENGINES

PART II

THE LOCOMOTIVE ENGINE

In studying the conditions affecting the performance of the engine proper, the amount of lead, outside lap, and inside clearance must be taken into consideration.

Lead. By *lead* is meant the amount the steam port is open when the engine is on *dead center* or when the piston is at the beginning of its stroke. This amount varies from 0 to $\frac{1}{4}$ of an inch in practice. By having the proper amount of lead, a sufficient amount of steam behind the piston is assured at the beginning of the stroke and assists in maintaining the steam pressure until the steam port is closed and the steam is thereby cut off. It also serves to promote smooth running machinery. Any admission of steam behind the piston before the end of the stroke results in negative work, hence the amount of lead should be limited and largely controlled by the speed of the machine.

Outside Lap. By the term *outside lap* is meant the amount the valve overlaps the outside edges of the steam ports when it is in its central position. One of the effects of increasing outside lap is to cause cut-off to take place earlier in the stroke, other conditions remaining unchanged. If, however, the amount of lap is increased and it is desired to maintain the same cut-off, the stroke of the valve must be increased. Within certain limits, outside lap increases the rapidity with which the valve opens the steam port, resulting in a freer admission of steam. The range of cut-off is decreased as the lap is increased, other conditions remaining the same.

When the cut-off is short, the exhaust is hastened, an effect which diminishes as the cut-off is lengthened. The amount by which the steam port is uncovered by the exhaust cavity of the slide valve is increased as the cut-off is shortened. Other things remaining constant the changing of any one of the events of stroke causes a corresponding change to a greater or less degree of each of the other events.

Inside Clearance. By the expression *inside clearance* is meant the amount the steam port is uncovered by the exhaust cavity of the valve when the valve is in its central position. Formerly it was customary to have an inside lap of about $\frac{1}{16}$ of an inch but in recent years in the development of engines which require a free exhaust at high speeds, the inside lap was reduced until now there is in some cases from $\frac{1}{8}$ to $\frac{3}{16}$ inches inside clearance. The effect of changing a valve from inside lap to inside clearance, other things remaining un-

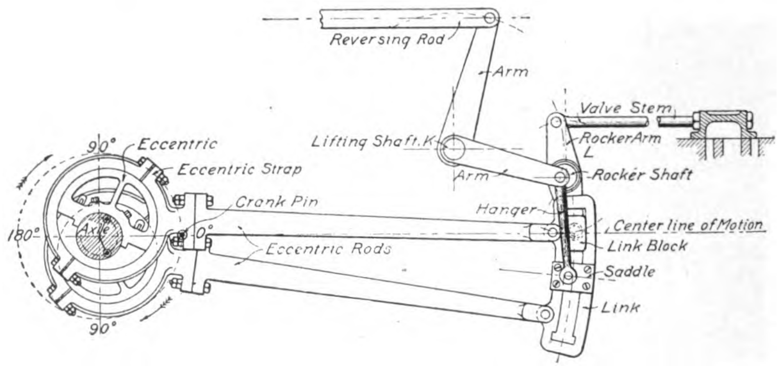


Fig. 64. Standard Stephenson Valve Gear.

changed, is to hasten release and delay compression and hence to increase the interval in which the exhaust port remains open. It also permits a greater extent of exhaust port opening. As a consequence, the exhaust is freer and the back pressure is reduced, giving an advantage in the operation of the engine, which is desired at high speeds. Experiments have shown that an increase in inside clearance for high speeds will bring about an increase in the power of the locomotive, but an increase in inside clearance at slow speeds entails a loss of power and a decrease in efficiency. The loss in power at low speeds, due to inside clearance, is greater at short cut-offs and diminishes as the cut-off is increased. Tests have shown that at moderate speeds, say, 40 to 50 miles per hour, all disadvantages are overcome.

VALVE MOTION

Requirements. The valve motion of a locomotive engine must meet the following regulations:

(1) It must be so constructed as to impart a motion to the valve which will permit the engine to be operated in either direction.

(2) It must be operative when the engine is running at a high or low speed and when starting a heavy load.

(3) It should be simple in construction and easily kept in order.

A number of valve gears have been developed which fulfill these requirements more or less satisfactorily, such as the Stephenson, the Walschaert, the Joy, and the fixed link, the Stephenson gear being the one most commonly used in the United States. A study will be made of the Stephenson and Walschaert gears, the latter resembling in some respects the Joy valve gear. The Walschaert gear has been extensively used in Europe for many years and of late years has become quite common in America. There are a few modifications of the Stephenson gear which have been made to meet structural requirements but the great majority of American engines are fitted with a device as illustrated in Fig. 64. The action of this device is fully explained in the article on "Valve Gears."

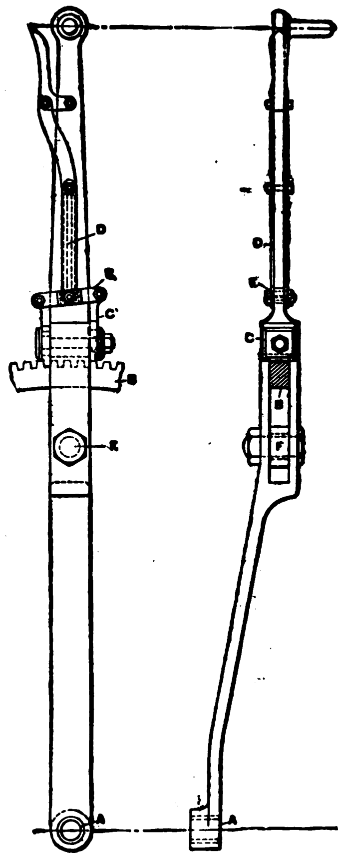


Fig. 65. Reversing Lever.

Stephenson Valve Gear. The Stephenson gear consists of the reverse lever, reach rod, lifting shaft, link hanger, link, eccentric, and rocker arm.

The *reversing lever* is given a variety of forms, a good design of which is illustrated in Fig. 65. The lever is pivoted at A, below the floor of the cab and can be moved back and forth beside the quadrant B to which it can be locked by means of the latch C. This latch is held down by a spring surrounding the rod D, acting on the center of the equalizer E. This makes it possible to use very fine graduations of the quadrant and by making the latch as shown, the cut-off can be regulated by practically what amounts to half notches.

The *reach rod,* or *reversing rod,* is fastened to the reversing lever at *F* and consists of a simple piece of flat iron having a jaw at one end by which it serves to connect the reversing lever and the lifting shaft *K*, shown in Fig. 64.

The *lifting shaft,* shown at *K*, Fig. 64, consists of a shaft held in brackets usually bolted to the engine frames to which are connected three arms, one being vertical and to which is attached the reach rod, and two horizontal ones from which the links are suspended.

The *link hanger* is a flat bar with a boss on each end. It carries the link by means of a pin attached to the link saddle, illustrated in Fig. 64.

The *link,* Fig. 64, is an open device held by the saddle and fitted with connections for the eccentric rod.

The *eccentrics,* Fig. 64, usually of cast iron, are fitted to the main driving axle.

The *rocker arm,* Fig. 64, consists of a shaft to which two arms are connected, the lower one of which is attached to the link block and the upper to the valve stem.

Setting the Valves. This is a comparatively simple operation but one requiring great care. On account of the angularity of the rods, it is impossible to adjust any link motion to give equal cut-off at all points for both strokes of the piston. The most satisfactory arrangement is one which provides for an equalization of the lead and cut-off at mid-gear. But even this will cause a variation of cut-off of from $\frac{3}{8}$ to $\frac{1}{2}$ of one per cent in the full gear part of the cut-off and at other points.

In setting the valves upon a locomotive, some means must be employed for turning the main driving wheels. This is usually accomplished by mounting the main drivers upon small rollers which can be turned by a ratchet or motor without moving the locomotive as a whole. If a set of rollers are not available, the locomotive may be moved to and fro by using pinch bars.

Before undertaking the setting of the valves, the length of the valve rod must be adjusted. To do this, set the upper rocker arm vertical if the valve seat is horizontal; if inclined, the rocker arm must be placed perpendicular to the plane of the valve seat. Next adjust the length of the valve rod so that it will connect with the rocker arm and the valve when the valve is in its central position. The next step is to locate the dead center points which points give the position of the crank on the dead center. It is very essential that this be done very accurately since a small movement of the crank at this position moves the piston but very little while the same movement causes a comparatively large movement of the valve. Hence, if the dead center points are not accurately located, the valves will not be set so accurately as they otherwise would be. To locate the dead center points, proceed as follows: First, secure a tram *d* as shown in Fig. 66. This tram should be made of a steel rod about $\frac{1}{4}$ inch in diameter having each end pointed, hardened, and tempered so as to retain a sharp point. With a center punch, make a center *e* on some fixed portion of the frame in such a position that when one point of

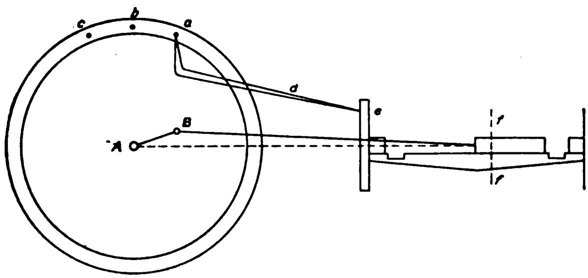


Fig. 66. Diagram for Locating Dead-Center Points.

the tram is in the center *e*, the other pointed end can be made to describe lines on the main driver. To locate the forward dead center, turn the driver ahead until the crank has almost reached the center line as shown in the position *A B*, Fig. 66; that is, when the crosshead is, say, $\frac{1}{2}$ inch from the extreme point of its travel. With the parts in this position, place the tram point in *e* as shown and locate the point *a* on the driver, and describe the line *f f* on the crosshead and guide. Next turn the driver ahead until the crank passes the dead center and the lines *f f* again coincide, when a second point *c* is marked by means of the tram at the same distance from the center of the axle as the point *a*. With a pair of dividers locate the mid-position *b* between *a* and *c*. In setting the valves for the head end, the required dead center will be located when one tram point is in the center *e* and the other in the center *b*. The dead-center point for the back stroke is located in the same manner as just described. An attempt to place the engine on dead center by measurements taken on the crosshead alone would likely result in an error, since the crank might move through an appreciable angle while passing the dead center and the consequent movement of the crosshead be inappreciable, hence the advisability of using the more exact method explained above is made apparent.

The reverse lever and all the parts having been connected, to set the valves for forward gear, the procedure is as follows: Place the reverse lever in its extreme forward position. When this is done turn the engine ahead until the valve is just beginning to cut off, as shown at *l*, Fig. 67. When this point is reached, stop the engine and make a small punch mark such as *a* on the cylinder casting. Then put one end of the tram *b* into the punch mark and describe an arc

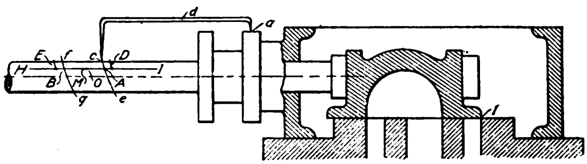


Fig. 67. Illustration of Method of Setting Locomotive Valves.

c e on the valve stem. Next turn the driver ahead until the valve is just cutting off on the other end. With the same center *a* as used before, describe another arc *f g* on the valve stem. These two arcs are known as the *port lines* and are to be the reference lines for the work which follows. Draw a straight horizontal line *H I* on the valve stem and where it intersects the arcs, make the center marks *A B*. The center *A* is the front port mark and the center *B* the back port mark. Next, place the reverse lever in the extreme backward position and locate points on the valve stem similar to the points *A* and *B*.

To avoid confusion, it is better to make all tram marks for the forward movement above the line *H I* and all those for the backward motion below.

In trying the forward movement of the valve, see that the reverse lever is in the extreme forward position, then by running the engine ahead, place the crank in turn on each dead center, and describe an arc on the valve stem. In trying the valve for the backward gear, place the reverse lever in its extreme back position and by running the engine backward, place the crank on each dead center and describe arcs on the valve stem as before. In either case, if the dead center is past, do not back up to it but either make another revolution o the engine or back beyond it some distance, then approach it from the proper direction. This must be done in order to eliminate all lost motion.

These trial tram lines should be compared with the port marks when the engine is placed in the forward and backward gear.

If the trial tram lines fall outside of the port marks, so much lead is indicated, while if they fall within the port marks, so much negative lead is indicated.

It is customary for railroad companies to set the valves on their locomotives to give equal lead. The method commonly employed is presented herewith. Having the reverse lever in the extreme forward notch, run the engine ahead, stopping it on the forward dead center. With the tram *b* in the center *a*, Fig. 67, describe the arc *D* above the line *H I*. Next turn the engine ahead until the back dead center is reached; using the tram *b* again with a center at *a*, describe the arc *E* above the line *H I*. With dividers, find a mid-point *O* between *E* and *D*. If the center *O* is ahead of the point *M*, which is midway between the port marks *A* and *B*, the eccentric blades which control the forward motion must be shortened an amount equal to the distance between *M* and *O*. When this is done, the lead will be equalized. If it is desired to increase the lead, move the forward eccentric toward the crank. To decrease the lead, move the forward eccentric away from the crank. After all of these changes have been made, repeat the operation in order to check the results. If this does not give the desired results, correct the error by repeating the process and continue by trial until the conditions sought for are obtained.

To set the valves for the back motion, proceed in the same manner as that described for the forward motion, all the changes being made on the eccentric blades and eccentric which control the backward motion.

In all that has been said regarding the setting of the Stephenson valve gear, it is assumed that the gear is one having *open rods;* that is, one in which the rods are open, not crossed when the eccentrics face the link.

Walschaert Valve Gear. The Walschaert valve gear is illustrated by the line diagram in Fig. 68-a. Fig. 68-b shows its application to a Consolidation freight locomtive. From a study of Fig. 68-a it is obvious that the motion of the valve is obtained from the crosshead and an eccentric crank attached to the main crank pin. In some designs, the eccentric pin is replaced by the usual form of eccentric attached to the main driving axle. The crosshead connection imparts a movement to the valve which in amount equals the lap plus the lead when the crosshead is at the extremities of the stroke, in which position the eccentric crank is in its mid-position. The lead of the valve is constant and can only be changed by altering the

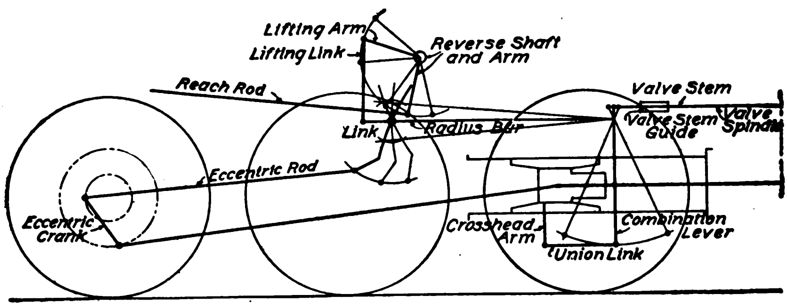


Fig. 68-a. Diagram of Walschaert Valve Gear.

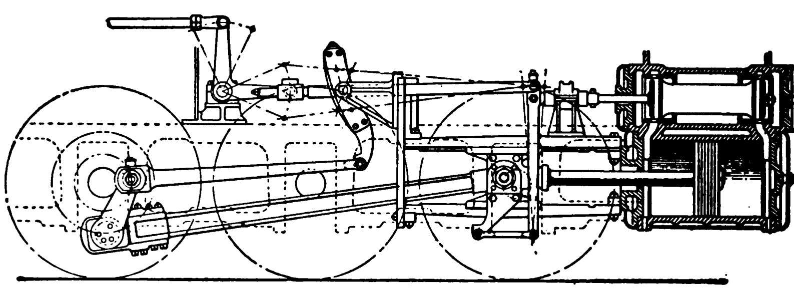


Fig. 68-b. Walschaert Gearing Mounted on a Consolidation Locomotive.

leverage relation of the combination lever. The eccentric crank actuates the eccentric rod which, in turn, moves the link to and fro very much the same as does the eccentric blade in the Stephenson gear. There is a radius bar, Fig. 68-a, which connects the link block with the valve stem. It is evident, therefore, that the valve obtains a motion from the eccentric crank, link, radius bar, and valve rod in a manner similar to the Stephenson, the main difference being in the crosshead connection which results in giving the valve a constant lead.

It is to be noted that in a valve having internal admission, the radius bar connects with a combination lever above the valve rod connection, as shown in Fig. 68-b, and that in a valve having external admission, the connection is made below the valve rod, as illustrated in Fig. 68-a; also, in a valve having internal admission, the eccentric crank follows the main crank, while in a case where the valve has external admission, it precedes the main crank. Theoretically, the eccentric crank is 90 degrees from the main crank but because of the angularity of the eccentric rod, it is usually two or three degrees more.

The Walschaert gear is operated by a reverse lever in the same manner as the Stephenson gear. In the Stephenson gear, a movement of the reverse lever causes the link to be raised or lowered, the link block remaining stationary, whereas in the Walschaert gear, the link remains stationary and the link block is raised or lowered. From a study of the two gears, it may be stated that the chief point of difference is that the Walschaert gives a constant lead for all cut-offs, whereas the Stephenson gives a different lead for different cut-offs.

The following steps given by the American Locomotive Company for adjusting the Walschaert valve gear are presented:

1. The motion must be adjusted with the crank on the dead centers by lengthening or shortening the eccentric rod until the link takes such a position as to impart no motion to the valve when the link block is moved from its extreme forward to its extreme backward position. Before these changes in the eccentric are resorted to, the length of the valve stem should be examined, as it may be of advantage to plane off or line under the foot of the link support which might correct the length of both rods, or at least only one of these would need to be changed.

2. The difference between the two positions of the valve on the forward and back centers is the lead and lap doubled and it cannot be changed except by changing the leverage relations of the combination lever.

3. A given lead determines the lap or a given lap determines the lead, and it must be divided for both ends as desired by lengthening or shortening the valve spindle.

4. Within certain limits, this adjustment may be made by shortening or lengthening the radius bar but it is desirable to keep the length of this bar equal to the radius of the link in order to meet the requirements of the first condition.

5. The lead may be increased by reducing the lap, and the cut-off point will then be slightly advanced. Increasing the lap introduces the opposite effect on the cut-off. With good judgment, these qualities may be varied to offset other irregularities inherent in transforming rotary into lineal motion.

6. Slight variations may be made in the cut-off points as covered by the preceding paragraph but an independent adjustment cannot be made except by shifting the location of the suspension point which is preferably determined by a model.

Comparison between Stephenson and Walschaert Gears. A comparison of the Stephenson and Walschaert valve gears shows

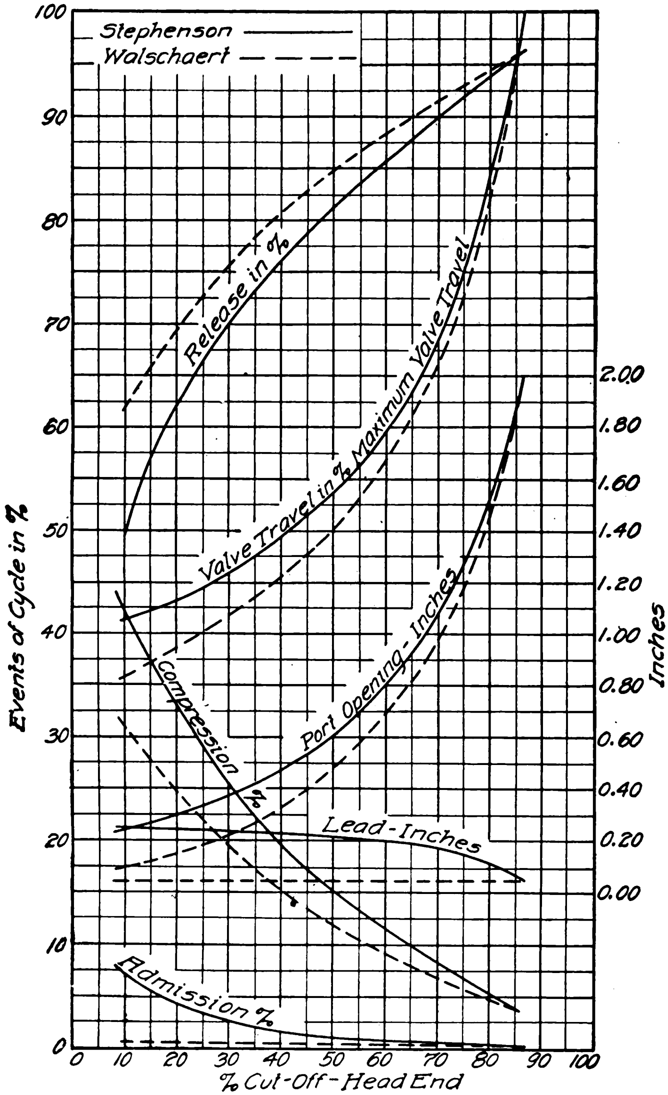


Fig. 69-a. Curves Showing Events for Head End of Forward Motion for Stephenson and Walschaert Gears.

that steam distribution in the former would not differ to a very great extent from that in the latter save in that produced by the constant lead. The factors in favor of the Walschaert gear are largely mechanical ones which may be designated as *easily accessible*

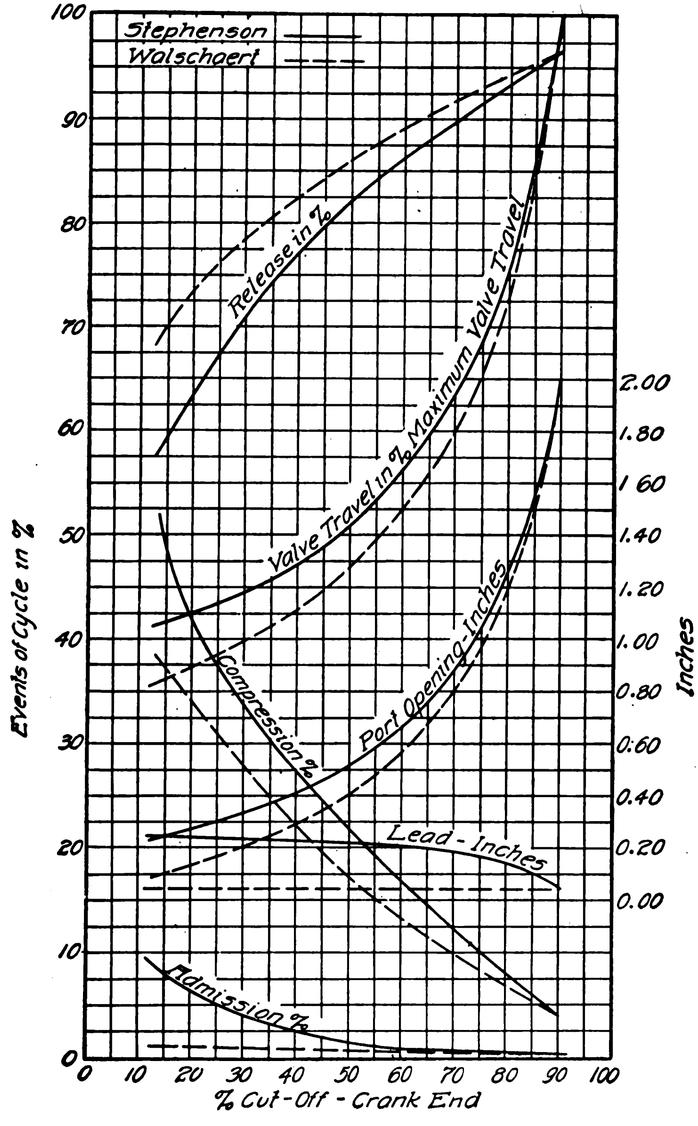


Fig. 69-b. Curves Showing Events for Crank End of Forward Motion for Stephenson and Walschaert Gears.

parts and a *less amount of care in maintenance.* The parts making up the Walschaert valve gear are outside of the frames where they

TABLE VIII

Comparative Dimensions of Stephenson and Walschaert Gears

	Stephenson Gear	Walschaert Gear
Type of valve	D-Slide	D-Slide
Steam lap in inches, H.E.	1.0	1.0
Steam lap in inches, C.E.	1.0	1.0
Exhaust lap in inches, H.E.	0	0
Exhaust lap in inches, C.E.	0	0
Lead at full gear in inches	$\frac{3}{64}$	$\frac{3}{64}$
Lead at mid gear in inches	$\frac{1}{4}$	$\frac{3}{64}$
Width of port in inches	1	1
Maximum valve travel in inches	6	6
Stroke of piston in inches	24	24
Length of connecting rod in inches	96	96
Radius of link arc in inches	60	
Length of radius rod in inches		46

can be easily reached in case of breakdowns and necessary repairs. Another advantage accruing from this fact is that the space between the frames is left open permitting bracing, which protects and strengthens the frames. This is not possible when the Stephenson gear is used. The smaller number of moving parts, hardened pins, and accessible bearings in the Walschaert gear result in fewer and less expensive repairs.

A study of the action of a valve on a given locomotive, when operated by means of a Walschaert gear and also a Stephenson gear, gave the results shown graphically in Figs. 69-a and 69-b. The

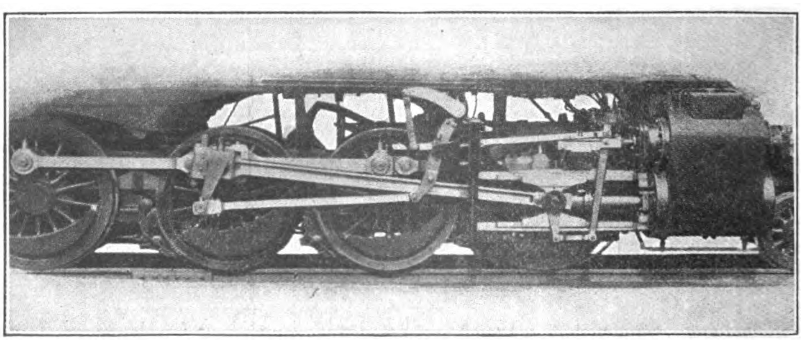


Fig. 69-c. Walschaert Valve Gear Mounted on Consolidated Freight Locomotive.

results were taken from Zeuner diagrams, drawn to represent the steam distribution given by each gear. The general dimensions of the two gears, taken from designs prepared for use on a given locomotive are shown in Table VIII.

The conditions for both the head end and crank end of the forward motion, in both Stephenson and Walschaert gears are represented in Figs. 69-a and 69-b. Each event of the cycle—valve travel, port opening, and lead—is plotted with reference to the cut-off. As can be seen, the Walschaert gear gives for all cut-off positions a later admission, later release, later compression, less lead, less port opening, and less valve travel than does the Stephenson gear. With the exception perhaps of lead, the differences are negligibly small for all cut-off positions beyond 50 per cent. With cut-off positions less than 50 per cent, however, these differences increase quite rapidly.

The Walschaert gear is applied to a locomotive in several ways, each having its own advantages. The method illustrated in Fig. 69-c gives the student a general idea how the scheme is worked out and applied in connection with a consolidative freight locomotive.

Valves. Until recent years the valve ordinarily used on locomotives was the *plain slide valve*, partially balanced. In the plain slide valve the full steam chest pressure is exerted over the whole of the back surface of the valve. The balancing of a valve consists in removing a portion of this pressure, thus decreasing the frictional resistance of the valve on its seat. The percentage of this pressure that is removed, or the *amount of balance*, varies from 45 to 90 per cent of the total face of the valve, and the average in practice is about 65 per cent. In the valve shown in Fig. 70, the balance is 69 per cent. The pinch of the packing ring on the cone slightly increases the pressure of the valve on its seat.

In Fig. 70, the valve, 1, is of the ordinary D type driven by the yoke, 2, which is forged as a part of the valve stem. To the back of the valve is bolted a circular plate, 3, having a cone turned thereon. On this cone is fitted a loose ring, 4, the inner face of which is beveled to the same degree as the taper of the cone. The ring is cut at one point and is, therefore, flexible. The open space at the cut in the ring is covered by an L-shaped clip which is placed on the outside and fastened to one end of the ring, the other end of the ring remaining free. This L-shaped clip reaches to the top of the ring at the outside and under the ring at the bottom to the taper of the cone. It thus forms joints just the same as the ring itself, making a continuous yet flexible ring. The ring is made of cast iron and is bored smaller than the diameter required for the working position. Therefore, before the steam chest cover is placed in position, it sets slightly higher on the cone than it does when at work. To the inner side of the steam chest cover, 6, is bolted a back plate, 5, against which the ring, 4, forms a steam tight joint. Owing to the raised position of the ring when first put on, the placing of the cover and the back plate forces the ring down over the cone. This expands the former to a larger

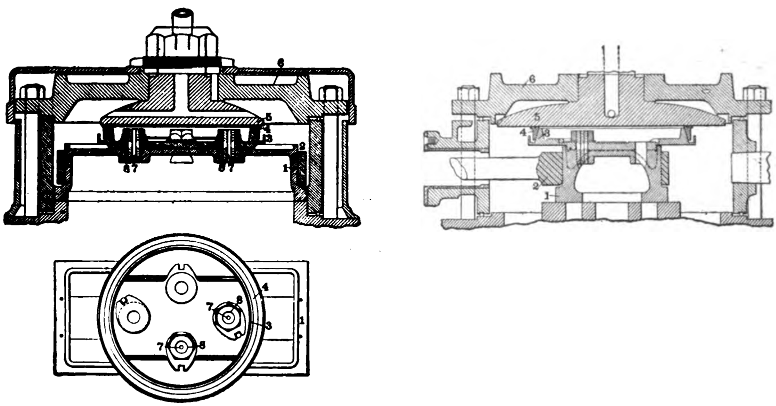


Fig. 70. Plain Slide Valve.

diameter and it is thus held in its expanded position under tension with the tendency to maintain the joint between itself and the wearing plate.

Another method employed in balancing a slide valve is to cut grooves in the top of the valve which extend across the four sides of the valve. In these grooves are placed carefully fitted narrow strips which rest on small springs which keep the strips pressed up against a pressure plate, thus keeping the steam away from a large part of the valve.

In order to provide for any leakage which may occur past the ring and to prevent an accumulation of pressure within the same, the holes, 7, are drilled through the studs, 8. These drain the space and accomplish the desired result.

A relief valve is placed on the steam chest. This is a check valve opening inward and serves to equalize the pressure in the two ends of the cylinder when the locomotive is coasting, thus preventing unequal pressure at either end.

Another form of valve which is now being extensively used is the *piston valve,* illustrated in Fig. 71. In this valve, the steam is admitted at the center in the space *A* and is exhausted at the ends. Such valves are self-balanced since they are entirely surrounded by steam. Another form of piston valve is constructed with a passage extending through its entire length which connects with a live steam passage. In this type of valve, steam is admitted at the ends of the valve at *B*, and when exhausted passes around the circular part *A* to the exhaust cavity. In piston valves, it only remains to pack the ends to prevent steam leaks. This is done by using packing rings. In Fig. 71, the

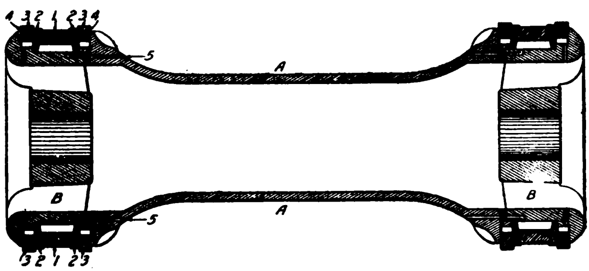


Fig. 71. Piston Valve.

packing consists of seven pieces at each end, numbered 1, 2, 3, and 4. Numbers 3 and 4 are the packing rings proper. They consist of the split rings, 3, and the L-shaped covering piece, 4, for the split in No. 3. The rings, 2, are solid and serve merely as surfaces against which the rings, 3, have a bearing. The wedge ring, 1, is split and can expand. The rings, 3, are turned larger than the diameter of the steam chest and are sprung into position. Small holes, 5, are drilled from the steam space *A* to a point beneath the wedge ring, 1. When the throttle valve is opened, steam enters the holes, 5, forcing the wedge, 1, out between the rings, 2. It locks the packing ring, 3, firmly between the ring, 2, and the lip of the valve. This prevents rattling and working loose of the rings, making the valve practically steam-tight.

A form of packing largely used and which is much simpler than the above, consists of ordinary snap rings inserted into annular grooves cut around the heads of the valves.

Valve Friction. Of the many different parts of a locomotive which have been studied from the scientific standpoint, few parts have been given more attention than the main steam valve. When the valves were small and steam pressures were not high, the force necessary to move the valve when in operation was not very great. With the pressures employed today and the sizes of steam ports found on our modern locomotives, the reduction of valve friction becomes a very important matter. From an examination of Figs. 70 and 71, it is an easy matter to see that the more completely a valve is balanced, the less work will be required to move it back and forth when in service.

Valve Tests to Determine Friction. The question was considered such an important one that the Master Mechanics' Association appointed a committee to investigate different types of valves under conditions of service. The committee conducted its experimental work, in 1896, upon the locomotive testing plant at Purdue University, Lafayette, Indiana. The Purdue locomotive, known as Schenectady No. 1, was used, having cylinders 17 inches in diameter by 24 inches stroke. The ports were 16 inches long, the steam port being $1\frac{1}{4}$ and the exhaust port $2\frac{1}{2}$ inches wide. The bridges were $1\frac{1}{8}$ inches wide. The valve had a maximum travel of $5\frac{1}{2}$ inches, steam lap, $\frac{3}{4}$-inch, exhaust lap, $\frac{1}{32}$-inch, and was set with a $\frac{1}{16}$-inch lead, with the reverse lever in its full forward position, and a $\frac{7}{32}$-inch negative lead, with the reserve lever in its full backward position.

Four different slide valves were tested as follows: unbalanced D-valve, Richardson balanced valve, American balanced valve with single balance ring, and American balanced valve with two balance rings. A fluid dynamometer was placed in position between the valve stem and rocker arm in such a manner as to measure the force necessary to overcome the friction of the valve when operated under different conditions. The valves weighed 78, $85\frac{1}{2}$, $79\frac{1}{4}$, and 84 pounds, respectively. The weight of the dynamometer was 105 pounds and that of the valve yoke 37 pounds. The Richardson valve had 56 per cent of the area of the valve face balanced by the use of flat strips held against the balance plate by springs. The American valves had $61\frac{1}{2}$ and 66 per cent of their areas balanced by using single and double balancing rings, respectively.

The power required to operate the different valves was determined by means of the fluid dynamometer to which was attached a steam engine indicator. The arrangement was such that pressure diagrams could be taken in which the length corresponded to the stroke of the valve and the height to the pressure of the fluid on the piston of the dynamometer. Tests were conducted at different cut-offs and speeds. A few of the results secured are presented in Tables IX and X.

TABLE IX

Valve Tests Showing Mean Pull in Pounds for Different Valves

(Steam Chest Pressure, 100 Pounds per Square Inch)

Cut-Off in Inches	22			9½		
Speed in M.P.H.	10	20	40	10	20	40
Richardson	382	396	772	361	442	468
American single	....	522	872	394	535	591
American double	....	488	762	412	500	568
Unbalanced	1118	1062	1207	1322	1240	1180

TABLE X

Valve Tests Showing Per Cent of I.H.P. of One Cylinder Required to Move Valve

Cut-Off in Inches	22			9½		
Speed in M.P.H.	10	20	40	10	20	40
Richardson	0.43	0.49	1.54	0.32	0.34	0.61
American single	0.48	0.65	1.91	0.27	0.40	0.67
American double	....	0.61	1.66	0.27	0.45	0.63
Unbalanced	1.20	1.30	2.42	0.82	....	1.62

The committee in their report to the society stated that the friction or resistance of unbalanced valves was about twice as great as that of balanced valves and recommended that the area of balance should equal the area of the exhaust port plus the area of the two bridges plus the area of one steam port. As a result of the work done by the committee and by some of the railway companies, it soon became evident that the D-valve for locomotive work was very inefficient. For this reason, in recent years the piston type of valve, which in itself is balanced, is being almost universally used.

RUNNING GEAR

The running gear of a locomotive is composed of the following important parts: Wheels, axles, rods, pistons, and the frames which form a connection between these parts.

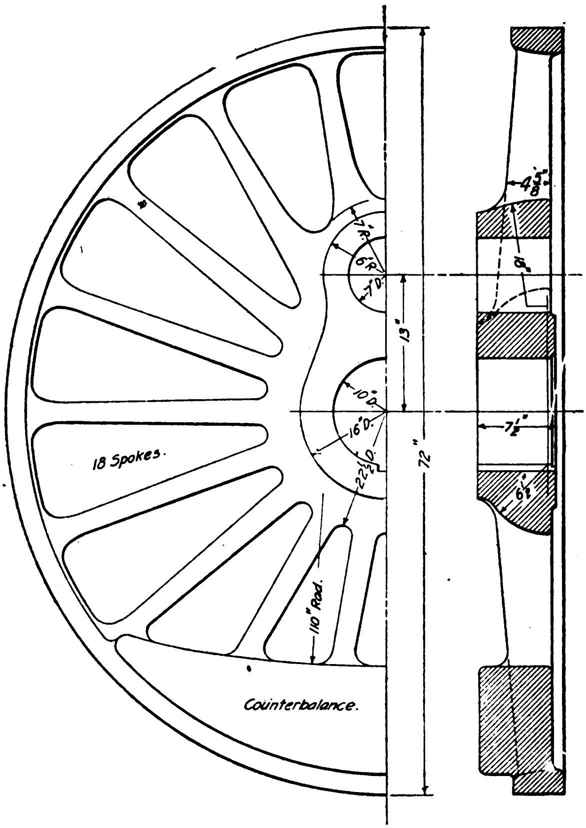


Fig. 72. Half-Elevation and Section of Driving Wheel.

Wheels. The driving wheels have a cast-iron or steel center protected by a steel tire. Until about 1896, cast iron was universally employed for wheel centers and is yet used for the smaller engines. For engines having large cylinders, where a saving of weight is important, cast steel is now used makes possible a considerably lighter construction. Such a wheel is illustrated in Fig. 72.

The universal method of fastening on the tire is to bore it out a trifle smaller than the diameter to which the center is turned, then expand it by heating and after slipping it over the center allow it to contract by cooling. The shrinkage commonly used is $\frac{1}{80}$ of an inch for each foot diameter of wheel center for all centers of cast iron or cast steel less than 66 inches in diameter. For centers more than 66 inches in diameter, $\frac{1}{60}$ of an inch for each foot diameter is allowed for shrinkage. This gives the following shrinkages:

TABLE XI

Shrinkage Allowance

Diameter of Center	Shrinkage	Bored Diameter of Tire
56	.058	55.94
58	.060	57.94
60	.063	59.93

The American Master Mechanics' Association recommends the following concerning wheel centers:

In order to properly support the rim and to resist the tire shrinking, the spokes should be placed from 12 to 13 inches apart from center to center, measured on the outer circumference of the wheel center. The number of spokes should equal the diameter of center expressed in inches divided by 4. If the remainder is $\frac{1}{2}$ or over, one additional spoke should be used. The exact spacing of the spokes according to this rule would be

$$3.1416 \times 4 = 12.56 \text{ inches}$$

Wheel centers arranged in this manner would have the following number of spokes:

TABLE XII

Spoke Data—General

Diameter of Centers	Number of Spokes	Diameter of Centers	Number of Spokes
38	10	72	18
44	11	74	19
50	13	76	19
56	14	78	19
62	16	80	20
66	17		

Among pattern makers and foundry men, there is an impression that an uneven number of spokes should be used so as to avoid getting two spokes directly opposite each other in a straight line. The following table has been made up on this basis:

TABLE XIII

Spoke Data—Foundry Rule

Diameter of Center	Number of Spokes	Pitch	Diameter of Center	Number of Spokes	Pitch
44	11	12.5	66	15	13.8
48	11	13.6	68	17	12.5
50	13	12.6	70	17	12.9
54	13	13.0	72	17	13.3
56	13	13.5	74	17	13.6
60	15	12.6	76	19	12.6
62	15	13.0	78	19	12.9

The spokes at the crank hub should be located so that the hub will lie between two of the spokes and thus avoid a short spoke directly in line with the crank pin hub.

Cast steel driving wheel centers should be preferably cast with the rims and uncut shrunk slots omitted whenever steel foundries will guarantee satisfactory castings. For wheel centers 60 inches in diameter and when the total weight of the engine will permit, the rims should preferably be cast solid without cores so as to obtain the maximum section and have full bearing surface for the tires.

It is difficult to get sufficient counterbalance in centers smaller than 60 inches in diameter so that it will be found very desirable to core out the rims to obtain the maximum lightness on the side next to the crank pin and in some cases on the counterbalance side in order to fill in with lead where necessary.

The American Master Mechanics' Association recommends a rim section as shown in Fig. 73 for wheel centers without retaining rings. The tire is secured from having the center forced through it by a lip on the outside $\frac{3}{8}$ inch in width and about $\frac{1}{8}$ inch in height, the tire being left rough at this point. The height of the lip, therefore, depends upon the amount of finishing left on the interior of the tire. Accurate measurements of tires after they have been in service for some time, especially when less than $2\frac{1}{2}$ inches in thickness, show that a rolling out or stretching of the tire occurs, and for reasonably heavy centers, these figures will account more for loose tires than any permanent set in the driving wheel center.

Counterbalance. A study of the construction of the driving wheel brings up the question of counterbalance since it is made a part of the wheel center. The counterbalance, Fig. 72, is the weight or mass of metal placed in the driving wheel opposite the crank to balance the revolving and reciprocating weights.

The revolving weights to be balanced are the crank pin complete, the back end of the main rod or connecting rod, and each end of each side rod complete. The sum of the weights so found which are attached to each crank pin is the revolving weight for that pin.

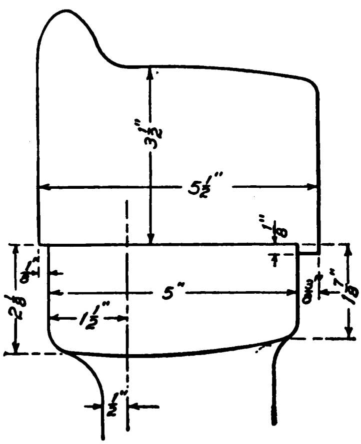


Fig. 73. Section of Rim of Driving Wheel.

The reciprocating weights to be balanced consist of the weight of the piston complete with packing rings, piston rod, crosshead complete, and the front end of the main rod complete. The weight of the rod should be obtained by weighing in a horizontal position after having been placed on centers.

The revolving weights can be counterbalanced by weights attached to the wheel to which they belong, while the reciprocating weights can only be balanced in one direction by adding weights to the driving wheels as all weights added after the revolving parts are balanced overbalance the wheel vertically exactly to the same extent that they tend to balance the reciprocating parts horizontally. This overbalance exerts a sudden pressure or hammer blow upon the rail directly proportional to its weight and to the square of its velocity. At high speeds, this pressure, which is added to the weight of the driver on the rail, may become great enough to injure the track and bridges.

The best form of counterbalance is that of a crescent shape which has its center of gravity the farthest distance possible from the center of the axle. The counterbalance should be placed opposite the crank pin as close to the rods as proper clearance will allow. The clearance should be not less than $\frac{3}{4}$ inch. No deficiency of weight in any wheel should be transferred to another. All counterbalance blocks should be cast solid. When it is impossible to obtain a correct balance for solid blocks, they may be cored out and filled with lead, which will increase their weight. In all such cases the cavities must be as smooth as possible. Holes should be drilled through the inside face of the wheel to facilitate the removal of the core sand.

In counterbalancing a locomotive, the following fundamental principles should be kept in mind:

1. The weight of the reciprocating parts, which is left unbalanced, should be as great as possible, consistent with a good riding and smooth working engine.
2. The unbalanced weight of the reciprocating parts of all engines for similar service should be proportional to the total weight of the engine in working order.
3. The total pressure of the wheel upon the rail at maximum speed when the counterbalance is down, should not exceed an amount dependent upon the construction of bridges, weight of rail, etc.
4. When the counterbalance is on the upper part of the wheel, the centrifugal force should never be sufficient to lift the wheel from the rail.

The following rules have been generally accepted for the counterbalancing of locomotive drive wheels:

1. Divide the total weight of the engine by 400, subtract the quotient from the weight of the reciprocating parts on one side including the front end of the main rod.
2. Distribute the remainder equally among all driving wheels on one side, adding to it the sum of the weights of the revolving parts for each wheel on that side. The sum for each wheel if placed at a distance from the driving wheel center, equal to the length of the crank, or at a proportionately less weight if at a greater distance, will be the counterbalance weight required.

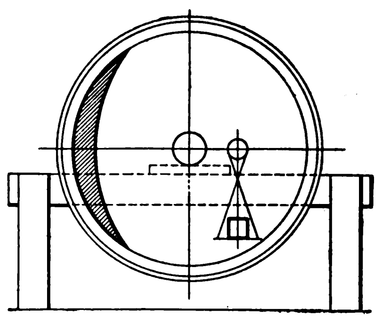


Fig. 74. Diagram Showing Method of Counterbalancing Driving Wheels.

The method of adjusting the counterbalance in the shop is as follows: After the wheels have been mounted on the axle and the crank pins put in place, the wheels are placed upon trestles as illustrated in Fig. 74. These trestles are provided with perfectly level straight edges upon which the journals rest. A weight pan is suspended from the crank pin as shown. In this pan is placed weight enough to just balance the wheels in such a position that a horizontal line will pass through the center of the axle and crank pin and counterbalance on one wheel, and a vertical line will pass through the axle and crank pin centers of the other side, the crank being above. The amount of weight thus applied, including the pan and the wire by which it is suspended, gives the equivalent counterbalance at crank radius available for balancing the parts. This weight found must not exceed that found to be necessary by the formula. Should the counterbalance be left with extra thickness, the extra weight can be turned off with little trouble after the trial described has been completed. This process should be repeated for the opposite side.

The weight of the reciprocating parts should be kept as low as possible, consistent with good design. Locomotives with rods disconnected and removed should not be handled in trains running at high rates of speed because of the danger arising from damage to the track and bridges, due to the hammer blow.

Axles. Driving and engine truck axles are made of open hearth steel, having a tensile strength not less than 80,000 pounds per square inch. Modern practice requires that axles conform to the tests and standards adopted by the American Railway Master Mechanics' Association and the American Society for Testing Materials. One axle is required to be tested from each heat. The test piece may be taken from the end of any axle with a hollow drill, the hole made by the drill to be not more than 2 inches in diameter nor more than 4½ inches deep. This test piece is to be subjected to the physical and chemical tests provided for in the code of the societies mentioned above.

All forgings must be free from seams, pipes, and other defects, and must conform to the drawings furnished by the company. The forgings, when specified, must be weighed, turned with a flat nosed tool, and cut to exact length and centered with 60 degree centers. All forgings not meeting the above requirements or which are found to be defective in machining and which cannot stand the physical chemical tests will be rejected at the expense of the manufacturers.

The above requirements, while intended for driving axles, apply in a general way to engine truck axles. Axles are forged from steel billets, of the proper size to conform to the size of the axles as required for standard gauge work.

In accordance with the foregoing, Table XIV is presented, which gives the sizes and the weights of billets for standard driving and engine truck axles.

TABLE XIV

Forged Steel Billets (Standard Sizes)

DRIVING AXLES			ENGINE TRUCK AXLES		
Diameter of Journal, Inches	Size of Billet, Inches	Weight of Billet, Pounds	Diameter of Journal, Inches	Size of Billet, Inches	Weight of Billet, Pounds
8	10 x 10	2590	5	7 x 7	970
8½	11 x 11	2900	5½	7 x 7	1170
9	11 x 11	3220	6	8 x 8	1380
9½	12 x 12	3570	6½	8 x 8	1600
10	12 x 12	3930	7	9 x 9	1830

After the axles are received in the rough state, the journals and wheel fits are turned up, in the shop, to the proper dimensions. In turning up the wheel fits, they are left slightly larger in diameter than the diameter of the axle opening in the wheel center. The wheel center is then forced on the axle by means of hydraulic pressure. Table XV gives the pressure employed in forcing-in engine truck and driving axles.

TABLE XV

Hydraulic Pressures Used in Mounting Axles

DRIVING AXLES			ENGINE TRUCK AXLES		
Diameter of Fit in Inches	Pressure Employed in Tons		Diameter of Fit in Inches	Pressure Employed in Tons	
	Cast-Iron Center	Cast-Steel Center		Cast-Iron Center	Cast-Steel Center
7 -7½	70–75	112–120	4 -4½	25–30	37–45
7½-8	75–80	120–128	4½-5	30–35	45–52
8 -8½	80–85	128–136	5 -5½	35–40	52–60
8½-9	85–90	136–144	5½-6	40–45	60–67
9 -9½	90–95	144–152	6 -6½	45–50	67–75
9½-10	95–100	152–160	6½-7	50–55	75–82
10 -10½	100–105	160–168	7 -7½	55–60	82–90
10½-11	105–110	168–176			

Crank-Pins. All specifications and test requirements mentioned under the discussion of driving and engine truck axles are applicable to crank-pins. Crank-pins are received by railroad companies in the rough forging and must, therefore, be turned to fit the wheel boss. They are forced in by hydraulic pressure, the pressures commonly employed being given in Table XVI.

TABLE XVI

Hydraulic Pressures Used in Mounting Crank-Pins

Diameter of Fit in Inches	Pressure Employed in Tons	
	Cast-Iron Center	Cast-Steel Center
3–3½	15–20	24–32
3½–4	20–25	32–40
4–4½	25–30	40–48
4½–5	30–35	48–56
5–5½	35–40	56–64
5½–6	40–45	64–72
6–6½	45–50	72–80
6½–7	50–55	80–88

Locomotive Frames. Among other details of importance in the construction of a locomotive, none is more important than the frame. The frame is the supporting element and the tie bar that connects all the various moving and fixed parts. Its present form and propor-

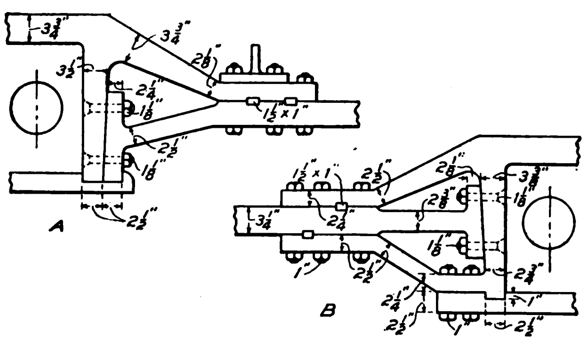


Fig. 75. Single Front Rail Locomotive Frames.

tions are due most largely to development rather than to pure design. It would be extremely difficult to analyze all the various forces to which the frames are subjected. There are two principal classes of locomotive frames, namely, the *single front rail* and the *double front rail.* The single front rail is illustrated in Fig. 75. At first the joint between the main frame and the front rail was made as shown at *A* in Fig. 75. The rear end of the front rail was bent downward with a

T-foot formed thereon by means of which it was connected to the main frame. The top member of the main frame was bent down and extended forward and connected to the front rail by means of bolts and keys. The T-head was fastened to the pedestal by two countersunk bolts. As locomotives grew in size, much trouble was experienced due to the countersunk bolts becoming loose or breaking. To overcome this difficulty, the form of joint shown in *B*, Fig. 75, was developed. Here the pedestal had a member welded to it which extended forward and upward to meet the front rail. The top member extended outward and downward as before. The front rail fitted between these two members and had a foot which rested against the pedestal. This latter form was used for many years, being changed in details considerably but retaining the same general arrangement. These forms of single bar frames continued to be used for many years and are employed at the present time for light locomotives. When the heavier types of locomotives, such as the Consolidation, made their advent, it became necessary to improve the

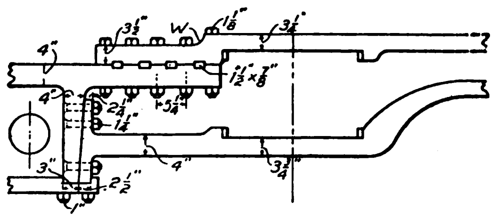


Fig. 76. Early Form of Double Front Rail Frame.

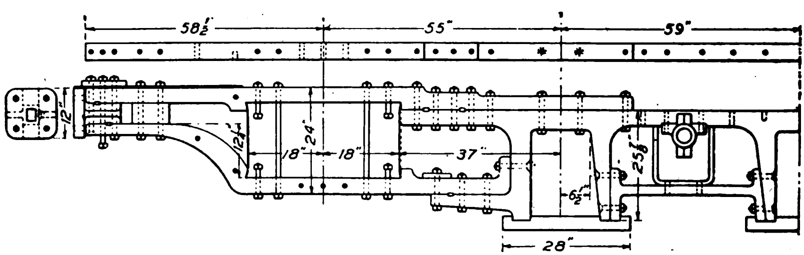


Fig. 77. Heavy Form of Double Front Rail Frame.

design of the frame. To meet this necessity, the double front rail frame was developed. Fig. 76 illustrates one of the earlier forms of this frame. The top rail was placed upon and securely bolted to the top bar of the main frame and the lower front rail was fastened to the pedestal by means of a T-foot with countersunk bolts. The same difficulty was experienced with this design as with the first form

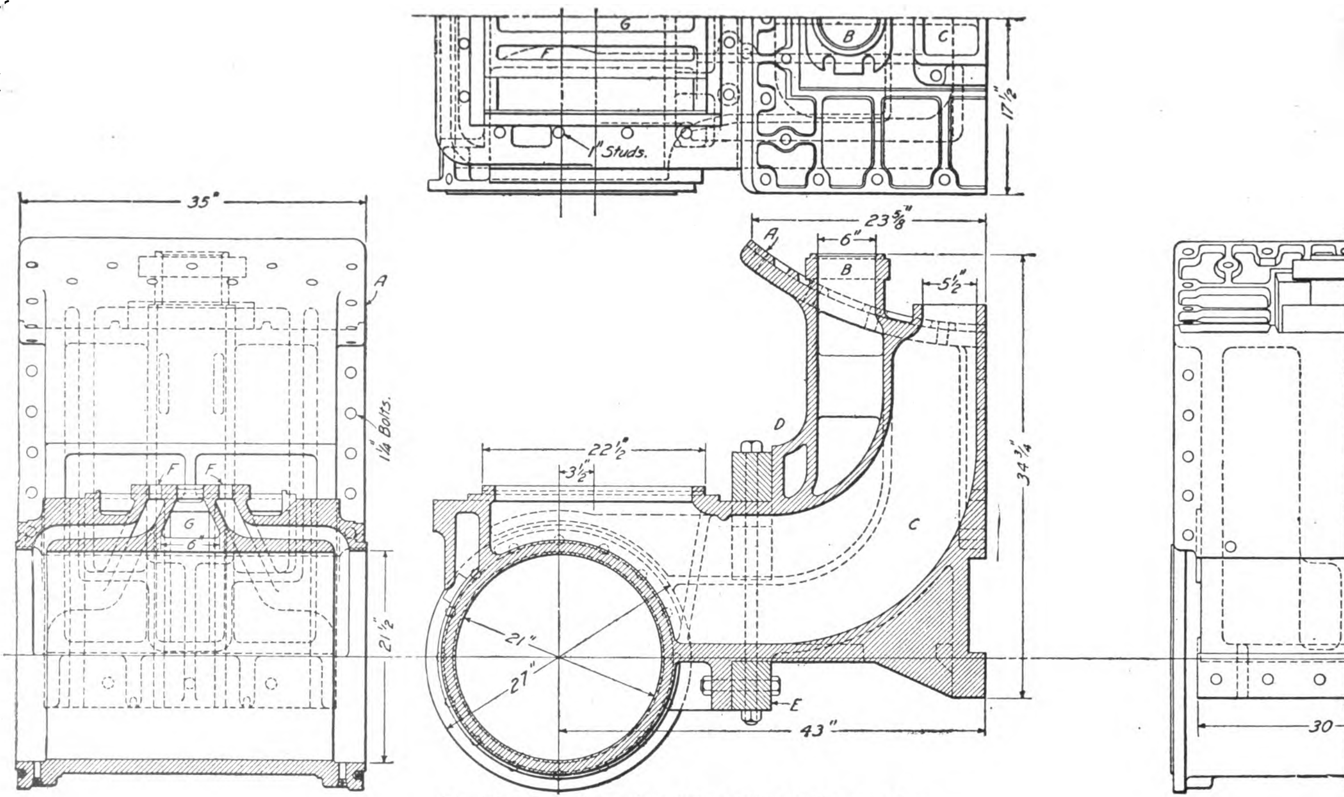


Fig. 78. Cylinder and Saddle of Simple Locomotive.

of the single front rail type, namely, the breaking of the bolts fastening the lower bar to the pedestal. This led to experiments being tried which resulted in many stages of advancement until a heavy and serviceable design was developed, as shown in Fig. 77. In this design the pedestal has a bar welded to it on which the lower front rail rests and to which it is connected by means of bolts and keys. The top front rail rests on top of the top main frame and extends back beyond the pedestal, thus giving room for the use of more bolts. The design shown in Fig. 77 is the one largely used on all heavy locomotives, it being slightly changed in detail for the various types.

In addition to the two general types of bar locomotive frames which are made of wrought iron or mild steel, a number of cast-steel frames are being used. The general make-up of the cast-steel frame does not differ materially from that of the wrought iron except in the cross-section of the bars. The bar frame is rectangular or square in cross-section whereas the sections of cast-steel frames are usually made in the form of an I.

Cylinder and Saddle. The cylinder and saddle for a simple locomotive, illustrated in Fig. 78, are constructed of a good quality of cast iron. The casting is usually made in two equal parts but it is not uncommon to find the saddle formed of one casting, each cylinder being bolted to it, making three castings in all. Fig. 78 illustrates the two-piece casting commonly used. The two castings are interchangeable and are securely fastened together by bolts of about 1¼ inches in diameter. The part of the casting known as the *saddle* is the curved portion *A*, which fits the curved surface of the smoke-box of the boiler. This curved surface after being carefully chipped and fitted to the smoke-box is then securely fastened to it by means of bolts. This connection must not only be made very securely but air tight as well, in order that the vacuum in the smoke-box may be maintained. In the cross-sectional view, the live steam passage *B* and exhaust passage *C* are shown. The steam enters the passage *B* from the branch pipe and travels to the steam chest from which it is admitted into the cylinder through the steam ports *F*. After having completed its work in the cylinder, it passes through the exhaust port *G* into the exhaust passage *C* to the stack. The cylinder casting is fastened to the frames of the locomotive as well as to the boiler. *D* and *E* show the connection of the saddle casting to the frame. In this case a frame having a double front rail is used, each bar being securely bolted to the casting.

The Piston and Rods. The pistons of locomotives vary greatly in details of construction but the general idea is the same in all cases. Since the pistons receive all the power the locomotive delivers, they must be strongly constructed and steam tight. All pistons consist of a metal disk mounted on a piston rod which has grooves on the outer edges for properly holding the packing rings. The pistons are

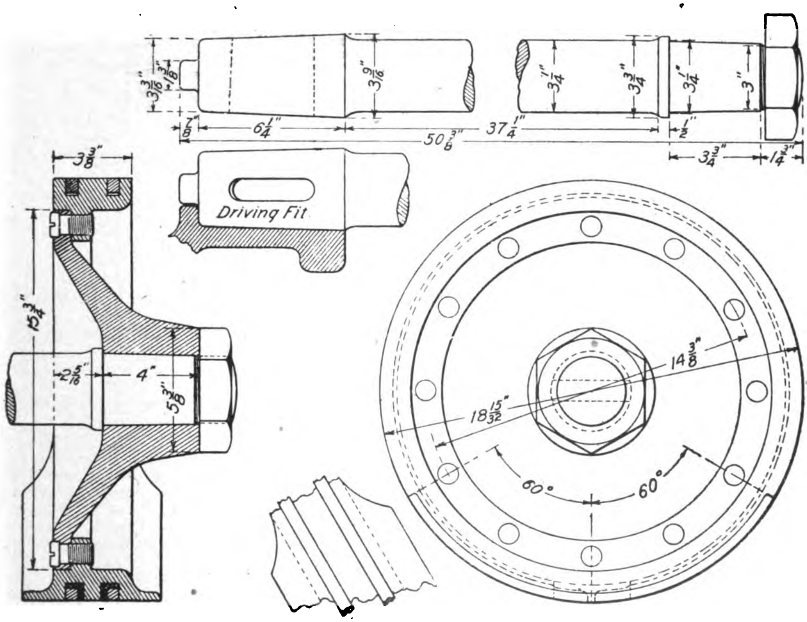


Fig. 79. Piston and Rods of Modern Locomotives.

commonly made of cast iron, but where great strength is required, steel is now being used. Fig. 79 illustrates the present tendency in design. The cylindrical plate is made of cast-steel and the packing rings, two in number, are made of cast iron. The packing rings are of the snap ring type and are free to move in the grooves.

As can be seen, the rim is widened near the bottom in order to provide a greater wearing surface. Fig. 79 also clearly shows the method used in fastening the piston to the piston rod. The piston rod is made of steel and has a tapered end which fits into the crosshead where it is secured by a tapered key. The crosshead fit is made accurate by careful grinding. The crosshead key should likewise be carefully fitted.

Crossheads and Guides. A variety of forms of crossheads and guides are now found in use on locomotives, two of the most

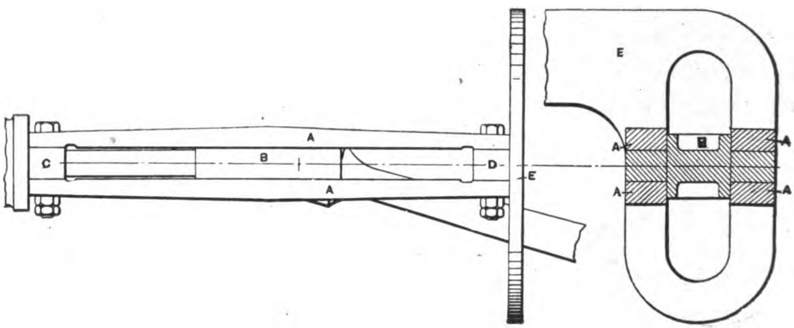


Fig. 80. Common Form of Crosshead and Guides.

common of which are illustrated in Fig. 80 and Fig. 81. The form illustrated in Fig. 80 is known as the *4-bar guide* and that shown in Fig. 81, as the *2-bar guide.* The form used depends largely on the type of engine. The 4-bar guide now used on light engines consists of four bars *A* which form the guide with the crosshead *B* between them. The bars are usually made of steel and the crosshead of cast-steel having babbitted wearing surfaces. The 4-bars *A* are

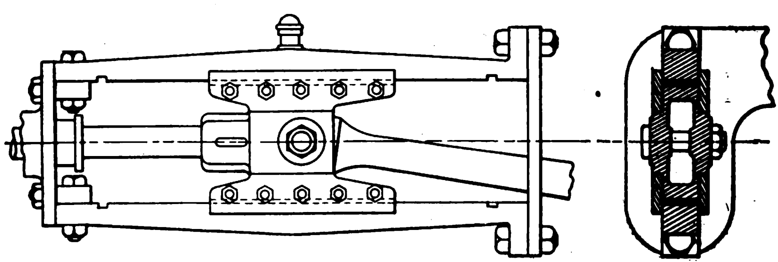


Fig. 81. Common Form of Crosshead and Guides.

bolted to the guide blocks *C* and *D* which are held by the back cylinder head and the guide yoke *E*, respectively. The guide yoke *E* is made of steel, extends from one side of the locomotive to the other, is securely bolted to both frames, and serves to hold the rear end of both guides. There is usually a very strong brace connected to the guide yoke which is riveted to the boiler. The wrist pin used in the crosshead of the 4-bar type is cast solid with the crosshead.

The 2-bar guide consists of two bars, one above and one below the center line of the cylinder with the crosshead between them. In this type the parts are more accessible for making adjustments and repairs and the wrist pin is made separate from the crosshead.

In the design of the crosshead, the wearing surface must be made large enough to prevent heating. In practice it has been found that for passenger locomotives the maximum pressure between the crosshead and guides should be about 40 pounds per square inch while

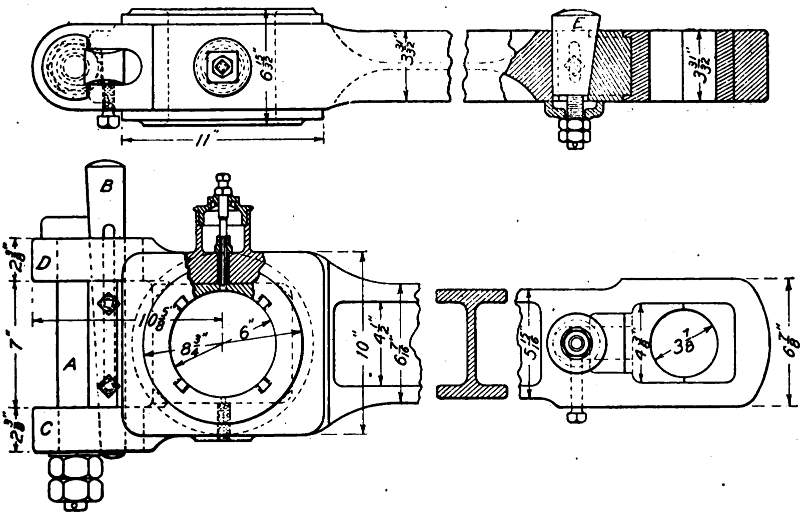


Fig. 82. Connecting Rod Details.

for freight locomotives it may be as high as 50 pounds per square inch. For crosshead pins, the allowable pressure per square inch of projected area is usually assumed at 4,800 pounds, the load on the pin to be considered as follows: For simple engines, the total pressure on the pin is taken to be equal to the area of the piston in square inches multiplied by the boiler pressure in pounds per square inch; for compound engines of the tandem and Vauclain types, the total pressure on the pin is taken to be equal to the area of the low-pressure piston in square inches multiplied by the boiler pressure in pounds per square inch, the whole being divided by the cylinder ratio plus 1. In the latter case, the cylinder ratio equals the area of the high-pressure cylinder divided by that of the low-pressure cylinder.

Connecting or Main Rods. Connecting or main rods are made of steel, the section of which is that of an I. The I-section gives the greatest strength with a minimum weight of metal. Fig. 82 illustrates modern practice in the design of connecting rods for a heavy locomotive. The design for passenger locomotives is quite similar to that shown. Aside from the general dimensions and weight of the rod, there are to be noted some important details in the manner in which the brasses are held and the means provided for adjusting them. The older forms of rods had a stub end at the crank pin end with a strap bolted to the rod. A key was used in adjusting the brasses.

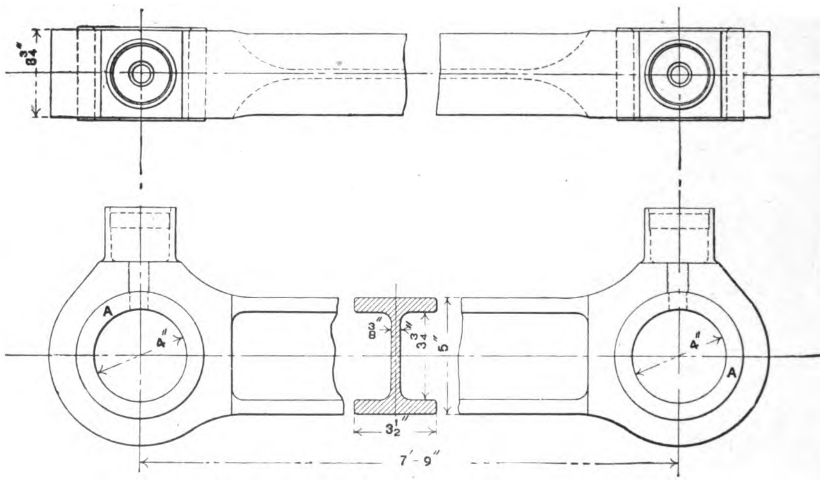


Fig. 83. Side Rod.

With the building of locomotives of greater capacity, this construction was found to be weak. The connecting rod shown in Fig. 82 has passed through several stages in the process of its development. The crank end is slotted, the brasses being fitted between the upper and lower jaw. The brasses are held in place by a heavy cotter *A* and a key *B*. The cotter is made in a form which prevents the spread of the jaws *C* and *D*. The adjustment of the brasses is made by means of the key *B* in the usual way. The brasses at the crosshead end are adjusted by the wedge *E*. The oil cups are forged solidly on the rod.

The Parallel or Side Rods. The parallel or side rods are also made with an I-section in order to obtain a maximum strength with a minimum weight of metal. Fig. 83 illustrates the form of side rods now being used. The rods are forged out of steel, in the same manner as connecting rods, having oil cups also forged on. The enlarged ends are bored for the brasses which are made solid and forced in by hydraulic pressure. In case the locomotive is one having more than two pairs of drivers, the side rods are connected by means of a hinged joint as shown at A, Fig. 84.

Both connecting rods and side rods are subjected to very severe stresses. They must be capable of transmitting tensional, compressional, and bending stresses. These stresses are brought about by the thrust and pull on the piston and by centrifugal force.

Locomotive Trucks. The trucks commonly used under the front end of locomotives are of two types, namely, the *two-wheeled* or *pony truck* and the *four-wheeled truck*.

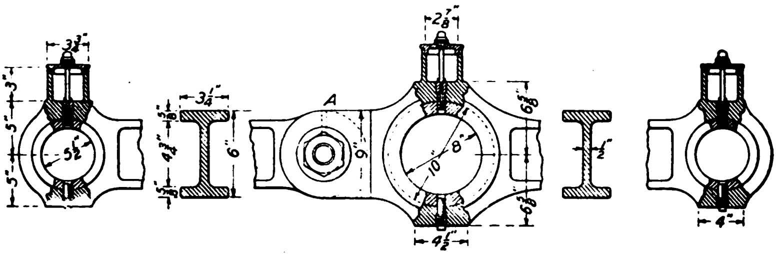


Fig. 84. Hinged Joint for Use with Locomotives Having More Than Two Pairs of Drivers.

The pony truck, illustrated in Fig. 85, consists essentially of the two wheels and axle, the frame, 1, which carries the weight of the front end of the locomotive and the radius bar, 2, pivoted to the cross bar, 3, which is rigidly bolted to the engine frame, 4. The radius bars serve to steady the truck and reduce the flange wear on the wheels when running on curves. A side movement is provided for at the center plate, which is made necessary on account of curves. The correct length of the radius bar is given by the following formula:

$$X = \frac{D\,R + D^2}{R + 2\,D}$$

where

R = length of rigid wheel base of engine in feet

D = distance in feet from front flanged driver axle to center of truck

X = length in feet of radius bar

The usual method of applying the weight to a pony truck is by means of the equalizing lever, 5. The fulcrum, 6, of this equalizing lever is located under the cylinders where the weight is applied. The front end of the equalizing lever is carried by the pin, 8, which, in

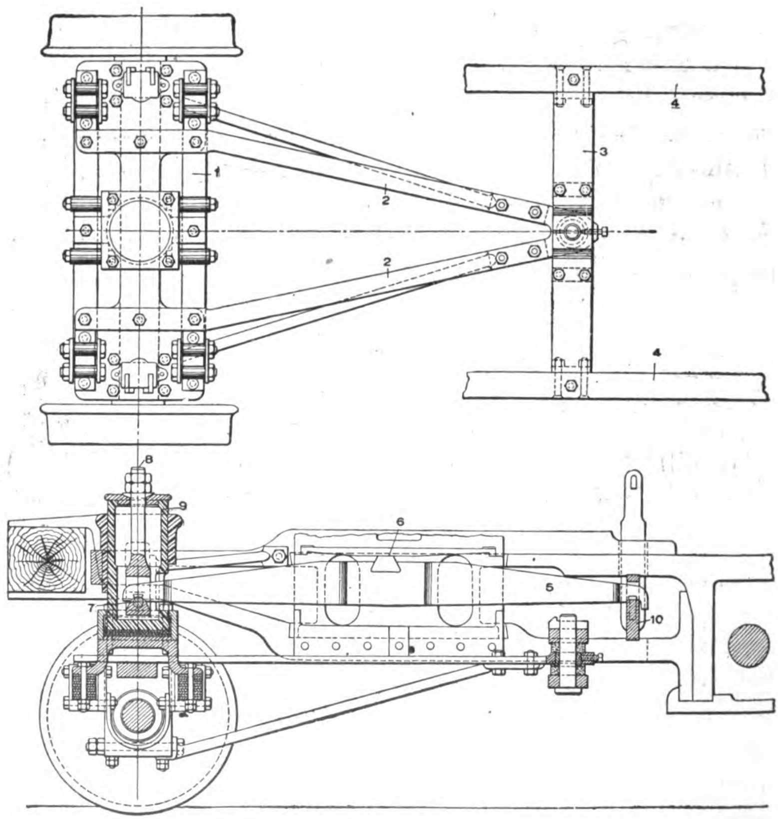


Fig. 85. Pony or Two-Wheeled Truck.

turn, is carried by the sleeve, 9, and transmits the load to the center plate while the rear end of the lever is supported by means of the cross lever, 10, which is carried by the driving wheel springs.

The four-wheeled truck is constructed in a number of different ways, one of which is illustrated in Fig. 86. The construction is simple, consisting of a rectangular frame, *A*, carrying a center plate, *B*. As in the case of the pony truck, the journals are inside of the wheels.

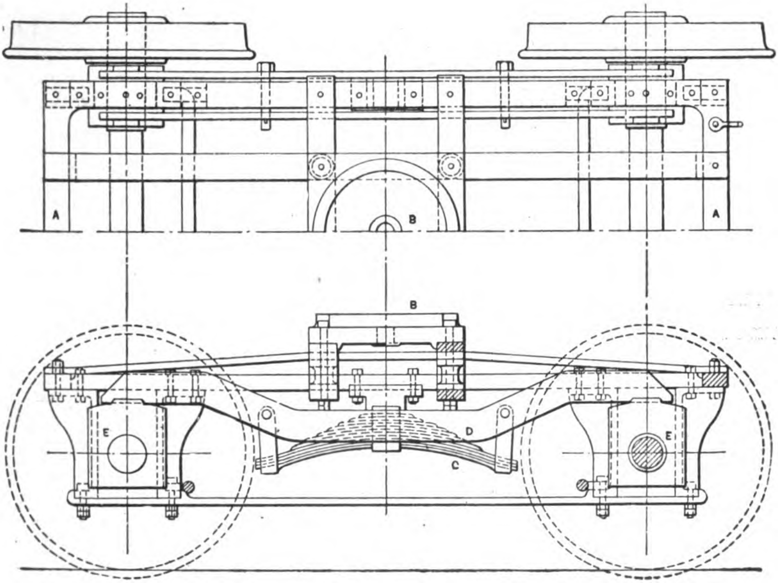


Fig. 86. Four-Wheeled Truck.

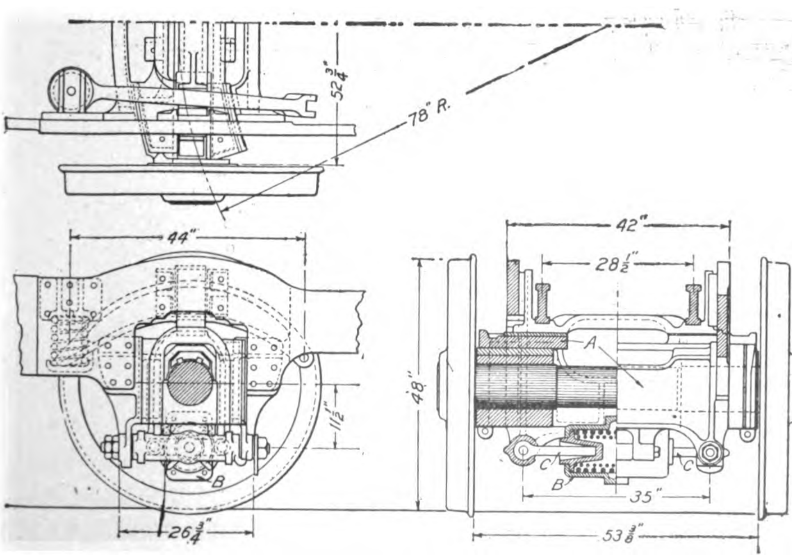


Fig. 87. Trailing Truck with Inside Bearings.

The truck, which is pivoted on the center plate, carries the front-end of the locomotive and serves as a guide for the other wheels of the locomotive.

The object in using a trailing truck, as stated earlier in this work, is to make possible the wide fire box which is necessary in certain types of locomotives. Two different types of trailing trucks are used and both have proven successful. One has an inside bearing, as illustrated in Fig. 87, and the other an outside bearing, as shown in Fig. 88. The former is perhaps the simpler of the two. The latter has a broad supporting base which improves the riding qualities of the locomotive.

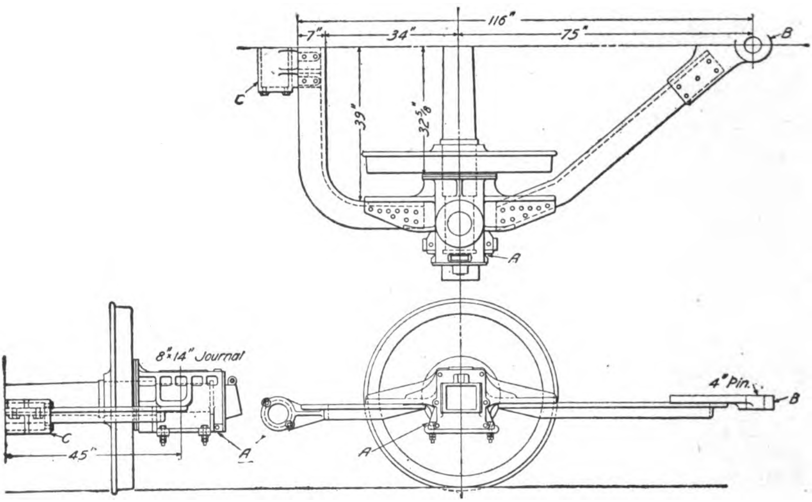


Fig. 88. Trailing Truck with Outside Bearings.

The radial trailing truck with inside bearings, Fig. 87, is fitted with a continuous axle box, *A*, with journal bearings at each end, these being provided at the frame pedestals with front and back wearing surfaces formed to arcs of concentric circles of suitable radii. To the lower face of the continuous axle box is attached a spring housing, *B*, fitted with transverse coiled springs having followers and fitted with horizontal thrust rods, *C*, which extend to the pedestal tie bars. These thrust bars terminate in ball and socket connections at each end. This combination of springs and thrust rods permits the truck to travel in a circular path and also permits the continuous axle box to rise and fall relatively to the frames. Motion along the circular arcs is limited by stops at the central spring casing, the springs tending to bring the truck to its normal central position when the locomotive passes upon a tangent from a curve. The load is transmitted to the continuous axle box through cradles on which the springs and equalizers bear, hardened steel sliding plates being interposed as wearing surfaces immediately over the journal bearings. The cradles are guided vertically by guides attached to the locomotive frames.

The radial trailing truck with outside bearings, as illustrated in Fig. 88, has journal boxes *A* rigidly attached to the frame, the forward rails of which converge to a point in which the pivot pin *B* is centered. The pin is fixed in a cross brace secured between the engine frames. The trailing truck frame extends back of the journal boxes in the form of the letter *U* at the center of which a spring housing *C* is mounted, containing centering springs and followers, performing the same functions as those of the radial truck with inside bearings, already described. The load in this case is transmitted to the journal boxes by springs which are vertically guided. Hardened rollers are generally used between what would otherwise be sliding surfaces. These rollers rest upon double inclined planes which tend to draw the truck to its normal and central position when displaced laterally as on a curve. The mutual action of these rollers and inclined planes is to furnish a yielding resistance to lateral displacement with a tendency to return to the normal position.

The Tender. The tender of a locomotive is used to carry the coal and water supply for the boiler. It is carried on two four-wheeled trucks having a frame work of wood or steel, the latter being mostly used at the present time. This frame supports the tank in which the water is stored, which, in the case of passenger and freight locomotives, is usually constructed in the shape of the letter U, the open end of which faces the fire door. The open space between the legs of the U is used for coal storage. The water is drawn from the tank near the two front corners. In these two front corners are placed tank valves which are connected by means of the tank hose and pipes to the two injectors. Near the back end of the tank is a manhole which permits a man to enter the inside to make repairs. This opening is also used in filling the tank at water towers. Tanks are made of open hearth steel, usually about $\frac{1}{4}$ of an inch in thickness, the sheets being carefully riveted together to prevent leaks. The interior of the tank is well braced and contains baffle plates which prevent the water from surging back and forth, due to curves and shocks in the train itself. The tank is firmly bolted to the frame.

Many of the engines designed for southern and western traffic burn oil and, as a rule, the railroads themselves furnish the specifications for the oil-burning equipment. Cylindrical tanks are used on the tender with the water tank forward, as a rule. Otherwise, the tender design is the same as for coal-burning locomotives.

The capacity of tenders has been increased as the locomotives which they serve have grown in size and power. Modern heavy locomotive tenders have a water capacity of from 3,000 to 9,000 gallons and a coal capacity of from 5 to 16 tons.

On switching engines, the back end of the tank is frequently made sloping in order to permit the engineer to see the track near the engine when running backward. Frequently a tool box is placed near the rear of the tank in which may be kept jacks, replacers, etc. A tool box for small tools and signals is usually placed at the front of the tender on either side. The coal is prevented from falling out at the front end by using gates or boards dropped into a suitably constructed groove. On locomotives used on northern railroads, the tanks are provided with a coil of steam pipes by means of which the water can be warmed and prevented from freezing.

Locomotive Stokers. The amount of water a locomotive boiler is capable of evaporating is limited by a number of conditions. It is possible to construct a locomotive of such dimensions that it would be capable of burning an amount of coal which would be physically impossible for a fireman to handle. Furthermore, the different methods of firing a locomotive by hand, as practiced by many firemen, are frequently very uneconomical and result in a great loss of fuel. Again, there are certain heavy freight runs on some railroads which require two firemen in order to get the train through on schedule time.

The above reasons and many others which might be mentioned have resulted in a demand for some form of automatic or mechanical stoker for locomotive work. In the last ten or fifteen years, much experimental work has been done along this line and a number of different types of stokers have been developed which have met with some success.

A locomotive stoker to be successful should meet the following requirements:

(a) It should be able to handle any desired quantity of coal and at the same time call for less physical effort on the part of the fireman than is required in hand firing.

(b) It should be able to successfully handle any grade of coal.

(c) It should be able to maintain full steam pressure under all conditions.

(d) It should not become inoperative under ordinary conditions of service.

(e) Its construction should permit of hand firing to meet emergency conditions.

Of the many types of locomotive stokers which have been developed and tried out, the following makes are characteristic and will serve for illustration.

Chain Grate Stoker. The chain grate stoker, invented as early as 1850, was thought at first to have solved the smoke problem. It was used to a limited extent in and about New York City, but for various reasons was soon abandoned. Its construction was quite similar to our present-day chain grate commonly used in power-plant work. It was mounted on wheels and could be drawn out of the fire-box on a track. Coal was shoveled into a hopper by the fireman and the chain grate was operated by a small auxiliary steam engine.

Hanna Locomotive Stoker. The Hanna locomotive stoker, developed by W. T. Hanna, is so constructed that the entire apparatus is readily applicable to any locomotive and is placed in the cab. It makes use of the ordinary fire door as a place through which the coal is jetted into the fire-box. It is operated by a small double-acting twin-engine placed in the floor of the cab, which serves to drive a screw propeller, which in turn causes the coal to be pushed upward and forward through a large pipe leading to the fire door. The engine can be reversed by means of a reversing valve, which changes the main valve from outside admission to inside admission.

Coal is shoveled into a hopper and from the hopper it is carried by the stoker mechanism to a distributing plate immediately inside of the fire door. From the distributing plate, the coal is thrown into the fire-box by the action of a number of steam jets which radiate from a central point on the plate. The speed of the small operating engine controls the rate of firing. Deflector and guide plates, located just inside of the fire door, are so arranged and under control of the fireman that the coal can be placed on any portion of the grate desired.

This stoker requires much physical work on the part of the fireman, since the coal must be broken into small lumps and the hopper kept filled. The larger lumps of coal will be deposited near the rear part of the grate, the finer particles being blown to the front portion. Much of the finer particles of coal will burn as dust and a part will be drawn through the flues without being burned at all.

Street Mechanical Stoker. The Street mechanical stoker consists of a small steam engine bolted to the top and left side of the back head of the boiler, which drives a worm gear and operates a chain conveyor. The conveyor bucket elevates the crushed coal from a hopper below and drops it on a distribution plate, located just inside of the fire door. From the distributing plate the coal is thrown into the fire-box by an intermittent steam jet, which is under the control of the fireman. There is a coal crusher on the tender, which is driven by another small steam engine. The coal, after being crushed, falls down a 45-degree inclined spout to the hopper below the deck. Some of the later designs use a screw propeller to carry the crushed coal from the tender to the hopper. The Street stoker does not require a great amount of physical work by the fireman. The large lumps of coal will fall near the rear portion of the grate as in the case of the Hanna stoker.

Crawford Mechanical Underfeed Stoker. The Crawford mechanical underfeed stoker, invented by D. F. Crawford, S.M.P. of the Pennsylvania Lines west of Pittsburgh, has been tried out on the Pennsylvania Lines and has given very satisfactory service. This stoker takes coal from beneath the tender and by means of a conveyor carries it forward to a hopper. From the hopper, two plungers, placed side by side, push the coal still farther ahead where two other plungers, one on each side, cause the coal to be pushed up through narrow openings to the ordinary shaking grate. Both the conveyor and the plungers are operated by a steam cylinder, containing a piston operated by the ordinary nine and one-half-inch Westinghouse air-pump steam valve. The conveyor consists of a series of hinged partitions, or doors, which carry the coal in one direction and slide over it when the motion is reversed. If the conveyor for any reason should become inoperative, a door in the deck can be opened and coal shoveled into the hopper below. If the stoking device should become inoperative, then coal can be fired by hand in the usual way. This stoker requires a minimum amount of physical labor from the fireman. It can be applied to any locomotive, but only at considerable cost. Its application reduces the grate area to a certain extent and thus reduces the steaming capacity of the boiler.

DESIGN OF PARTS OF THE ENGINE

The design of the parts of the locomotive engine proper, like that of the boiler, is a subject which cannot be handled properly in the space allotted in this book. These designs are the result of a gradual development of the proper proportions based upon the tests of each part in actual service. The specifications for materials and workmanship are rigidly drawn and as carefully lived up to, for in railroad service the chances for failure of any part of the engine, because of the excessive vibration, are many, and the destructive effect of such failure is out of all proportion to the original manufacturing expense. These conditions, therefore, make perfect action and excessive reliability prime necessities in engine design. A few formulas, for the most part based on rational assumptions, are presented for the calculation of some of the most important parts.

Axles. The stress in the axles is combined in many ways. The principal stresses are, first, bending stresses due to the steam pressure on the piston; second, bending stresses due to the dead weight of the engine; third, torsional or shearing stresses due to unequal adhesion of the wheels on the rails; and fourth, bending stresses due to the action of the flanges on the rails while rounding curves. Let

W = the area of the piston in square inches multiplied by the boiler pressure in pounds per square inch

L_1 = the lever arm in inches or the distance from the center of the main or connecting rod to the center line of the frame

O = the lever arm in inches or the distance from the center of the side rod to the center line of the frame

M = bending moment or the load in pounds times the lever arm in inches

d = the diameter of axle in inches

R = the section modulus which for a solid circular section $= .0982\ d^3$

If there are only two pairs of drivers, the force W will be equally distributed between the crank pins as shown in A, Fig. 89.

If the force W, the total steam on the piston, is assumed to act alone, the maximum fiber stress in pounds per square inch produced in the axle will be

$$S_1 = \frac{W\ L_1}{2\ R}$$

for the main axle, and

$$S_1 = \frac{W\ O}{2\ R}$$

for the back axle.

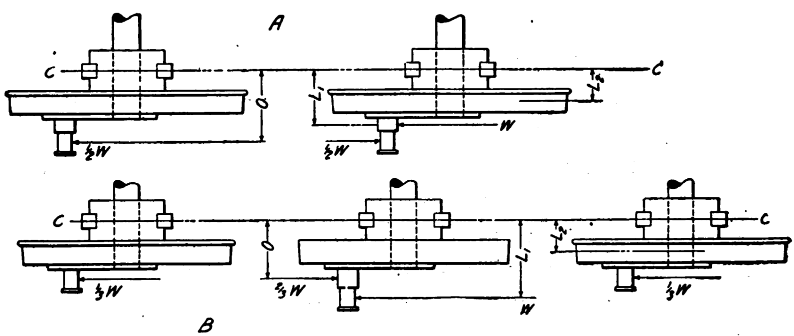


Fig 89. Force Diagram for Drivers.

Let

W_1 = the dead load in pounds on each journal

and

L_2 = lever arm in inches or the distance from the center of the driving box or frame to the center line of the rail.

Then, if the force W_1 be assumed to act alone, the maximum fiber stress in pounds per square inch produced in the axle will be

$$S_2 = \frac{W_1\ L_2}{R}$$

Let

L_3 = the crank radius, or one-half the length of the stroke in inches.

If the twisting of the axle alone is considered, the torsional or shearing stress in pounds per square inch produced in the axle will be

$$S_3 = \frac{W L_3}{2 R}$$

Because of certain existing conditions which affect the amount of torsion or twisting of the axle, only one-half of the theoretical stress should be used, as it is not probable that under any circumstances could more be transmitted by the axle to the opposite side.

Let

D = the diameter of drivers in inches

F = the centrifugal force in pounds

W_2 = the weight in pounds of the moving mass of wheels plus the weight carried by them

g = the acceleration of gravity in feet per second = 32.2

r = the radius of curvature of the track in feet

v = the velocity of the locomotive in feet per second

If the action on a curve alone is considered, the maximum fiber stress in pounds per square inch produced in the axle will be

$$S_4 = \frac{F D}{2 R}$$

where

$$F = \frac{W_2 v^2}{r g}$$

Considering all stresses acting together, we get the resultant maximum fiber stress in pounds per square inch in the axle to be

$$S'' = \frac{S'}{2} + \sqrt{\frac{(S')^2}{4} + \frac{(S_3)^2}{2}}$$

where

$$S' = \sqrt{(S_1)^2 + (S_2)^2}$$

In this equation, the bending stress due to the centrifugal force while rounding curves does not appear since it is assumed that this will neutralize that due to the dead load on the axle.

The following allowable fiber stresses in pounds per square inch have been used in successful designs:

TABLE XVII

Fiber Stresses

Type of Locomotive	Iron	Steel
Consolidation	7,500	8,500
10 wheel or Mogul	8,500	9,500
8 wheel passenger	10,500	13,000

Example. Determine the fiber stresses in the driving axle of an 8-wheel passenger locomotive having the following dimensions: cylinder 20 inches in diameter, length of stroke 26 inches, steam pressure 200 pounds per square inch, and other dimensions as listed:

O = 21.5 inches
R = 65.77 for an axle $8\frac{3}{4}$ inches in diameter
W_1 = 18,000 pounds
L_2 = $7\frac{1}{2}$ inches
L_3 = 13 inches
D = 75 inches
g = 32.2
r = 955 feet
v = 88 feet per second (60 miles per hour)
W_2 = 42,500 pounds

Solution.

$$S_1 = \frac{W\,O}{2\,R} = \frac{62700 \times 21.5}{2 \times 65.77}$$

$$= 10250 \text{ pounds per square inch}$$

$$S_2 = \frac{W_1\,L_2}{R} = \frac{18000 \times 7.5}{65.77}$$

$$= 2050 \text{ pounds per square inch}$$

$$S_3 = \frac{W\,L_3}{2\,R} = \frac{62700 \times 13}{2 \times 65.77}$$

$$= 6200 \text{ pounds per square inch.}$$

As previously stated, this value would probably never exceed one-half this amount, which assumption gives a fiber stress of 3,100 pounds per square inch.

$$F = \frac{W_2 v^2}{r g} = \frac{42500 \times (88)^2}{955 \times 32.2}$$

$$= 10700 \text{ pounds}$$

$$S_4 = \frac{F D}{2 R} = \frac{10700 \times 75}{2 \times 65.77}$$

$$= 6055 \text{ pounds per square inch}$$

The flange pressure would probably not exceed one-third of the total centrifugal force, the remainder being absorbed by the elevation of the outer rail. If this were true, then

$$S_4 = \frac{6055}{3} = 2018 \text{ pounds per square inch}$$

which, as can be seen, just about neutralizes the stress due to the dead weight.

$$S' = \sqrt{(S_1)^2 + (S_2)^2}$$

$$= \sqrt{10250^2 + 2050^2}$$

$$= 10450 \text{ pounds per square inch}$$

Therefore,

$$S'' = \frac{S'}{2} + \sqrt{\frac{(S')^2}{4} + \frac{(S_3)^2}{2}}$$

$$= \frac{10450}{2} + \sqrt{\frac{(10450)^2}{4} + \frac{(3100)^2}{2}}$$

$$= 10990 \text{ pounds per square inch}$$

Therefore, an $8\frac{3}{4}$ steel axle is large enough for an 8-wheel passenger locomotive since the allowable fiber stress of 13,000 pounds per square inch is not exceeded.

If the locomotive under consideration was one having three pairs of drivers instead of two, the total piston pressure would be distributed as shown in *B*, Fig. 78.

Crank Pins. Crank pins are calculated for strength by the following methods:

In *A*, *B*, and *C*, Fig. 90, is shown the manner in which the forces act on the crank pins of three different types of locomotives.

Let

W = the boiler pressure in pounds per square inch, times area of the piston in square inches

S = the safe fiber stress in pounds per square inch

L = the lever arm in inches or the distance from the face of the wheel to the center of the main rod

M = maximum moment in inch pounds or force in pounds times the lever arm in inches

P_1 = the force in pounds transmitted to the side rod

d = the diameter of crank pin in inches

L_1 = the side rod lever arm in inches or the distance from the face of the wheel center to the center line of the side rod

R = the section modulus of the crank pin which for a circular section = $.0982\ d^3$

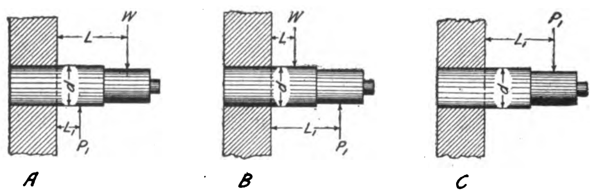


Fig. 90. Action of Force on Crank Pins in Different Types of Locomotives.

Having given the above conditions, we may write

$$M = W L - P_1 L_1$$

and

$$S = \frac{M}{R} = \frac{M}{.0982\ d^3}$$

From this last equation

$$d^3 = \frac{M}{.0982\ S}$$

Finally, substituting the value of M we get

$$d = \sqrt[3]{\frac{W L - P_1 L_1}{.0982\ S}}$$

This equation may be used in finding the diameter of the main crank pin on any type of locomotive when the loads and lever arms are known and the safe fiber stress has been assumed. It should be remembered, however, that for an 8-wheeled locomotive it is

$$P_1 = \frac{W}{2}$$

and for a 10-wheeled locomotive it is

$$P_1 = \frac{W}{3}$$

For crank pins other than main pins on engines having the main rod on the outside, no calculations need be made for bending.

To calculate the back pin, the load is applied as shown in C, Fig. 80, and we have

$$M = P_1 L_1$$

and finally

$$d = \sqrt[3]{\frac{P_1 L_1}{.0982 S}}$$

The maximum allowable working stress in pounds per square inch for crank pins is as follows:

TABLE XVIII

Working Stress for Crank Pins

Class of Locomotives	Steel	Iron
Freight locomotive	15,000	12,000
Passenger locomotive	12,000	10,000

In addition to figuring the crank pins for bending, the bearing surface must be given some attention. In order to prevent overheating and to secure the best results, the pin must be designed so that the unit pressure will not exceed an amount determined by past experience. This allowable pressure in practice varies from 1,600 to 1,700 pounds per square inch of projected area, the projected area being the diameter of the pin multiplied by its length. It often happens that it is necessary to make the pin larger than is required for safe strength in order that the allowable bearing pressure may not be exceeded.

Piston Rods. Because of the peculiar conditions of stress and loading of a piston rod, a very high factor of safety must be used in its design. It is subjected to both tensional and compressional stresses and must be capable of resisting buckling when in compression. Reuleaux gives the following formulae for determining the diameter of piston rods:

Considering tension alone

$$d = .0108\ D\ \sqrt{P}$$

and considering buckling

$$d = .0295\ D\ \sqrt{\frac{L}{D}}\ \sqrt[4]{P}$$

where

D = diameter of cylinder in inches
d = smallest diameter of piston rod in inches
L = length of the piston rod in inches
P = the boiler pressure in pounds per square inch

Example. Given a locomotive having cylinders 20 inches in diameter, piston rod 46 inches long, and carrying a boiler pressure of 190 pounds per square inch. Determine the diameter of the piston rod necessary.

SOLUTION. Considering the problem from the standpoint of tension only, we have

$$\begin{aligned} d &= .0108 \times 20\ \sqrt{190} \\ &= 2.98 \text{ inches} \end{aligned}$$

The dimensions of the rod determined from the standpoint of buckling would be

$$\begin{aligned} d &= .0295 \times 20\ \sqrt{\frac{46}{20}}\ \sqrt[4]{190} \\ &= 3.3 \text{ inches} \end{aligned}$$

The size which would probably be used would be, say, 3½ inches, which would allow for wear.

From the above figures, it is evident that if a piston rod is made strong enough to withstand buckling, it will be sufficiently large to resist the tensional stresses which may come upon it.

Frames. As has been previously stated, the frames of a locomotive are very difficult to design because of the many unknown factors which affect the stresses in them. The following method of proportioning wrought-iron and cast-steel frames will give safe values for size of parts although the results thus found will be greater than usually found in practice.

Let

P = the thrust on the piston or the area of the piston in square inches multiplied by the boiler pressure in pounds per inch

A = the area in square inches of the section of the frame at the top of the pedestal

B = the area in square inches of the section of the frame at the rail between the pedestals

C = the area in square inches of the section of the lower frame between the pedestals

Then

$$A = \frac{P}{2600}$$

$$B = \frac{P}{3000}$$

$$C = \frac{P}{4400}$$

Cylinders. The formula commonly used in determining the thickness of boiler shells, circular tanks, and cylinders is

$$t = \frac{p\,d}{2\,f}$$

where

t = thickness of cylinder wall in inches

p = pressure in pounds per square inch

d = diameter of cylinder in inches

f = safe fiber stress which for cast iron is usually taken at 1500 pounds per square inch

For cylinder heads, the following empirical formula may be used in calculating the thickness:

$$T = .00439\, d \sqrt{p}$$

where

T = the thickness of the cylinder head in inches

p = boiler pressure in pounds per square inch

d = diameter of stud bolt circle

Cylinder specifications usually call for a close grain metal as hard as can be conveniently worked. The securing of the proper proportions of a cylinder for a locomotive is a matter of great importance in locomotive design. The cylinders must be large enough so that with a maximum steam pressure they can always turn the driving wheels when the locomotive is starting a train. They should not be much greater than this, however, otherwise the pressure on the piston would probably slip the wheels on the rails. The maximum force of the steam in the cylinders should therefore be equal to the adhesion of the wheels to the rails. This may be assumed to be equal to one-fourth of the total weight on the driving wheels. The maximum mean effective piston pressure in pounds per square inch may be taken to be 85 per cent of the boiler pressure.

As the length of the stroke is usually fixed by the convenience of arrangement and the diameter of the driving wheels, a determination of the size of the cylinder usually consists in the calculation of its diameter. In order to make this calculation, the diameter of the driving wheels and the weight on them, the boiler pressure, and the stroke of the piston must be known. With this data, the diameter of the cylinder can be calculated as follows:

The relation between the weight on the drivers and the diameter of the cylinder may be expressed by the following equation:

$$W = \frac{.85\ d^2\ p\ L}{C\ D}$$

where

W = the weight in pounds on drivers
d = diameter of cylinders in inches
p = boiler pressure in pounds per square inch
L = stroke of piston in inches
D = diameter of drivers in inches
C = the numerical coefficient of adhesion

From the above equation, the value of d may be obtained since the coefficient of adhesion C may be taken as .25. The equation then becomes

$$W = \frac{.85\ d^2\ p\ L}{.25\ D}$$

from which

$$d = \sqrt{\frac{.25\ W\ D}{.85\ p\ L}}$$

Example. What will be the diameter of the cylinders for a locomotive having 196,000 pounds on the drivers, a stroke of 24 inches, drivers 63 inches in diameter. and a working steam pressure of 200 pounds per square inch?

SOLUTION.

$$d = \sqrt{\frac{.25 \times 196000 \times 63}{.85 \times 200 \times 24}}$$
$$= 27.5 \text{ inches}$$

The above formula gvies a method of calculating the size of cylinders to be used with a locomotive when the steam pressure, weight on drivers, diameter of drivers, and stroke are known. This formula is based upon the tractive force of a locomotive or the amount of pull which it is capable of exerting.

The *tractive force* of a locomotive may be defined as being the force exerted in turning its wheels and moving itself with or without a load along the rails. It depends upon the steam pressure, the diameter and stroke of the piston, and the ratio of the weight on the drivers to the total weight of the engine, not including the tender. The formula for the tractive force of a simple engine is

$$T = \frac{.85\ p\ d^2\ L}{D}$$

where

T = the tractive force in pounds
d = diameter of cylinders in inches
L = stroke of the piston in inches
D = diameter of the driving wheels in inches
p = boiler pressure in pounds per square inch

When indicator cards are available, the mean effective pressure on the piston in pounds per square inch may be accurately determined and its value p_1 may be used instead of .85 p, in which case the formula becomes

$$T = \frac{p_1\ d^2\ L}{D}$$

Some railroads make a practice of reducing the diameter of the drivers D by 2 inches in order to allow for worn tires.

In the case of a two-cylinder compound locomotive, the formula for tractive force is

$$T = \frac{.85\ p\ (d_1)^2\ L}{1 + \left(\frac{d_1}{d_2}\right)^2 D}$$

where

D = the diameter of the drivers in inches
d_1 = diameter of low-pressure cylinder in inches
d_2 = diameter of high-pressure cylinder in inches

Train Resistance. The resistance offered by a train per ton of weight varies with the speed, the kind of car hauled, the condition of the track, journals and bearings, and atmospheric conditions.

Taking the average condition as found upon American railroads, the train resistance is probably best represented by the Engineering News formula

$$R = \frac{S}{4} + 2$$

in which

R = the resistance in pounds per net ton (2000 pounds) of load
S = speed in miles per hour

The force for starting is, however, about 20 pounds per ton which falls to 5 pounds as soon as a low rate of speed is obtained. The resistance due to grades is expressed by the formula

$$R' = 0.38\ M$$

in which

R' = the resistance in pounds per net ton of load
M = grade in feet per mile

The resistance due to curves is generally taken at from .5 to .7 pounds per ton per degree of curvature. Taking the latter value and assuming that locomotives on account of their long rigid wheel base produce double the resistance of cars, we have

R'' = .7 C for cars, and
R'' = 1.4 C for locomotives

in which

R'' = the resistance in pounds per net ton due to curvature
C = the curvature in degrees

Considerable resistance is offered by wind but this is of such a nature that calculations are extremely difficult to make which would be of any practical value.

The resistances mentioned above do not take into account that due to the acceleration of the train. This may be expressed by the formula

$$R''' = .0132\ v^2$$

in which

v = the speed in miles per hour attained in one mile when starting from rest, being uniformly accelerated

R''' = resistance in pounds per net ton due to acceleration

Locomotive Rating. Since the locomotive does its work most economically and efficiently when working to its full capacity, it becomes necessary to determine how much it can handle. The determination of the weight of the train which a locomotive can handle is called the *rating*. This weight will vary for the same locomotive under different conditions. The variation is caused by the difference in grade, curvature, temperature conditions of the rail, and the amount of load in the cars. The variation due to the differences of car resistance arising from a variation of the conditions of the journals and lubrication is neglected because of the assumption of a general average of resistance for the whole.

The usual method of rating locomotives at present is that of tonnage. That is to say, a locomotive is rated to handle a train, weighing a certain number of tons, over a division. This is preferred to a given number of loaded or empty cars because of the indefinite variation in the weights of the loads and the cars themselves.

In the determination of a locomotive rating there are several factors to be considered, namely, the power of the locomotive, adhesion to the rail, resistance of the train including the normal resistance on a level, and that due to grades and curves, value of momentum, effect of empty cars, and the effect of the weather and seasons.

The power of a locomotive and its adhesion to the rails has already been considered. From the formula given, the tractive power can be calculated very closely from data already at hand.

There are three methods in use for obtaining the proper tonnage rating. First, a practical method which consists in trying out each class of engine on each critical or controlling part of the division and continuing the trials until the limit is reached. Second, a more rapid and satisfactory method is to determine the theoretical rating. Third, the most satisfactory method is, first, to determine the theoretical rating and then to check the results by actual trials.

The value of the momentum of a train is a very important element in the determination of the tonnage rating of locomotives on most railroads. In mountainous regions, with long heavy grades, there is little opportunity to take advantage of momentum, while on undulating roads, it may be utilized to the greatest advantage. An approach to a grade at a high velocity when it can be reduced in ascending the same, enables the engine to handle greater loads than would otherwise be possible without such assistance. Hence, stops, crossings, curves, water tanks, etc., will interfere with the make-up of a train if so located as to prevent the use of momentum. It is necessary, therefore, to keep all these points in mind when figuring the rating of a locomotive for handling trains over an undulating division.

The ordinary method of allowing for momentum is to deduct the velocity head from the total ascent and consider the grade easier by that amount.

For example: Suppose that a one per cent grade 5,000 feet long is so situated that trains could approach it at a high speed. The total rise of the grade would be 50 feet but 15 feet of that amount could be overcome by the energy of the train, leaving 35 feet that the train must be raised or lifted by the engine. The grade in which the rise is 35 feet in 5,000 would be a 0.7 per cent grade, so that if the engine could exert sufficient force to overcome the train resistance and that due to a 0.7 per cent grade, the train could be lifted the remainder of the height by its kinetic energy. In this case, the 5,000 feet of one per cent grade could be replaced by a grade of 0.7 per cent 5,000 feet long, and the effect on the load hauled by the engine would be the same if in the latter case the energy of the train were not taken into account. Since the height to which the kinetic energy raises the train is independent of the length of the grade, its effect becomes far less when the grades are long than when short. Thus, for a one per cent grade 1,000 feet long, the total rise being only 10 feet, the kinetic energy would be more than sufficient to raise the weight of the train up the entire grade leaving only the frictional resistance to be overcome by the engine; whereas if the grade were 50,000 feet in length, or a total rise of 500 feet, the energy of the train would only reduce this rise about 15 feet, leaving a rise of 485 feet or the equivalent of a 0.99 per cent grade to be overcome by the engine, a reduction not worth considering.

It is thus seen that the length of a grade exerts a great influence on the value of the momentum.

Within ordinary limits, the following formula gives very accurate results

$$= \frac{d^2 L p_1}{D\left(R' + \frac{a}{2.64}\right)\left(1 - \frac{V^2 - v^2}{.00566\, a\, l\left(1 + \frac{2.64 R'}{a}\right)}\right)}$$

where

T = number of tons including engine, which can be hauled over a grade with velocities of V and v

d = diameter of cylinder in inches

L = length of stroke in inches

p_1 = mean effective pressure in pounds per square inch

D = diameter of driver in inches.

R' = resistance in pounds per ton on a level track due to friction, air curves, and velocity, which may be taken at 8 pounds per ton

a = grade in feet per mile

l = length of grade in feet

V = velocity in miles per hour at foot of grade

v = velocity in miles per hour at top of grade

Thus, with an engine having cylinders 17 inches in diameter, a stroke of 24 inches, driving wheels 62 inches in diameter, and running at a velocity of 30 miles per hour, the formula gave a rating of 738 tons. On actual tests, it was possible to handle 734 tons with a speed of 10 miles an hour at the top of the grade.

The effect of empty cars is to reduce the total tonnage of the train below what could be handled if they were all loaded. The resistance of empty cars when on a straight and level track varies from 30 to 50 per cent more per ton of weight than loaded cars.

In using the formula given above, loaded cars are assumed. For empty cars, 40 per cent should be added. That is to say, if a train is composed of empty and loaded cars and is found to have a certain resistance, 40 per cent should be added to the portion of resistance due to the empty cars.

There is considerable difference of opinion regarding the allowance which should be made for the conditions of weather, etc. The following is a fair allowance which has been found to give satisfactory results in practice: Seven per cent reduction for frosty or wet rails; fifteen per cent reduction for from freezing to zero temperature; and twenty per cent reduction for from zero to twenty degrees below.

The use of pushing or helping engines over the most difficult grades of an undulating track will increase the train load and thus reduce the cost of transportation.

LOCOMOTIVE APPLIANCES

In order to enable the engineer to operate and control a locomotive successfully and economically a certain number of fittings on the locomotive are necessary. These fittings consist chiefly of the safety valves, whistle, steam gauge, lubricator, water gauges, blower, throttle valve, injector, air brake, and signal apparatus.

Safety Valves. The universal practice at present is to use at least two safety valves of the pop type upon every locomotive boiler. On small locomotives where clearances will permit, the safety valves are placed in the dome cap. On large locomotives where the available height of the dome is limited, the safety valves are usually placed on a separate turret. When limiting heights will not permit the use of turrets, the safety valves may be screwed directly into the roof of the boiler.

The construction of a good safety valve is such that when it is raised, the area for the escape of steam is sufficient to allow it to escape as rapidly as it is formed, and that as soon as the pressure has fallen a pre-determined amount, it will close.

It should be so designed that it can neither be tampered with nor get out of order. It must act promptly and efficiently and not be affected by the motion of the locomotive. These conditions are all fulfilled in the type of valve shown in section in Fig. 91. In this design, the valve *a* rests on the seat *b b* and is held down by a spindle *c*, the lower end of which rests on the bottom of a hole in the valve *a*. A helical spring *d* rests on a collar on the spindle. The pressure on the spindle is regulated by screwing the collar *e* up or down. The valve seat *b b* may be rounded or straight. Outside of the valve seat there is a projection *f*, beneath which a groove *g* is cut in the casing. When the valve lifts, this groove is filled with steam which presses against

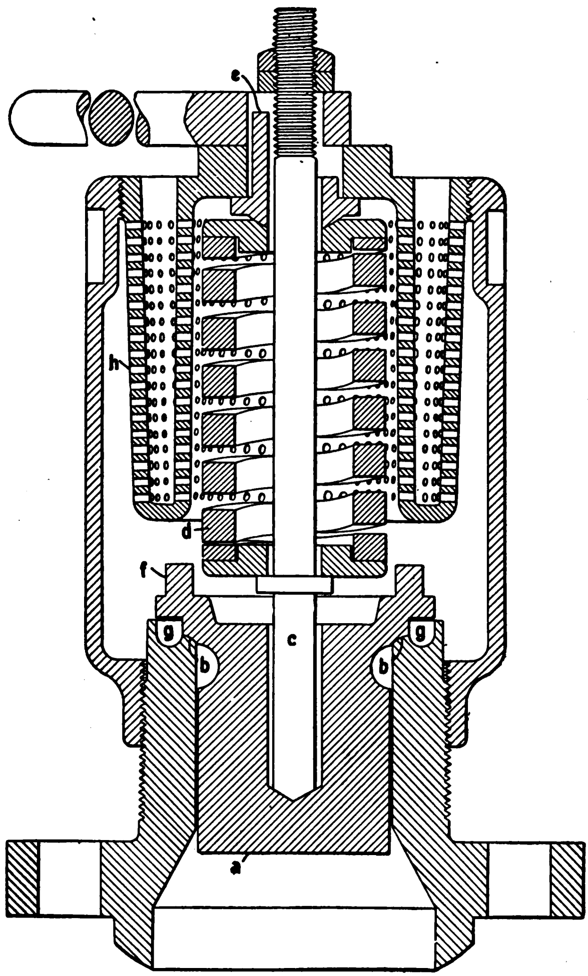


Fig. 91. Section of Safety Valve.

that portion of the valve outside of the seat, and, by thus increasing the effective area of the valve, causes it to rise higher and to remain open longer than it otherwise would without this projection. The adjustment of the valve is usually made so that after opening, it will permit steam to escape until the pressure in the boiler is about 4 pounds below the normal pressure. The steam escaping through the small holes *h*, is muffled, thus avoiding great annoyance.

Another form of safety valve which is being largely used is that shown in Fig. 92. The principle of its operation is the same as that just described. It is said to be very quiet and yet gives effective relief. It is being adopted by several railroads.

The Injector. The injector may be defined as an apparatus for forcing water into a steam boiler in which a jet of steam imparts its energy to the water and thus forces it into the boiler against boiler pressure. Injectors are now universally employed for delivering the feed water to the boiler. Two injectors are always used, either one of which should have a capacity sufficient to supply the boiler with water under ordinary working conditions. They are located one on either side of the boiler. Injectors may be classified as *lifting* and *non-lifting*, the former being most commonly used. The lifting injector is placed above the high water line in the tank, therefore in forcing water into the boiler, it lifts the water through a height of a few feet. The non-lifting injector is placed below the bottom of the water tank, hence the water flows to the injector by reason of gravitation.

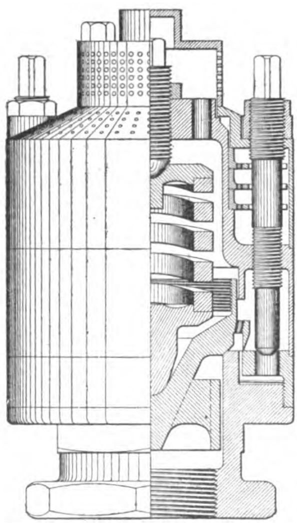


Fig. 92. Another Form of Safety Valve.

There are a great many different injectors on the market. All work upon the same general principle, differing only in the details of construction. One type only will be described, namely, the Sellers injector illustrated in Fig. 93.

Sellers Injector. To operate this injector, the method of procedure is as follows: Draw starting lever, 33, slowly. If the water supply is hot, draw the lever about one inch and after the water is lifted, draw the lever out the entire distance. The cam lever, 34, must be in the position shown. To stop the injector, push the starting

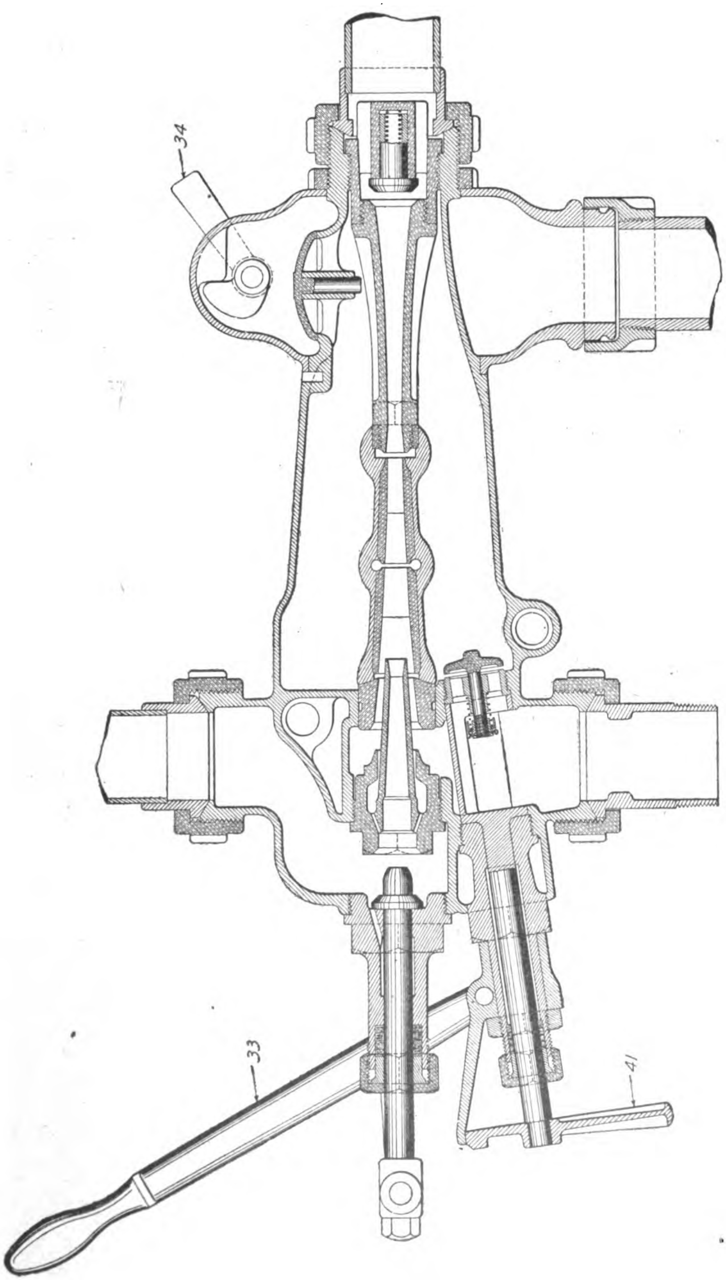


Fig. 93. Sellers Injector.

lever in. To regulate the amount of flow of water after the injector has been started, adjust the regulating handle, 41. If it is desired to use the injector as a heater, place the cam lever, 34, in the rear position and pull the starting lever slowly.

The injector is not a sensitive instrument but requires care to keep it in working condition. It should be securely connected to the boiler in easy reach of the engineer. All joints must be perfectly tight to insure good working conditions. All pipes, hose connections, valves, and strainers must be free from foreign matter. Most failures of injectors are due largely to the presence of dirt, cotton, waste, etc., in the strainers. It is not possible to mention in detail all circumstances which produce injector failures but the complaints commonly heard are as follows:

1. The injector refuses to lift the water promptly, or not at all.

2. The injector lifts the water but refuses to force it into the boiler. It may force a part of the water into the boiler, the remainder being lost in the overflow.

Unless these failures are due to the wearing out of the nozzles which may be renewed at any time, they may be largely avoided by keeping in mind the following points:

All pipes, especially iron ones, should be carefully blown out with steam before the injector is attached, the scale being loosened by tapping the pipes with a hammer.

All valves should be kept tight and all spindles kept tightly packed.

When a pipe is attached to the overflow, it should be the size called for by the manufacturer.

The suction pipe must be absolutely tight since any air leak reduces the capacity of the injector.

The delivery pipe and boiler check valve must be of ample dimensions.

The suction pipes, hose, and tank valve connections must be of ample size and the hose free from sharp kinks and bends.

The strainer should be large enough to give an ample supply of water even if a number of the holes are choked.

The injector is one of the most important boiler appliances, for upon the ability of the injector to promptly supply the necessary water depends the movement of trains. It is, therefore, very necessary to keep the injector in perfect repair by following the hints given above.

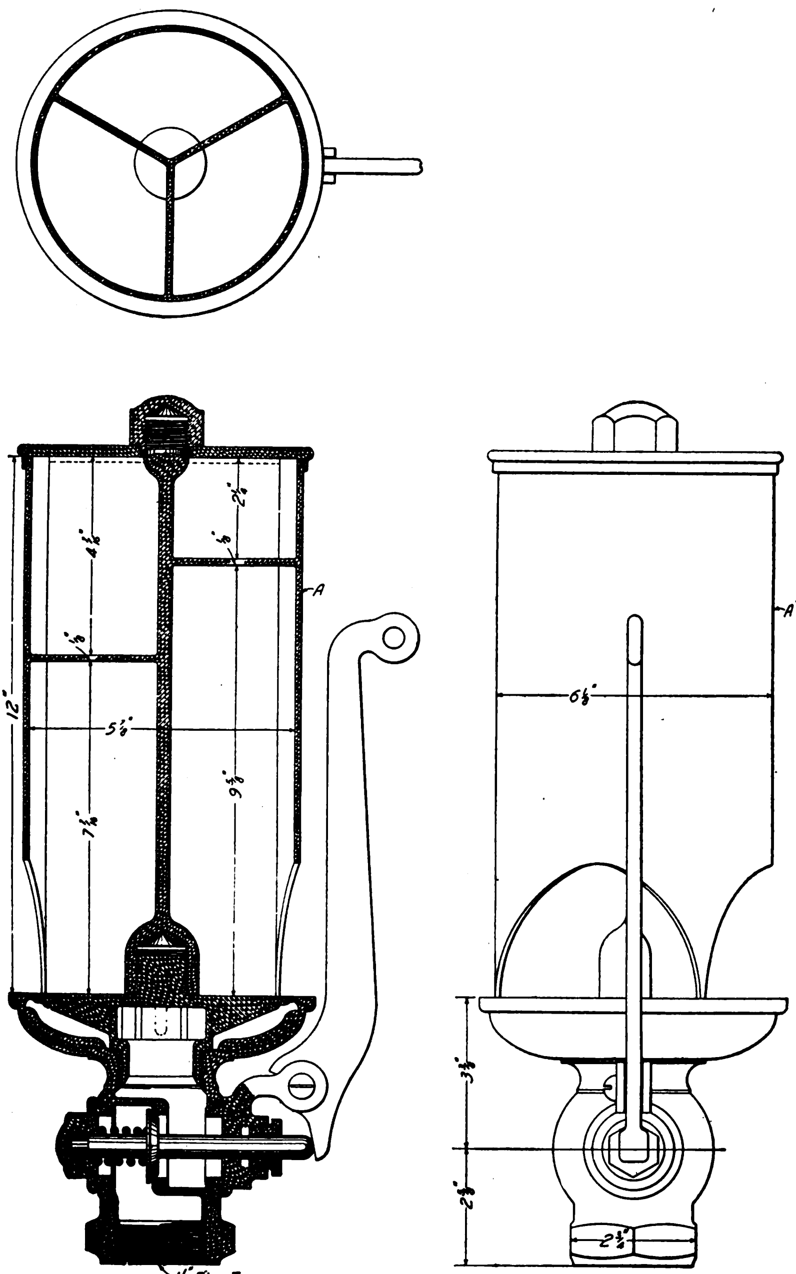


Fig. 94. Locomotive Whistle.

The Whistle. The whistle is used for signaling purposes and consists of a thin circular bell, Fig. 94, closed at the top and sharp at the lower edge. Steam is allowed to escape from a narrow circular orifice directly beneath the edge of the bell. A part of the escaping steam enters the interior of the bell and sets up vibrations therein. The more rapid these vibrations, the higher the tone of the whistle. The tone is affected by the size of the bell and the pressure of the steam. The larger the bell, the lower will be the tone. The higher the steam pressure, the higher the tone. In order to avoid the shrill noise of the common whistle, chime whistles are commonly used, one type of which is illustrated in Fig. 94. In this illustration the bell is divided into three compartments of such proportions that the tones harmonize and give an agreeable chord.

Steam Gauges. The usual construction of the steam gauge will not be presented here but reference is made to the instruction paper on "Boiler Accessories."

Water Gauges. Water gauges are also fully explained in the instruction paper on "Boiler Accessories."

The Blower. The blower consists merely of a steam pipe leading from and fitted with a valve in the cab to the stack where it is turned upward. The end of this pipe is formed into a nozzle. The escaping steam gives motion to the air exactly as already explained for the exhaust and thus induces a draft through the fire-box. It is used when the fire is to be forced while the engine is standing.

Throttle Valve. The throttle valve now in universal use is some form of a double-seated poppet valve, as illustrated in Fig. 95. In this type, two valves *a* and *b* are attached to a single stem, the upper valve being slightly the larger. The lower valve *b* is of such a diameter that it will just pass through the seat of the valve *a*. The steam, therefore, exerts a pressure on the lower face of *b* and the upper face of *a*. As the area of *a* is the greater, the resultant tendency is to hold the valve closed. The valve is, therefore, partially balanced. It will be difficult to open large throttle valves such as are now used on locomotives carrying high steam pressures, with the ordinary direct form of leverage. In such cases, it will be necessary to give a strong, quick jerk to the throttle lever before the valve can be moved from its seat. The arrangement of leverage shown in Fig. 95 obviates this difficulty. The rod *c* connects with a lever in the cab and communicates its movement to the bell crank *d*, whence it is carried by the stem *e* to the valve. The pivot of the bell crank is provided with a slotted hole. At the start, the length of the short arm is about $2\frac{1}{4}$ inches while the long arm is about $9\frac{1}{2}$ inches. After the valve has been lifted from its seat and is free from excess pressure on *a*, the projecting arm *A* on the back of the bell crank comes in contact with the bracket *B* on the side of the throttle pipe and the bell crank takes the position shown by the dotted lines in the figure. The end of the projecting arm *A* then becomes the pivot and the length of the short arm of the lever is changed to $9\frac{1}{2}$ inches and that of the long arm to about $11\frac{1}{2}$ inches.

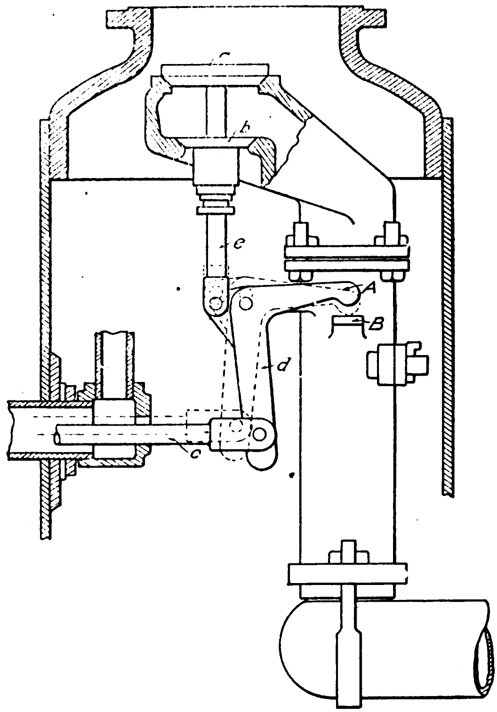


Fig. 95. Throttle Valve.

Dry Pipe. The dry pipe connects with the throttle valve in the steam dome and extends from the dome to the front flue sheet, terminating in the T, which supplies steam to the steam pipes. It is evident, therefore, that the dry pipe must be of such capacity that it will supply both cylinders with a sufficient amount of steam. The following sizes are usually used:

TABLE XIX

Dry Pipe Sizes

Diameter of Cylinder in Inches	Diameter of Dry-Pipe in Inches
14–17	5
17–19	6
19–21	7
21	8

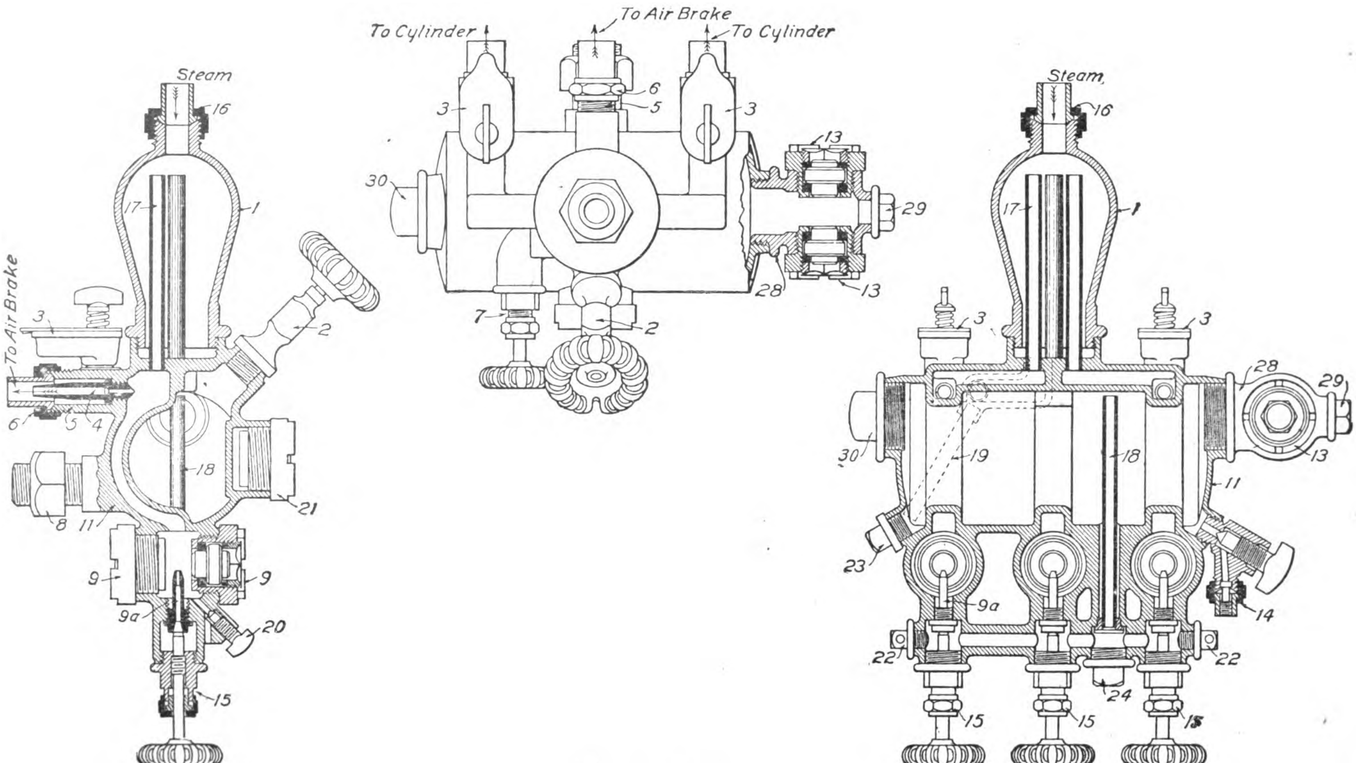


Fig. 96. Lubricator.

Lubricator. The lubricator, one of the most essential locomotive appliances, is usually supported by a bracket from the back head of the boiler in convenient reach of the engineer. It may be a two-, three-, or four-sight feed lubricator as the case demands, the number of sight feeds indicating the number of lubricating pipes supplied by the lubricator. For instance, a two-sight feed lubricator has two pipes, one leading to each steam chest. A triple-sight feed is used to supply oil to both steam chests and also to the cylinder of the air pump. In using superheaters, it has been found necessary to oil the cylinders as well as the valves, hence the need of the four-sight feed lubricator. Fig. 96 shows sections of a well-known make of a triple-sight feed lubricator. The names of the parts are as follows:

1. CONDENSER	15. REGULATING VALVES
2. FILLING PLUG	16. TOP CONNECTION
3. HAND OILER	17. EQUALIZING PIPE
4. CHOKE PLUG or REDUCING PLUG	18. OIL PIPE
5. TAILPIECE	19. WATER PIPE
6. DELIVERY NUT	20. SIGHT FEED DRAIN VALVE
7. WATER VALVE	21. EXTRA GLASS AND CASING
8. STUD NUT	22. CLEANING PLUG
9. SIGHT FEED GLASS AND CASING	23. BODY PLUG
9a. FEED NOZZLE	24. OIL PIPE PLUG
11. BODY	28. GAUGE GLASS BRACKET
13. GAUGE GLASS AND CASING	29. CLEANING PLUG
14. WASTE COCK	30. GAUGE GLASS CAP.

The lubricator is fastened to the boiler bracket by means of the stud nut, 8. In brief, the operation of the lubricator, as illustrated in Fig. 96, is as follows:

Steam is admitted to the condensing chamber, 1, through the boiler connection, 16. The steam condenses in the condenser and passes through the equalizing pipe to the bottom of the oil reservoir. The lubricator is filled at the filling plug, 2. As the condensed steam fills up the lubricator, the oil level is raised until the oil passes through the tubes, 18, to the regulating valve, 15, from whence it is permitted to pass drop by drop through the sight feed glass, 9, to the different conveying pipes. To fill the lubricator, first be sure that the steam valve is closed, then remove the filling plug and pour in the necessary amount of oil. After the filling plug has been replaced, open the steam valve slowly and let it remain open. After this, regulate the flow of oil by means of the regulating valves, 15.

Air Brake and Signal Equipment. The air brake and signal equipment are fully explained in the instruction book on the "Air-Brake" and will not be presented.

RAILWAY SIGNALING

Railway signaling is a very important subject and one to which a great deal of attention has been directed in recent years; it is by no means a new subject, however, nor has its development been rapid. It early became evident that signals are necessary in governing the movement of trains, so we find that as the traffic and speed of trains increased, the demand for improvements in signaling likewise increased.

Although there are a great many kinds of signals on the market, they may all be classed under four general types, namely, *audible*, *movable*, *train*, and *fixed signals*. The audible signal is well known as the bell, whistle, and torpedo.

Whistle Signals. One long blast of the whistle is the signal for approaching stations, railroad crossings, and junctions. (Thus ——.)

One short blast of the whistle is the signal to apply the brakes to stop. (Thus —.)

Two long blasts of the whisle is the signal to release the brakes. (Thus —— ——.)

Two short blasts of the whistle is an answer to any signal unless otherwise specified. (Thus — —.)

Three long blasts of the whistle to be repeated until answered is the signal that the train has parted. (Thus —— —— ——.)

Three short blasts of the whistle when the train is standing, to be repeated until answered, is a signal that the train will back. (Thus — — —.)

Four long blasts of the whistle is a signal to call in the flagman from the west or south. (Thus —— —— —— ——.)

Four long, followed by one short blast of the whistle, is the signal to call in the flagman from the east or north. (Thus —— —— —— —— —.)

Four short blasts of the whistle is the engineman's call for signals from switch tenders, watchmen, trainmen, and others. (Thus — — — —.)

One long and three short blasts of the whistle is a signal to the flagman to go back and protect the rear of the train. (Thus —— — — —.)

One long, followed by two short blasts of the whistle, is the signal to be given by trains when displaying signals for a following train to call the attention of trains of the same or inferior class to the signals displayed. (Thus —— — —.)

Two long followed by two short blasts of the whistle is the signal for approaching road crossings at grade. (Thus —— —— — —.)

A succession of short blasts of the whistle is an alarm for persons or cattle on the track and calls the attention of trainmen to the danger ahead.

Bell Cord Signals. One short pull of the signal cord when the train is standing is the signal to start.

Two pulls of the signal cord when the train is running is the signal to stop at once.

Two pulls of the signal cord when the train is standing is the signal to call in the flagman.

Three pulls of the signal cord when the train is running is the signal to stop at the next station.

Three pulls of the signal cord when the train is standing is the signal to back the train.

Four pulls of the signal cord when the train is running is the signal to reduce the speed.

When one blast of the signal whistle is heard while a train is running, the engineer must immediately ascertain if the train has parted, and, if so, take great precaution to prevent the two parts of the train from coming together in a collision.

Movable Signals. Movable signals are used to govern the movement of trains in switching and other service where demanded. They are made with flags, lanterns, torpedoes, fusees, and by hand. The following signals have been adopted as a standard code by the American Railway Association:

Flags of the proper color must be used by day and lamps of the proper color by night or whenever from fog or other cause, the day signals cannot be clearly seen.

Red signifies danger and is a signal to stop.

Green signifies caution and is a signal to go slowly.

White signifies safety and is a signal to continue.

Green and *white* is a signal to be used to stop trains at flag stations for passengers or freight.

Blue is a signal to be used by car inspectors and repairers and signifies that the train or cars so protected must not be moved.

An explosive cap or torpedo placed on the top of the rail is a signal to be used in addition to the regular signals.

The explosion of one torpedo is a signal to stop immediately. The explosion of two torpedoes is a signal to reduce speed immediately and look out for danger signals.

A fusee is an extra danger signal to be lighted and placed on a track at night in case of accident and emergency.

A train finding a fusee burning on the track must come to stop and not proceed until it has burned out. A flag or a lamp swinging across the track, a hat or any object waved violently by any person on the track, signifies danger and is a signal to stop.

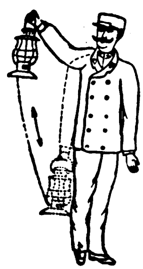


Fig. 97. Signal to Go Ahead.

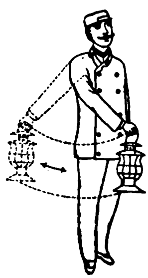


Fig. 98. Signal to Stop.

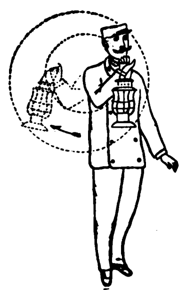


Fig. 99. Signal to Back Up.

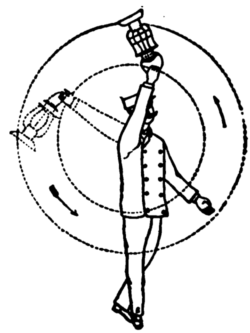


Fig. 100. Signal that Train has Parted.

The hand or lamp raised and lowered vertically is a signal to move ahead, Fig. 97.

The hand or lamp swung across the track is a signal to stop, Fig. 98.

The hand or lamp swung vertically in a circle across the track when the train is standing is a signal to move back, Fig. 99.

The hand or lamp swung vertically in a circle at arm's length across the track when the train is running is a signal that the train has parted, Fig. 100.

Train Signals. Each train while running must display two green flags by day, Fig. 101, and two green lights by night, one on each side of the rear of the train, as makers to indicate the rear of the train.

Each train running after sunset or when obscured by fog or other cause, must display the head light in front and two or more red lights in the rear, Fig. 102. Yard engines must display two green lights instead of red except when provided with a head light on both front and rear.

When a train pulls out to pass or meet another train the red lights must be removed and green lights displayed as soon as the track is

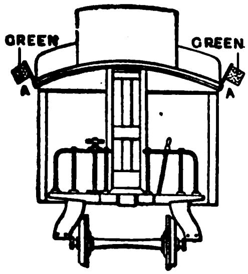


Fig. 101. Day Rear Signal.

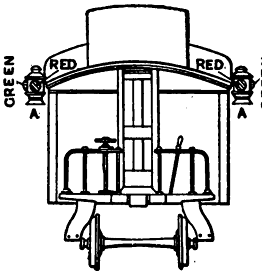


Fig. 102. Night Rear Signal.

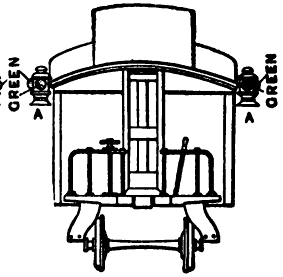


Fig. 103. Night Signal of a Clear Track.

clear, Fig. 103, but the red lights must again be displayed before returning to its own track.

Head lights on engines, when on side tracks, must be covered as soon as the track is clear and the train has stopped and also when standing at the end of a double track.

Two green flags by day and night, Fig. 104, and in addition two green lights by night, Fig. 105, displayed in places provided for that purpose on the front of an engine denote that the train is followed

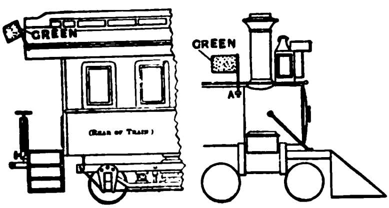


Fig. 104. Day Signal of a Train Behind.

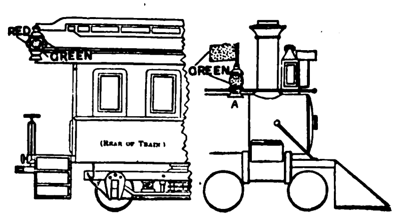


Fig. 105. Night Signal of a Train Behind.

by another train running on the same schedule and entitled to the same time table rights as the train carrying the signals.

An application of the above rules to locomotives running backward are shown in Figs. 106, 107, and 108.

Fig. 106 shows the arrangement of flags when a locomotive is running backward by day without cars, or pushing cars and carrying signals for a following train. There are two green flags, one at *A* and one at *B*, on each side. The green flag at *A* is a classification signal and that at *B* is the marker denoting the rear of the train.

Two white flags by day and night, Fig. 109, and in addition two white lights by night, Fig. 110, displayed in places provided for that

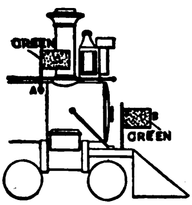


Fig. 106.

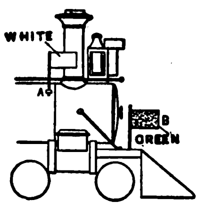


Fig. 107.

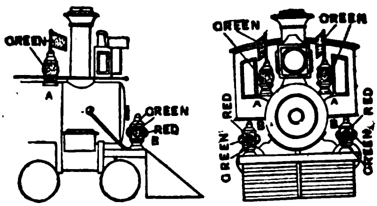


Fig. 108.

Signal of Train Behind or Locomotive Running Backward.

purpose on the front of an engine, denote that the train is an extra. These signals must be displayed by all extra trains but not by yard engines.

Fig. 107 shows the arrangement of flags on a locomotive which is running backward by day without cars or pushing cars and running extra. There is a white flag at *A* and a green one at *B*. The white flag is a classification signal and the green flag is the marker denoting the rear of the train.

Fig. 108 shows the arrangement of flags and lights on a locomotive which is running backward by night without cars or pushing

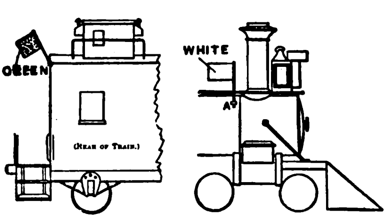


Fig. 109. Day Signal on Extra Train.

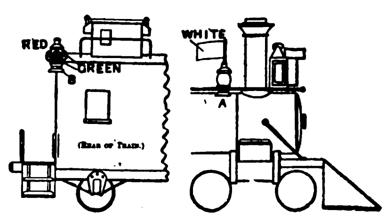


Fig. 110. Night Signal on Extra Train.

cars and carrying signals for a following train. There is a green flag and light at *A* and a combination light at *B*. The green light and flag at *A* serve as a classification signal. The combination light at *B* is a marker showing green on the side and the direction in which the engine is moving and red in the opposite direction.

Fig. 110 shows the arrangement of flags and lights on a train running forward by night and running extra. There is a white flag and white light at A as a classification signal. At B there is a combination light. This combination light shows green to the sides and front of the train and red to the rear.

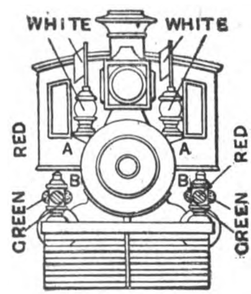


Fig. 111.
Night Signal on Locomotive Running Backward, as an Extra.

Fig. 111 shows the arrangement of flags and lights on a locomotive running backward by night without cars or pushing cars and running extra. There are white flags and white lights at A A as classification signals. At B B there are combination lights showing green on the sides and the direction in which the engine is running, and red in the opposite direction. The combination lights serve as markers.

Fig. 112 shows the arrangement of green marker flags on the rear of the tender of a locomotive which is moving forward by day without cars.

Fig. 113 shows the arrangement of combination lights used as markers on the rear of the tender of a locomotive which is running forward at night without cars. The combination light shows green at the sides and front and red at the back.

Fig. 114 shows the arrangement of lights on the rear of the tender

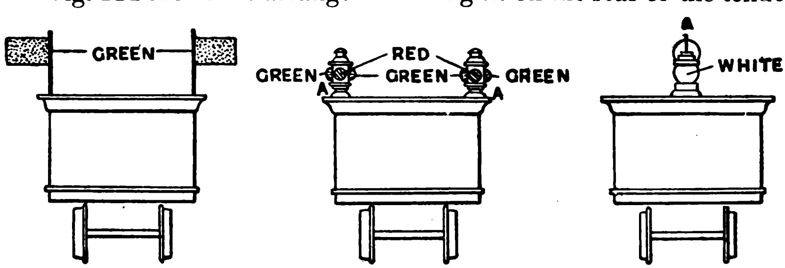


Fig. 112. Fig. 113. Fig. 114.
Signals on Tender for Engine Running Without Cars.

of a locomotive which is running backward by night. There is a single white light at A.

Fig. 115 shows the arrangement of lights on a passenger train which is being pushed by an engine at night. There is a white light at A on the front of the leading truck.

Fig. 116 shows the arrangement of lights on a freight train which is being pushed by an engine at night. There is a single white light at *A*.

Fixed Signals. Fixed signals consist in the use of posts or towers fixed at definite places and intervals having attached to them a system of rods, levers, and bell cranks to properly operate the arms or semaphores. The target is one form of fixed signal.

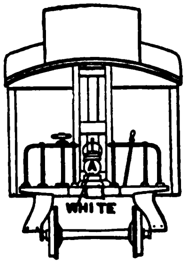


Fig. 115.
Night Signal for Passenger Train pushed by an Engine.

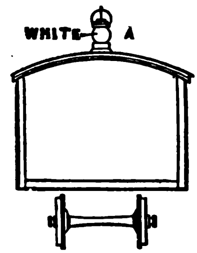


Fig. 116.
Night Signal for Freight Train Pushed by an Engine.

Targets are used to indicate, by form or color or both, the position of a switch. A target usually consists of two plates of thin metal at right angles to each other attached to the switch staff. The setting of the switch from the main line to a siding, for example, turns the staff through a quarter revolution thus exposing one or the other of the disks to view along the track. The disks or targets are usually painted red and white, respectively. When the red signal is exposed, the switch is set to lead off to the siding. When the white one is exposed, the switch is closed and the main line is clear. At night, a red and green or red and white light shows in place of the target.

The semaphore may now be considered as the standard method of controlling the movement of trains. It consists of an arm *A*, Fig. 117, pivoted at one end and fastened to the top of a post. When in the horizontal position, it indicates danger. When dropped to a position of 65 or 70 degrees below the horizontal, as in Fig. 118, it indicates safety.

At night, the semaphore is replaced by a light. There are two systems of light signals; one is to use a red light for danger, a green light for safety, and a yellow light for caution. The other is to use red for danger, white for safety, and green for caution. The method of operation is to have a lantern *B*, Fig. 118, attached to the left-hand side of the signal post in such a position that when the semaphore arm is in the horizontal position, the spectacle glass *C* will intervene between the approaching engine and the lantern as in Fig. 117. This spectacle glass is red. Where green is to be shown with a semaphore in the position shown in Fig. 118, the spectacle frame is double, as in Fig. 119, the upper glass being red and the lower green.

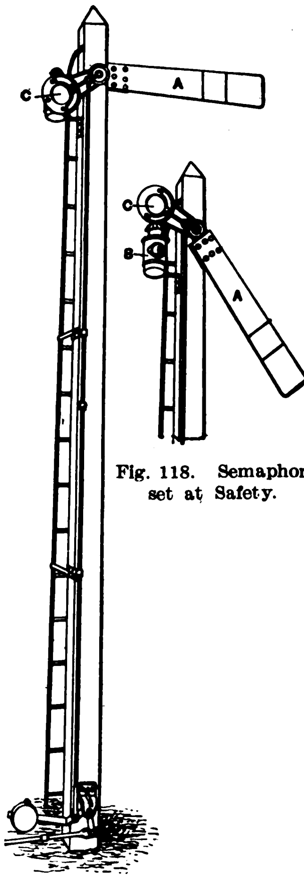


Fig. 118. Semaphore set at Safety.

Fig. 117. Semaphore Set at Danger Signal.

Semaphore arms are of two shapes, square at the ends as in Figs. 117, 118, and 119, and with a notched end, as in Fig. 120. The square ended semaphore is used for what is known as the *home* and *advanced signals*, and the notched end for *distance signals*. Semaphores are set so as to be pivoted at the left-hand end as viewed from an approaching train. The arm itself extends out to the right.

The use of home, distance, and advanced signals is as follows: The railroad is divided into blocks at each end of which a home signal is located. When the home signal is in a horizontal position or danger position, it signifies that the track between it and the next one in advance is obstructed and that the train must stop at that point.

The distance signal is placed at a considerable distance in front of the home signal, usually from 1,200 to 2,000 feet, and serves to notify the engineer of the position of the home signal. Thus, if when he passes a distance signal, the engineer sees it to be in a horizontal position, he knows that the home signal is in the danger position also and that he must be prepared to stop at that point unless it be dropped to safety in the meantime. The distance signal should show the cautionary light signal at night.

The advanced signal is used as a supplementary home signal. It is frequently desirable, especially at stations, to permit a train to pass a home signal at danger in order that it may make a station stop and remain there until the line is clear. An arrangement of block signals is shown in Fig. 121. There are three home signals *A*, *B*, and *C* on the west bound track, the distance between them being the length of the block. This distance may vary from 1,000 feet to several miles. *D*, *E*, and *F* are the corresponding home signals for the east bound track. The distance signals *G*, *H*, *I*, and *K* protect the home signals *B*, *C*, *E*, and *F*; *L* is the advanced signal at the station *M* for the home signal *B*. Thus, a train scheduled to stop at *M* will be allowed to run past the home signal at *B* when it is at danger and stop in front of the advanced signal *L*. When *L* is lowered to safety, the train can move on.

The signals of the block are usually interlocked, that is, one signal cannot be moved to danger or safety until others have been moved. The signals of two succeeding stations are also interlocked, usually electrically.

Block System. The term *block* as used above applies to a certain length of track each end of which is protected by means of a distance and home signal. The length of a block varies through wide limits

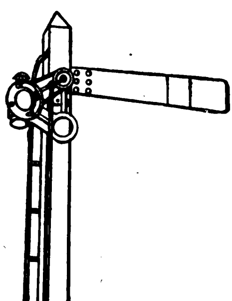


Fig. 119. Home Semaphore Signal.

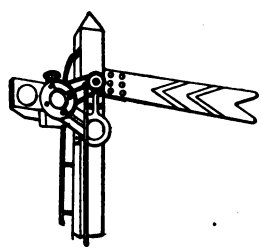


Fig. 120. Distance Semaphore Signal.

depending upon the nature of the country, amount of traffic, and speed of trains. The heavier the traffic, the more trains there are to be run, so it is desirable to run the trains as close together as possible. Hence, the blocks should be as short as safety will permit. On the other hand, as the speed of the train increases, the time required to pass over a given distance is diminished, hence the length of a block may be increased. The length of the block differs for single-, double-, and four-track roads. Ordinarily the blocks are from ten to twelve miles long. There are a number of different kinds of block systems named as follows, according to the way in which they are operated: the *staff, controlled manual, automatic,* and *telegraph* systems. All of these systems are similar in their principle of operation, differing only in the means used in securing the desired results. For instance, the controlled manual is operated by a tower man but the mechanism is partly automatic so that he cannot throw his signals until released by mechanism at the other end of the block which electrically locks his signals.

The working of the lock and block system between two stations *A* and *B*, Fig. 121, is as follows: When a train approaches *A*, the operator pulls his signal to clear, provided there is no other train in the block. As the train passes the signal and over a short section of insulated track, the wheels short circuit the track which carries an electric current. This action operates electrical apparatus which permits the semaphore arm to go to the danger position by force of gravity. After the operator has cleared the signal, an electric locking machine works in such a way that the signal cannot again be cleared until the train has passed over another section of insulated track as it passes out of the block at the station *B*. When the train passes this second section of track and short circuits the track, an electric current is automatically sent back through line wires to *A* and unlocks the machine, giving the operator at *A* permission again to clear his signal permitting another train to enter the block.

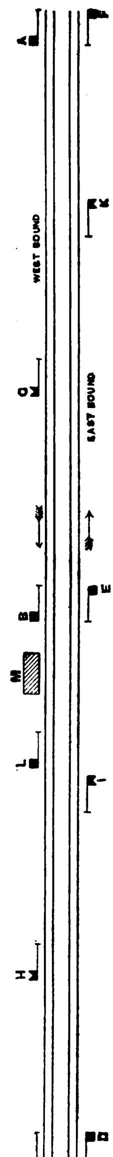


Fig. 121. Diagram of Lock and Block System.

The above description of the lock and block or controlled manual system will make clear the following established principles of interlocking:

1. *Each home signal, lever in that position which corresponds to the clear signal must lock the operating levers of all switches and switch locks which, by being moved during the passage of a train running according to that signal, might either throw it from the track, divert it from its intended course, or allow another train moving in either direction to come into collision with it.*

2. *Each lever so locked must in one of its two positions lock the*

original home signal in its danger position, that position of the lever being taken which gives a position of switch or switch lock contrary to the route implied by the home signal when clear.

3. *Each home signal should be so interlocked with the lever of its distance signal that it will be impossible to clear the distance signal until the home signal is clear.*

4. *Switch and lock levers should be so interlocked that crossings of continuous tracks cannot occur where such crossings are dependent upon the mutual position of switches.*

5. *Switch levers and other locking levers should be so interlocked that the lever operating a switch cannot be moved while that switch is locked.*

Levers at one signal station are locked from the station in advance. Thus, the signal *A*, Fig. 121, cannot be put to clear until freed by the operator at *B*. *B* cannot be cleared until freed by *C*, etc.

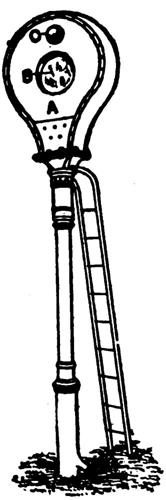


Fig. 122. Hall Disk Signal.

Levers and signals may be operated by hand, pneumatic, or electric power, the last two either automatically or by an operator.

Hall Signal. Disk signals are also used for block signaling and are usually automatic. The Hall signal, illustrated in Fig. 122, is an example of this kind. It consists of a glass case *A* containing electric apparatus operated by a current controlled by the passage of a train. When the block is closed, a red disk fills the opening *B* by day, and a red light shows at *C* by night. A clear signal is indicated by a clear opening at *B* by day and a white light at *C* by night.

When a single track is to be operated by block signals, it is customary to put two semaphores on one pole, as shown in Fig. 123. The arm extending to the right as seen from an approaching train is the one controlling the movement of that train.

Dwarf Signals. These are in all respects similar to the regular semaphore differing only in their size. They are usually short arms painted red, standing from two to four feet from the ground, and are similar to the home signal. They are used only to govern movement for trains on secondary tracks or movements against the current of traffic on main tracks when such reverse movement becomes necessary, and where necessary in yards. They are especially used for governing the movement of trains in backing out of train sheds at terminals.

Absolute and Permissive Block Signaling. Block signaling should always be absolute, that is, when the home signal is at danger no trains should be allowed to pass. It should never be cleared until the whole block in advance is emptied; that is, the signal at *B*, Fig. 121, should never be set to clear until the last preceding train has passed the home signal at *C*.

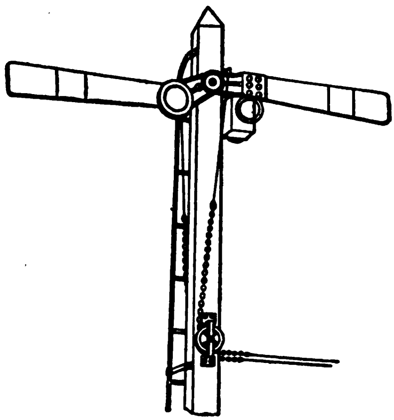


Fig. 123. Semaphore Block Signal for Single Track.

Permissive signaling introduces a time element into the system and is practiced by many roads. Thus, when a certain time, usually from 5 to 10 minutes, has elapsed after a train has passed a home signal, a following train is allowed to proceed though the signal still remains at danger. The following train is notified of the occupancy of the block by the preceding train by the display of a cautionary signal, usually a green flag or light from the tower at the signal so passed. It is a dangerous system and one subversive of good discipline and safety.

LOCOMOTIVE OPERATION

Running. The actual handling of a locomotive on the road can only be learned by practice with the engine itself. There are, however, certain fundamental principles which must be borne in mind and applied.

FIRING. Before taking charge of a locomotive, a considerable period must be spent as a fireman. The first things to be learned are the principles governing the composition of fuels.

The difference between the work of a locomotive boiler furnace and one under a stationary boiler is that in the former the rate of fuel consumption is very much greater than in the latter. In locomotive boilers it often occurs that 150 pounds of bituminous coal is burned per square foot of grate area per hour while a consumption of 200 pounds per square foot per hour is not unusual.

Different fuels require different treatment in the fire-box.

Bituminous coal is the most common fuel used on American railroads. It varies so much in chemical composition and heat value that no fixed rule for burning it can be laid down. The work of the fireman varies more or less with each grade of coal used. Ordinarily, the fuel bed should be comparatively thin. It may vary in thickness from 6 to 10 inches or even more, depending on the work the locomotive is called upon to perform. The fuel bed should be of sufficient thickness to prevent its being lifted from the grate under the influence of the draft created by the exhaust.

In order to obtain the best results, the stoking must be very nearly constant. Three shovelfuls at a time have been found to give very good results. The fire door should be closed between each shovelful so as to be only open on the latch. This delivers air to complete the combustion of the hydrocarbon gases which are distilled the moment the fresh coal strikes the incandescent fuel. In placing the fuel in the fire-box, it is well to heap it up slightly in the corners and allow the thinnest portion of the bed to be in the center of the grate. The frequency of the firing depends upon the work the engine is called upon to do.

The fire should always be cleaned at terminals and when the grade is favorable the slice bar may be used and the clinker removed through the furnace door while running.

Anthracite coal. In using anthracite coal, it is best, whenever possible, to do the stoking on favorable grades and at stations. The thickness of the fuel bed varies in size with the kind of coal used. It may vary from three inches with fine pea and buckwheat coal to 10 inches with large lumps. The fuel should be evenly distributed over the entire grate. The upper surface of an anthracite coal fire must never be disturbed by the slice bar while the engine is working. When it is necessary to use the slice bar, it should be done only when there is ample time after its completion to enable the fire to come up again and be burning vigorously before the engine resumes work.

FEEDING THE BOILER. Feeding the boiler is a matter requiring skill and judgment, especially where the locomotive is being worked to its full capacity. The injector is now the universal means employed for feeding the locomotive boiler. Where it is possible, the most satisfactory way is to use a constant feed which will be average for the entire trip. In this way the water level will rise and fall but will always be sufficient to cover the crown sheet. Under no circumstances should the water level be allowed to fall below the lower gauge cock.

Where a constant feed cannot be used, the injector may be worked to its full capacity on favoring grades and at station stops. This will give a storage of water to be drawn upon when the engine is working to its full capacity on adverse grades. Under such circumstances, the stopping of the feed may enable the fire to maintain the requisite steam pressure, whereas the latter might fall if the injector were to be kept at work. Further, the use of the injector on down grades and at stations keeps down the steam pressure and prevents the loss of heat by the escape of steam through the safety valves when the fire is burning briskly and the engine is not working.

THE USE OF STEAM. The manner in which an engineer uses the steam in the cylinders is one of the controlling elements in the economical use of coal. In starting, the reverse lever must be thrown forward so that steam is admitted to the cylinders for as great a portion of the stroke of the piston as the design of the valve motion will permit. As the speed increases, the lever should be drawn back, thus shortening the cut-off. It will usually be found that when the engine is not overloaded, a higher speed will be attained and maintained with a short than with a long cut-off. The reason is that with a late cut-off, so much steam is admitted to the cylinder that it cannot be exhausted in the time allowed, resulting in an excessive back pressure which retards the speed.

Experiments have proven, however, that it is not economical to use a cut-off which occurs earlier than one-fourth stroke, for when the cut-off occurs earlier than this, the cylinder condensation will more than offset the saving effected by the increased expansion so obtained. For this reason when the engine is running under such conditions that a cut-off earlier than one-fourth stroke can be used with the throttle wide open, it may be better to keep the point of cut-off at one-fourth stroke and partially close the throttle, thus wiredrawing the steam. The wiredrawing of the steam serves to superheat it to a limited extent and thus to diminish the cylinder condensation which would occur were saturated steam at the same pressure being used.

When running with the throttle valve closed, the reverse lever should be set to give the maximum travel to the valve in order to prevent the wearing of the shoulders on the valve seats.

LEARNING THE ROAD. Learning the road is one of the most important things for the engineer to accomplish. He must know every grade, curve, crossing, station approach, bridge, signal and whistle or bell post on the division over which he runs. He must know them on dark and stormy nights as well as in the daytime. He must always know where he is and never be at the slightest loss as to his surroundings. He must not only know where every water tank is located but should also make himself familiar with the qualities of the various waters they contain. Then when he has a choice of places at which to take water he may choose that containing the mallest amount of scale-forming matter.

Grades. In the learning of a road an intimate knowledge of the grades is of the first importance to the engineer. He must know what his engine can handle over them, how it must be handled when on them, and how they must be approached. An engine will frequently be able to take a train over a grade if it has a high speed at the foot, whereas if a stop or slackening of the speed were to be made at the foot of the grade it would be impossible to surmount it with the entire train.

Handling Trains. Handling trains over different profiles of track requires different methods. On adverse grades, the work is probably the simplest. In such conditions the train is stretched out to its fullest extent. Every car is pulling back and the checking of the movement of the front of the train meets with an immediate response throughout the whole train. The grade also prevents sudden acceleration at the front. It is, therefore, necessary merely to keep the engine at work.

On favoring grades, the whole train when drifting is crowding down upon the locomotive and is likely to be bunched or closed together. Under these conditions, it is necessary to apply the air brakes which are at the front end and keep them applied so as to hold the speed under control and prevent the train from running away. Care should be taken in the application of the driving wheel brakes on long down grades lest the shoes heat the tires and cause them to become loose.

The greatest danger of injury to a train arises in passing over ridges and through sags. First, in leaving an adverse grade in passing over a ridge to a favoring grade, the engineer must be careful not to accelerate the front end of the train too rapidly lest it break in two before the rear end has crossed the summit. There is greater danger, however, in running through a dip where the grade changes from a favoring to an adverse one. Where brakes have been applied at the rear of the train and the slack prevented the train from becoming bunched, there is not the same danger as when the brakes have been applied at the front of the train. In the latter case, if the engineer is not careful in pulling out the slack, the train may be parted. Accidents of this class will be minimized if in every case the slack is taken up slowly. A steady pull will not break the draft rigging of the car, whereas a sudden jerk may pull it out.

In case a train does break in two, the engine and front portion should be kept in motion until the rear portion has been stopped. In so doing a collision may be avoided. Where air brakes are applied to the entire train, the rear portion will stop first owing to the proportional increase of weight and momentum of the locomotive.

Freight trains require on the whole more careful handling than passenger trains. There is more slack in the couplings of the former than in the latter and the trains are much longer, consequently the shocks at the rear of a freight train, due to variation in speed, are much more severe than on passenger trains. The system of handling, while practically the same for both classes, requires more care in order to avoid accidents with a freight train than with a passenger train.

THE END OF THE RUN. When the run has been finished, the engineer should make a careful inspection of all parts of the engine so as to be able to report any repairs which may be needed in order to fit the locomotive for the next run. The roundhouse hostler should then take the engine and have the tender loaded with coal, the tank filled with water, and the fire cleaned. The engine should then be put over the pit in the roundhouse, carefully wiped, and again inspected for defects.

Inspection. The inspection of locomotives should be thorough. It should embrace the condition of every exposed wearing surface and the behavior of every concealed one. All bolts and nuts should be examined to ascertain if they are tight. The netting in the front end should be examined at frequent intervals to make sure that it is not burned out. The stay-bolts should be inspected periodically in order that those broken may be replaced. Wheels and all parts of the running gear and mechanism should be carefully scrutinized for cracks or other defects.

Cleaning. Cleaning the engine should be done after every trip, since dust and dirt may cover defects which may be serious and ultimately cause a disaster.

Repairs. Repairs of a minor nature can be made in the roundhouse and should receive prompt attention. Roundhouse repairs include such work as the replacing of the netting in the smoke-box, cleaning of nozzles, expanding and caulking leaky flues, refitting the side and connecting rod brasses, refitting valve seats, regrinding leaky cab fittings, adjusting driving box wedges, repairing ash pans, replacing grates, renewing brake shoes, resetting valves, repairing water tanks, and sometimes may be extended to the re-boring of cylinders. To this list must also be added the regular work of renewing all packing and cleaning out the boiler.

Emergencies. Emergencies are constantly arising in locomotive running where a breakage of some part should be repaired while on the road. The part affected and the extent of the fracture has much to do with the possibility of running the engine home under its own steam. A few methods of dealing with the more common breakages will be given.

Broken Side Rods. If a side rod breaks, the ends of the broken rod should be disconnected and the rod on the opposite side of the engine should be removed. An attempt should never be made to run a locomotive with only one side rod connected as the engine would be badly out of balance and trouble would arise when the driver attempted to pass the dead center.

Broken Connecting Rod. If a connecting rod is broken without injury to the cylinder, the crosshead and piston should be blocked at one end of the stroke and the broken parts of the rod removed. The removal of the side rods depends upon the extent of injury to the crank pin on the broken side. All side rods should be left in position if the crank pin on the broken side is uninjured, otherwise all should be removed. The valve rod should be disconnected from the rocker arm and the valve stem clamped with the valve in the central position.

The valve stem may be clamped by screwing down one of the gland nuts more than the other, thus cramping the stem. It may also be secured by the use of the clamp shown in Fig. 124. This consists of two parts having V-shaped notches which are securely fastened to the valve stem by a bolt on either side. This is done after having passed the gland studs through the two slotted holes, which prevents any longitudinal movement of the stem after the nuts on the studs have been screwed home. The crosshead should be forced to one end of the guides with the piston against the cylinder head. In this position, it can be secured by a piece of wood cut to fit snugly between it and the guide yoke.

When the parts on one side have been blocked in this way, the engine can be run to the shop with one side working.

Broken Driving Springs. In case a driving spring breaks, a block of wood should be inserted between the top of the driving box and the frame. This can be done by first removing the broken spring and its saddle, then running the other drivers on wedges to lift the weight off the driver with the broken spring. The piece of wood should then be inserted and the pair of drivers run up on wedges. After this is done, the fallen end of the equalizing lever should be pried up until it is level and blocked in this position. All parts which are liable to fall off should be removed.

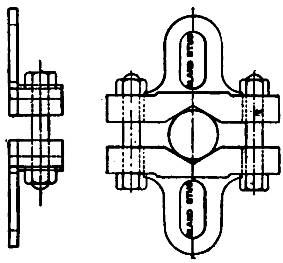


Fig. 124. Clamp for Repair of Broken Connecting Rod.

Low Water. If for any reason the water gets low in the boiler or if through accident some of the heating surface is laid bare, the fire should be dampened by throwing dirt into the fire-box. A stream of water should never be turned on the fire.

Foaming. If foaming occurs, the throttle should be slowly closed. This prevents the water height dropping suddenly and uncovering the crown sheet. If there is a surface blow-off, it should be opened and the impurities on the surface of the water blown off. If the foaming is caused by grease which has collected in the tank, the tank should be overflowed at the next water station and a couple of quarts of unslacked lime placed in it. If this cannot be obtained, a piece of blue vitriol, which may be obtained at almost any telegraph office, may be placed in the hose back of the screen.

Broken Steam Chest. In case a steam chest becomes fractured, either the lower joint of the steam pipe on the side of the accident should be pried open and a blind wooden gasket inserted, or the steam chest and valve should be removed and a piece of board laid over the steam openings and firmly clamped in position by the studs of the steam chest.

The above are a few of the accidents which may occur on the road. To prepare for emergencies, the best method is to study the locomotive and devise means of making temporary repairs for every accident imaginable, then when the accident does occur, the remedy can be promptly applied.

TRAIN RULES

The American Railway Association has adopted a uniform code of train rules which have been accepted by the railroads of the United States. These rules briefly stated are as follows:

All trains are designated as regular or extra and may consist of one or more sections. An engine without cars in service on the road is considered a train.

All trains are classified with regard to their priority of right to the track.

A train of an inferior class must in all cases keep out of the way of a train of a superior class.

On a single track all trains in one direction specified in the time table have the absolute right of track over trains of the same class running in the opposite direction.

When trains of the same class meet on a single track, the train not having the right of track must take the siding and be clear of the main track before the leaving of the opposite train.

When a train of inferior class meets a train of a superior class on a single track, the train of inferior class must take the siding and clear the track for the train of superior class five minutes before its leaving.

A train must not leave a station to follow a passenger train until five minutes after the departure of such passenger train unless some form of block signaling is used.

Freight trains following each other must keep not less than five minutes apart unless some form of block signaling is used.

No train must arrive at or leave a station in advance of its scheduled time.

When a passenger train is delayed at any of its usual stops more than — minutes, the flagman must go back with a danger signal and protect his train, but if it stops at any unusual point, the flagman must immediately go back far enough to be seen from a train moving in the same direction when it is at least — feet from the rear of his own train.

When it is necessary to protect the front of the train, the same precautions must be observed by the flagman. If the fireman is unable to leave the engine, the front brakeman must be sent in his place.

When a freight train is detained at any of its usual stops more than — minutes, where the rear of the train can be plainly seen from a train moving in the same direction at a distance of at least — feet, the flagman must go back with danger signals not less than — feet, and as much farther as may be necessary to protect his train but if the rear of his train cannot be plainly seen at a distance of at least — feet, or if it stops at any point which is not its usual stopping place, the flagman must go back not less than — feet, and if his train should be detained until within ten minutes of the time of a passenger train moving in the same direction, he must be governed by rule No. 99.

Rule No. 99 provides that when a train is stopped by an accident or obstruction, the flagman must immediately go back with danger signals to stop any train moving in the same direction. At a point — feet from the rear of his train, he must place one torpedo on the rail. He must then continue to go back at least — feet from the rear of his train and place two torpedoes on the rail ten yards apart (one rail length), when he may return to a point — feet from the rear of his train, where he must remain until recalled by the whistle of his engine. But if a passenger train is due within ten minutes, he must remain until it arrives. When he comes in, he will remove the torpedo nearest to the train but the two torpedoes must be left on the rail as a caution signal to any train following.

When it is necessary for a freight train on a double track to turn out on to the opposite track to allow a passenger train running in the same direction to pass, and the passenger train running in the opposite direction is due, a flagman must be sent back with a danger signal as *provided in Rule No. 99 not less than —feet in the direction of the following train and the other train must not cross over until one of the passenger trains arrive. Should the following passenger train arrive first, a flagman must be sent forward on the opposite track with danger signals as provided in Rule No. 99, not less than —feet in the direction of the overdue passenger train before crossing over. Great caution must be used and good judgment is required to prevent detention to either passenger train. The preference should always be given the passenger train of superior class.*

If a train should part while in motion, trainmen must use great care to prevent the detached parts from coming into collision.

Regular trains twelve hours or more behind their scheduled time lose all their rights.

All messages or orders respecting the movement of trains or the condition of track or bridges must be in writing.

Passenger trains must not display signals for a following train without an order from the Superintendent, nor freight trains without an order from the Yard Master.

Great care must be exercised by the trainmen of a train approaching a station where any train is receiving or discharging passengers.

Engine men must observe trains on the opposite track and if they are running too closely together, call attention to the fact.

No person will be permitted to ride on an engine except the engineman, fireman, and other designated employes in the discharge of their duties without a written order from the proper authorities.

Accidents, detentions of trains, failure in the supply of water or fuel, or defects in the tracks or bridges must be promptly reported by telegraph to the Superintendent.

No train shall leave a station without a signal from its conductor.

Conductors and engine men will be held equally responsible for the violation of any rules governing the safety of their trains and they must take every precaution for the protection of their trains even if not provided for by the rules.

In case of doubt or uncertainty, no risks should be taken.

TIME TABLES

Time tables are the general law governing the arrival and leaving time of all regular trains at all stations and are issued from time to time as may be necessary. The time given for each train on the time table is the scheduled time of such trains.

Each time table from the moment it takes effect supersedes the preceding time table and all special relations relating thereto and trains shall run as directed thereby, subject to the rules. All regular trains running according to the preceding time table shall, unless otherwise directed, assume the times and rights of trains of corresponding numbers on the new time table.

On the time table, not more than two sets of figures are shown for a train at any point. When two times are shown, the earlier is the arriving time and the later the leaving time. When one time is shown, it is the leaving time unless otherwise indicated.

Regular meeting or passing points are indicated on the time table.

The words "Daily," "Daily except Sunday," etc., printed at the head and foot of a column in connection with a train indicate how it shall be run. The figures given at intermediate stations shall not be taken as indicating that a train will stop, unless the rules require it.

Trains are designated by numbers indicated on the time table.

LOCOMOTIVE TROUBLES AND REMEDIES

OPERATING PROBLEMS

Distinctive Features of Locomotive. A new locomotive is very much like any other new piece of machinery, in that, if care has been used in its construction by experienced mechanics, it should operate in a satisfactory manner when properly handled. In a few respects it differs very materially from other steam power plants. First, when it is in operation it is not stationary but moves from place to place on a suitably constructed track. This feature alone requires a form of construction peculiar to its kind. As a result we find that the different movable parts involved are far greater in number than in other power plants of equal power and are included in much less space. Second, because of the large number of parts the chances for wear are much greater than in ordinary power plants, and on this account it is not to be expected that a locomotive will operate as quietly after it has been in service for some time as it otherwise would. Then again it must be borne in mind that it is impossible to obtain perfect track conditions, and for this reason the various parts cannot be safely "set up" as snugly as would be possible under ideal conditions.

There are so many points which naturally should come under Troubles and Remedies that it will be possible to mention only a few of the more important.

Pounds. For convenience of expression it will probably simplify matters to refer to all disagreeable and annoying jerks and sounds familiar to the locomotive engineer and fireman as "pounds". By different individuals these characteristic sounds may be referred to as clicks, knocks, jerks, thumps, pounds, bumps, thrashes, etc. In actual practice they are sometimes very difficult to locate. If a serious pound is neglected or disregarded, it may be the cause of ultimately disabling the locomotive. Because of this fact an effort should be made to locate all troublesome pounds and report them promptly, for by so doing the engineer will relieve himself of further responsibility. An experienced locomotive engineer naturally becomes familiar with all the various sounds produced by a locomotive when in operation and can very often locate a pound which develops suddenly by the particular sound. Perhaps one of the most difficult pounds to locate is one caused by a loose piston. Improvements made in more recent locomotives reduce the chances for the development of such pounds very materially. When they do develop, they often will deceive old experienced operators. They usually develop rather suddenly and sound as if there was much lost motion somewhere, when as a matter of fact the exact amount of lost motion may be exceedingly small. Such a pound will probably be taken for a loose driving box or crosshead.

Locating Pound. Having detected an unusual knock or pound, it should be located and corrected at the first opportunity. When it has been determined from which side of the locomotive the pound issues, it can be definitely located in the following manner: Block the driving wheels as securely as possible with the crank-pin on the side in question at the top quarter and have the fireman open the throttle slightly, to give the cylinders a little steam, and then reverse the engine a few times while an examination is made of the various points where a pound is liable to develop. The crank pin is placed on the upper quarter because in that position the parts are freer to move than with it at any other point. If it were placed at either dead center, steam could be admitted at but one dead center, no matter where the reverse lever was placed.

Causes of Pounds. Pounds may result from improper lubrication of various parts, such as the valve and piston, main axle, main crank-pin, and crosshead, or lost motion in the reciprocating parts. Pounds will also result from loose wedges, loose knuckles, wedges down or stuck, broken engine frame, cylinders loose on frame, loose pedestal braces, imperfect fitting of shoes and wedges, loose oil cellars, and shoulders worn on either the shoes or wedges or on both. At times when the boiler is priming badly, water in sufficient quantities may enter the cylinder and cause pounds and endanger the safety of the parts. Improper valve setting or adjustment may be the cause of pounds or noises of different character. In this case the usual cause would most probably be too late admission or too great compression. Other conditions remaining the same, admission should increase as the speed increases. In order to determine whether or not the valve adjustment is responsible for unusual noises or knocks, it will usually be necessary to take indicator diagrams from which a study can be made of the steam distribution.

The valve gear or reversing mechanism is frequently the cause of numerous rattling noises. The valve gears commonly employed embody a number of pins, links, movable parts, etc., which become worn and result in lost motion. The wear on any one part may not be very noticeable, but in the aggregate the lost motion may be quite large. The locomotive engineer can usually locate the badly worn parts when the locomotive is stationary by having the fireman throw the reverse lever first forward then backward, repeating the operation as often as necessary, while inspecting the various parts. This method would probably not disclose lost motion which might exist in the eccentrics.

The side rods cannot be operated successfully if adjusted too snugly. For this reason they are made to work with freedom and frequently produce a rattling sound. This rattling should not be confused with a pound.

Steam Waste. The steam necessary to do the work in the cylinders required in hauling a train of a given tonnage at a given speed is very often augmented by wastes of various kinds, which should be reduced to a minimum. These wastes may be due to improper care of the engine, either on the road or in the roundhouse or both, to improper manipulation when on the road, and to the use of bad water. Still other wastes may be due to high steam pressures and high rates of evaporation.

Waste from Piston and Valve Rods. The most common sources of leakage are steam blows. When these occur into the atmosphere from the piston and valve rods, it is quite noticeable, and they may constitute a very great loss, especially where high steam pressures are employed. Besides being a direct loss, under certain conditions the presence of the steam in the air may obstruct the view ahead, making operation more hazardous. Anything which causes undue vibration of the piston and valve rods will eventually cause leaky packing. For this reason the guides should be kept in proper adjustment to prevent vertical movement of the crosshead. In engines using piston valves with inside admission, there will ordinarily not be trouble by steam leaks around the valve rods.

Waste from Cylinder and Valve Piston Packing. It sometimes happens that losses occur due to steam blowing past the packing rings of the cylinder piston or the valve. Indicator cards will usually show such leaks, but as a rule they can be detected by the sound of the exhaust. Such steam blows are more difficult to locate in compound than in simple engines. A practical method of detecting steam blows past the cylinder and valve piston packings consists in blocking the engine in different positions of the crank and noting the presence or absence of steam at the cylinder cocks or stack.

Waste Due to Priming. The use of water which causes priming eventually causes steam blows. Priming is frequently so serious that the whistle cannot be blown without closing the throttle in order to reduce the water level in the boiler. In aggravated cases where water is carried over into the cylinders, it not only endangers the cylinder heads, etc., but sooner or later injures the piston and valve packing, piston and valve rod packing and valve seat, causing leaks and serious waste of steam.

Waste from Safety Valve. Another common waste of steam occurs through the safety valve, caused oftentimes by a careless manipulation of the fire. Such losses occur most frequently when the locomotive is standing on a siding or coasting. This may seem to be a small matter, but if we consider a road using 1000 locomotives per day and each fireman permitting the safety valve to blow on an average of 10 minutes per day, the amount of steam wasted daily would approximate 1,000,000 pounds, which would represent a waste of fuel per day of about 75 tons. Such waste can be reduced to a minimum by the intelligent manipulation of the injectors, dampers, and fire door.

Care of Boiler. *Importance.* The life of a locomotive boiler depends largely upon the systematic and intelligent attention it receives and the particular locality in which it is used. The time elapsing between cleanings and washings varies between wide limits with different roads and different localities, depending largely upon the character of the service and water used. The proper blowing out by the engineer in order to prevent undue concentration of material in solution is of much importance. Some roads require this blowing out to be done while running and others at terminal points. The removal of sediment or sludge, such as soft scale, mud, etc., can best be accomplished at terminals after the water has had time to become more quiet.

Much importance is attached to the manner of cooling down and washing out. When done hurriedly the boiler usually suffers. The following directions for washing and cleaning boilers are abstracted from instructions furnished employes by one of our well-known railroads.

Cooling Boiler. Boilers should be thoroughly cooled before being washed. When cooled in the natural way, the steam should be blown off and the water retained above the top of the crown sheet and allowed to stand until the temperature of the steel in the fire-box is reduced to about 90° F., after which time the water may be drawn off and the boiler washed. When the locomotive cannot be spared from service long enough to be cleaned in this manner, the following plan should be carried out.

After the steam pressure has dropped considerably, start the injector and continue filling the boiler until the injector will no longer operate. Then connect the water pressure hose to the feed hose between the engine and tender and fill the boiler full, permitting steam to blow through some outlet at the top of the boiler. Next open the blow-off cock or valve and permit the water to escape, but at a rate less than that entering from the water hose, so as to keep the boiler completely filled. Continue the process until the fire-box sheet has been reduced in temperature to about 90° F., at which time shut off the water, open all plugs, and allow the boiler to completely empty.

Washing Boiler. Washing may now be begun by first washing the flues by the side holes opposite the front end of the crown sheet. Next wash the top of the crown sheet at the front end, then between the rows of crown bars, if provided, and bolts, directing the stream toward the back end of the crown sheet. After washing through the holes near the front end of the crown sheet, continue washing through the holes, in order, toward the back end of the crown sheet, in such a manner as to work the mud and scale from the crown sheet toward the side and back legs of the boiler and thus prevent depositing it on the back ends of the flues. Continue washing, using the holes in the boiler head, with the swivel attachment on the hose, working from the front to the rear, endeavoring to thoroughly wash the top of the boiler as well as all stays and the crown sheet.

Next wash the back end of the flues through suitably located holes and afterward the water space between the back head and the door sheet through the holes in the back head, using the angle nozzle. The inside arch flues should also be washed thoroughly from the back head and scraped with the proper form of scraper.

If washout plugs are provided in the front flue sheet, wash through them, using a long pipe nozzle of sufficient length to reach the back flue sheet. If the holes are among the flues, the nozzle should be a bent one and should be revolved as it is drawn from the back end toward the front.

Now wash through the holes near the check valves at the front end of the boiler, using straight and angle nozzles with swivel connection. Then wash through the holes in the bottom of the barrel near the rear end, using the straight nozzle directly against the flues and reaching as far as possible in all directions. Both the straight and bent nozzles should now be used through the front hole in the bottom of the barrel, in the same manner as before, to clean the flues and the space between the flues and the barrel.

After washing the barrel completely, clean the back end of the arch flues, making sure they are free from scale. Next by using bent nozzles in the side and corner holes of the water legs, thoroughly clean the side sheets and finally clean off all scale and mud from the mud ring by means of straight nozzles in the corner holes. It should not be assumed that because the water runs clear from the boiler that it is clean and free from scale. Carefully examine all spaces with a rod and light and, if necessary, use a pick, steel scraper, or other suitable tool in removing the accumulation of scale.

Drifting. In operating a locomotive on the road the engine frequently runs with a closed throttle, as is the case in bringing the train to a stop or when "dropping" down grades. This condition is known and spoken of as *drifting*. Under such circumstances there may be little or no steam in the cylinders yet the effects of expansion and compression will be present. As a result, if the reverse lever is set near the central position the compression will be relatively high and expansion will be carried so far that a vacuum will result which will draw gases and cinders from the "front end" through the exhaust pipe into the cylinders. It is easily seen that the presence of smoke and cinders in the cylinders may prove to be a serious matter.

To prevent the conditions just described from arising, the reverse lever, when drifting, should be carried in the full position corresponding to the direction of travel, for in this position a vacuum will probably not be formed and no foreign matter will enter the cylinders. As a safeguard against damaged cylinders and valves both steam chests should be fitted with relief valves. Such valves are applied one to each steam chest and are arranged to open inwardly and admit atmospheric air whenever the pressure in the steam chest falls below that of the atmosphere and to close suddenly when the throttle is opened. They should be constructed to open by gravity so when once opened they will remain open and will not be worn out by being rapidly opened and closed during the drifting period. It is important that they be made of ample size to admit air freely, otherwise at high speeds a vacuum might be formed in the steam chests and smoke and cinders still be drawn into the cylinders.

Fuel Waste. Leaks or wastes of steam or hot water are always a direct drain upon the coal pile from which no benefit is received. The different ways in which steam is wasted, which were considered under Steam Waste, constitute a loss of fuel. The presence of scale on the heating surface of the boiler reduces the amount of heat which could otherwise be transmitted, thus requiring more coal to be burned, which is a waste of fuel. There are other large wastes of fuel in which steam plays no part, such as the generation of smoke and carbon monoxide, the emission of sparks, and the loss of coal which never enters the fire door.

Waste from Smoke. Of all the losses attending the firing of bituminous coal that due to the generation of smoke attracts the most attention since it is so readily seen because of its color. When such coal is thrown into a hot furnace the lighter hydrocarbons are distilled off first, and if an insufficient supply of oxygen is furnished to completely burn them, smoke will be observed coming from the stack. The actual heat loss in carbon contained in the smoke is small as compared to that in the carbon monoxide gas formed. Both of these losses are due to an insufficient supply of oxygen furnished by the air. The presence of smoke indicates a shortage of air and for this reason is a valuable guide to efficient firing. The temperature must be maintained sufficiently high to burn the gases as they are driven off the coal. No part of the fire-box should be permitted to become chilled, and in order to maintain a uniform temperature over the entire surface of the fire, the coal must be evenly distributed. To insure rapid burning, the large pieces of coal should be broken up so as to present a more nearly uniform size. An alert and efficient fireman will endeavor to take advantage of the physical characteristics of the road and will fire lightly and regularly, keeping the fire door slightly open for a few seconds, if necessary, to admit sufficient air to burn the lighter gases which are driven off. The steam gage should be constantly watched and the supply of air regulated as far as possible by the dampers. Much good will result from the engineer co-operating with the fireman in handling the locomotive in an intelligent manner and informing him from time to time of his intended movements.

Waste from Sparks. The loss in cinders and small pieces of coal being ejected through the stack is quite large. In extreme cases it may reach 10 or 15 per cent of the total weight of the coal fired. The heating value of these *sparks*, as they are usually termed, varies between 70 and 90 per cent of the coal as at first fired. Sparks are not only wasteful of coal but are very dangerous to property in the immediate vicinity of the track. For these reasons the fireman should endeavor at all times to handle his fire in such a manner as to minimize the amount of sparks formed, and the netting in the front end should be kept in constant repair to prevent large holes from forming which would permit large quantities of sparks to be thrown out.

LOCOMOTIVE BREAKDOWNS

Possible Causes. In the operation of a railroad it is of great importance that trains should be kept running on schedule as nearly as possible. It frequently happens, however, that accidents to the locomotive of greater or less consequence prevent trains from maintaining their schedules, which in many instances could be avoided by a little forethought on the part of the engineer. The efficient engineer who inspects his engine regularly for loose bolts, nuts, and keys, looks for defects, and carefully examines any cracks, flaws, etc., is seldom troubled with annoying and sometimes dangerous accidents while on the road. Breakdowns will, of course, occur at times even though all precautionary measures have been taken. Space will not permit of reference to the many different accidents which may occur. The following list contains those most commonly experienced:

1. Collision of two approaching trains
2. Collision of a moving with a standing train
3. Collision of trains at the crossing of two tracks
4. Running into an open drawbridge
5. Engine running with no one on it to bring it under control
6. Derailment of the front truck, drivers, or tender

7. Explosion of the boiler
8. Collapse of a flue
9. Overheated crown sheet
10. Running into an open switch at too great a speed
11. Blowing out of a bolt or cock or any accident which leaves a hole in the boiler for the escape of steam or water
12. Failure of the injectors or check valves
13. Breaking or bursting of a cylinder, cylinder head, steam chest, or steam pipe
14. Breaking or bending of a crank pin or connecting rod
15. Breaking of a tire, wheel, or axle
16. Breaking of a spring, spring hanger, or equalizer
17. Breaking of a frame
18. Failure of any part of the valve gear
19. Failure of the throttle valve
20. Breaking of the smoke-box front or door
21. Failure of the connection between the engine and tender or between the tender and first car
22. Failure of the air pump or braking apparatus

In case of an accident it is assumed that the engineer will first comply with his book of rules in regard to signals, flagman, etc., and will not overlook or neglect the boiler while working on a disabled engine. If the locomotive has left the track and is in such a position that the crown sheet is exposed, the fire should be killed at once if at all possible. This can be accomplished by throwing dirt, gravel, etc., into the fire-box. If water is convenient it can be used, but with great care.

Collisions. *Duties of Engineer.* When it is seen that a collision is about to occur the first move of the engineer should be to stop the train if possible by shutting off the steam and applying the brakes in emergency. If the brakes on the locomotive are known to be impaired in any way then the engine should be reversed, sand being used to give the maximum amount of resistance. When reversing the engine at high speeds, care must be used to prevent damage to the various parts.

The most common form of collision is what is known as a *rear-end* collision, that is, a collision of trains running in the same direction. It usually happens when the train ahead stops and fails to send back a flagman or the flagman does not go back far enough. In all cases of collision it is the duty of the engineer to remain on the locomotive until after he has applied all possible means of checking the speed of the train. This is especially true if it is a passenger train where the lives of numerous passengers are in danger. On seeing danger ahead, the engineer should first close the throttle valve, then apply the brakes in emergency. It is important that the throttle be closed in case a collision is inevitable, because if it is left open and the collision does not happen to totally disable the engine, it will of its own power crush through the wreckage and do additional damage.

Runaway Locomotive. Sometimes a locomotive will run away while standing in a yard or on a siding, with no responsible person on it to keep it under control. The collisions which sometimes result in such cases prove very destructive. In order to prevent a locomotive running away in such a manner, the throttle valve should always be carefully closed, the cylinder cocks should be opened, and the reverse lever placed in its central position. Under such conditions if the throttle should be opened by accident, the engine would not start and any leakage of the throttle would not accumulate in the cylinder but would escape to the atmosphere through the cylinder cocks.

Derailments. If the locomotive leaves the rails for any reason whatsoever, the throttle valve should be closed and the brakes applied. As soon as the locomotive has come to a stop, protection should be made against approaching or following trains. If the locomotive remains in an upright position and the crown sheet and flues are protected by being covered with water, the fire need not be drawn. In case they are exposed the fire should be drawn, or covered with dirt, gravel, or fine coal, or quenched with water. If not off too badly or too far away from the track, the engine can usually be made to help itself on without the aid of another by using blocking under the wheels and by the aid of "replacers". The engine can, as a rule, be placed on the track easier by moving it in a direction opposite to that in which it ran off.

If conditions are such that the locomotive cannot help itself on the track, it will probably be necessary to secure the assistance of another. If it is too great a distance from the track or over on its side, it will be necessary to send for the wrecking crew.

Explosion of Boiler. It is not always possible to determine the real cause of a boiler explosion, since it sometimes happens that all evidence is obliterated. It has been said that all boiler explosions are due to the fact "that the pressure inside the boiler is greater than the strength of the material of which the boiler is constructed". Failure is due to one of two causes, namely, insufficient strength to withstand the ordinary working pressures, or a gradual increase of pressure in excess of that which it was designed to carry.

Lack of strength may be due to incorrect design, defective material and workmanship, or reduction in size of plates, stays, etc., due to corrosion, wear and tear, and neglect. Overpressure is usually due to defective safety valves or to safety valves set by pressure gages which indicate pressures much less than the real amount.

Collapse of Flue. If a flue collapses while in service, the escaping steam and water will usually extinguish the fire. When the pressure is reduced sufficiently, an iron or wood plug can usually be driven into the ends of the tube in question, which will effect an emergency repair and permit the locomotive to return under its own steam. It may be necessary to run under a reduced steam pressure. The injectors should be used in reducing the pressure to make sure of plenty of water being kept in the boiler. Iron plugs are preferable but, if they are not at hand, wood plugs may be used. The iron plugs are placed with a long bar. The wood plugs are made on the end of a pole and partially cut off, so that when placed they can easily be broken off. The plug will burn slightly but not to any great extent inside the end of the flue. If the failure occurs in a flue located back of the steam pipes, it may be necessary to let the boiler cool down before the temporary repair can be made. If the steam obscures the back end of the flue, it sometimes can be drawn up the stack by starting the blower.

If a fitting is accidentally broken off, permitting steam or water to blow out, or if a hole is made in any way which permits the escape of steam or water, either can be temporarily repaired in the manner indicated above. Metal plugs are preferable but wood can be used if necessary. In plugging flues or any holes where steam or water is escaping, care must be exercised to prevent being struck by the plug in case it blows out.

Disconnecting after Breakdown. The disconnecting of one side of a locomotive usually implies that the machine is to continue its journey. It is made necessary by an accident to a cylinder piston, piston rod, steam chest, valve gear, connecting rod, etc. As an example, let it be assumed that a locomotive has met with an accident and one of the cylinder castings is broken. The work that must be done in order that the locomotive may continue its journey is explained in the following:

Method of Procedure. If the crank-pin, connecting rod, and crosshead are uninjured, they need not be removed, but the piston rod should be disconnected from the crosshead and the piston and all removed from the cylinder. If, however, any of the above-mentioned parts are injured and will not function properly, then the main or connecting rod must be taken down on the injured side. In removing the rod care should be exercised to keep all the rod attachments in place as that will be of much assistance when replacing the rod. Next move the piston to the back end of the cylinder as far as it will go and fasten securely by placing wood blocks between the guides so as to fill the space between the crosshead and the end of the guide bars. As a safeguard the wood blocks should be secured by means of rope to prevent them from falling out of position should they become loosened. On some types of locomotives it may not be possible to block the piston in the extreme backward position because of a lack of clearance. In such cases the crosshead should be blocked in the forward position. The back position should be used whenever possible, because if the crosshead became loose in that position and was shot forward it would do less damage than if freed from the forward position. After the crosshead is securely blocked, the valve rod should be disconnected from the rocker and valve stem and the valve moved to its central position so as to cover both steam ports and prevent steam from entering the cylinder. By opening the cylinder cocks and slowly admitting steam by means of the throttle valve, it can be known whether or not the valve is correctly located. If not properly located steam will blow from one of the cylinder cocks. If no steam is discharged at either cylinder cock it is probably correctly set. When it has been correctly set the position of the valve must be secured by clamping the valve stem and wedging or tying it in place. With these changes properly made, the locomotive should be able to proceed on its way with but one side doing work.

In case of injury to both sides the locomotive would not be able to proceed under its own power. The connecting rods may be removed from both sides if the conditions demand it, but the side rods should not be removed unless seriously damaged. When the locomotive is proceeding with one side only doing work and it is necessary to remove one or more of the side rods because of injury, the corresponding side rods on the other side should also be removed. Under such conditions the speed of the locomotive should be kept very low because of the effect of the counterbalance on the track.

When both sides are disconnected and the locomotive is being towed back to the shop, attention must be given to proper draining of the various pipes, etc., if the temperature is below the freezing point. It is never necessary to remove the eccentric straps unless it becomes so on account of some injury.

The accidents to a locomotive when in service are numerous. Some may be more serious than others. Space does not permit covering all the possible emergency repairs which it may be necessary to apply. In most cases the character of the breakdown will suggest the remedy.

DUTIES OF LOCOMOTIVE ENGINEER*

WATCHING HIS ROAD

Acquaintance with Route of Prime Importance. To the casual observer a locomotive runner has a fairly easy billet. Perhaps not one person in a hundred of those who see him sitting in his cab, complacently awaiting the signal to start his train, has any idea of the multiplicity of his duties.

Of course, as a prerequisite to all his other functions comes the care of his engine, either standing or under way, but interwoven with this knowledge are other matters of detail, for

* The following observations on Locomotive Driving were prepared by John H. Jallings, Mechanical Engineer, Chicago.

example, an intimate knowledge of his time table as it applies to the different parts of his run. This he must have learned so thoroughly that he can instantly say how long it should take to travel on schedule time between any two points in his run. To be able to accomplish this it is absolutely essential that the engineer know the grades, the curves, the switches, the sidings, the crossings, the stations, and the semaphores he will have to go over or pass *en route*. This means that he will have to know them thoroughly, both backward and forward, for having completed his run today he will have to return by the same route tomorrow, in which case all these items will come to him in reverse order.

These features have such an important bearing on the successful performance of his duties that, were he ever so skillful in the care of his engine, he would be quite incompetent to take his engine and train over another route which was unfamiliar to him. This statement may seem somewhat paradoxical, yet it is absolutely true and in our development we will try to make the reason clear.

Regulating Steam Supply. There is no type of boiler which has to supply such an abundance of steam on short notice as that of the locomotive. Nevertheless, with all its capabilities, conditions frequently arise during the run which test its capacity to the limit and make it absolutely necessary to conserve the boiler resources.

Preparing for Grade. Thus on approaching a heavy up-grade, the skillful engineer will see that his fireman so stokes his fire that there is a thick bed of fuel on the grates and will himself pump water into his boiler to as high a level as can be carried with safety; all this must be accomplished just before the engine arrives at the foot of the grade. While climbing the grade the feed water is shut off, the furnace door is kept closed, and the throttle opened just far enough to enable the engine to mount the grade on schedule time, making it without unnecessary strain or labor.

If these precautions are neglected, the fireman will have to shovel fuel so hard during the climb that he will become exhausted before the summit of the grade is reached; this drawback, coupled with the large losses in steaming capability due to opening the furnace door for the purpose of stoking, will prevent the engine from maintaining the requisite head of steam for making this part of the run on schedule time.

Good Firing Practice. Theoretically, no air should be permitted to enter the furnace that does not pass through the fire but in practice this cannot be accomplished, because every time the fire door is opened it admits a large volume of cold air which passes over (not through) the fire directly into the tubes, tending to cool the water and decreasing the boiler's steaming capacity, For this reason, the stoking should always be done a very few shovelsful at a time and the fire door quickly closed to give the fire a little time for recuperation before re-firing. Another very essential duty of the fireman in stoking is to watch for *holes* in the fire. For various reasons, some portions of the bed of fuel will burn out quicker than the rest, and wherever this occurs it leaves a hole through which air will pass in greater volume than through the rest of the fire; as this air is comparatively cooler than if it had forced its way through the burning fuel, it has the same effect on the steam-making power of the boiler as the open fire door, though not to the same extent. Hence, the skillful fireman, on opening his furnace door, will look for these holes and fill them with fuel when he fires; if more of them appear than he can fill at one time he must stoke more frequently.

The bed of fuel should be kept, as far as possible, at a uniform thickness of about 10 to 12 inches although some engines are designed for a heavier bed than this. The coal is usually broken into pieces of $2\frac{1}{2}$ to 3 inches and enough for one stoking is laid on the deck of the engine before the fire door; the shovel is also heaped full and held ready before the fire door is opened, thus accomplishing the firing as quickly as possible.

Taking Advantage of Downgrade. It will readily be seen from the preceding description how essential it is that the driver and his fireman should know the exact location of the grades and the necessity for due preparation.

Of course on the return trip the same grade will have to be retraversed but with all the running conditions reversed. In this case the throttle should be closed, the train running down hill without steam, and the reverse lever should be thrown forward into the last notch of the quadrant; this gives the cylinder valves full stroke in order to equalize the wear on the valve face as much as possible, for at this time the absence of any lubricant between the valve and cylinder face is liable to cause more rapid wear than under ordinary working conditions. Under such conditions in former days, it was a part of the fireman's duty to walk out on the foot board and *tallow the valves*, that is, to introduce a lubricant through a tallow cup in the steam chest cover. Today, most engines are fitted with sight-feed lubricators which feed cylinder oil constantly to the valves and cylinders while the engine is in motion under steam.

The attentive engineer will also take advantage of this opportunity to replenish the water in his boiler, if necessary, because he can pump up while not using steam and at the same time prevent the pressure in the boiler from rising to the blowing-off point. In the interests of economical operation, such a condition is to be avoided but may easily arise when no steam is being used and with fuel burning on the grate bars. For this reason the damper should be closed, care having been taken before reaching the downgrade to let the fuel bed get thin. On its way down, the fire can be cleaned and fresh fuel added in readiness to resume steam-making as soon as the level is reached again.

Curves. The exact location of every curve on the run must be known to a certainty, first, because it is essential, in order to avoid derailment and for general safety that the speed of the train be slackened below the normal while passing around curves. All curves are constructed with the outer rail some inches higher than the inner rail, the exact amount being determined by the radius of the curve and the speed with which the train should make the curve. This tilting of the train counteracts to some extent the centrifugal force developed in rounding the curve but this precaution must be supplemented by slackening the speed also. Again, many curves occur in cuts, that is, at places where it has been found essential, in making the roadbed, to cut through a small hill so as to preserve the uniformity of the grade. Sometimes a curve will occur in a woods or at the entrance to a forest, and it would be manifestly dangerous to approach and enter such a place without giving warning of the approach of the train.

Hence it is the rule, when approaching a curve, to sound the whistle before arriving at the curve. This precaution is more especially essential if it be a single track road.

Switches. A knowledge and a clear remembrance of the location of all switches and sidings are necessary because of the liability of a switch onto the main line being left open through neglect or willfulness. Therefore, the driver on approaching a switch observes first of all the position of the switch target, next the position of the rails, never trusting to the target alone, for sometimes rods connecting the target with the track get disconnected or bent; the engineer can see very clearly whether the track he is running on forms one continuous line past the switch or not. He should, at the same time, assure himself that the frog and wing rails have not become misplaced. These are conditions that do not very often arise but when they do the consequences are so terrible, if not seen in time, that it pays to be on the lookout for them constantly. The main point is to have the train well in hand at all times, and to this end speed must be reduced when passing switches or the ends of sidings. All station yards have a number of switches, and it is customary to slow down while going through them, more especially if intending to stop there. But many trains pass through the smaller towns without stopping and must also frequently pass sidings at certain places on the line between stations and all these places must be watched closely by the driver. In order to do this properly, he must know beforehand when he is about to approach them.

Culverts and Bridges. The location of every culvert and every bridge must be known and a keen lookout kept for any derangement in connection with them. Swing and draw bridges are usually guarded by a semaphore, and it is the rule on nearly all roads that every train shall come to a *FULL STOP* about 200 feet from the bridge approach and await the dropping of the semaphore arm before proceeding, and then only at a slow speed until the bridge has been crossed.

Running Time. It is considered an unpardonable offense for an engine driver to arrive at a station ahead of time though some roads do allow one minute variation. This latter is not material, provided it is borne in mind and the rule lived up to; the idea is to have the right of way clear before the arrival of the train, for otherwise a very embarrassing result may ensue.

For these reasons it is very essential that the engine driver make himself thoroughly acquainted with his time table. He must not only know the exact time he is due at any station on his run, but he must know by rote just the number of miles between stations, mentally calculating the necessary speed of his train and seeing that his engine meets the requirements between stops. These speeds vary because of road conditions, and proper allowance must be made for grades, curves, conditions of road-bed, etc., otherwise it will be impossible for him to meet the requirements. Hence, the driver automatically registers in his mind certain landmarks along the road—a house here, a certain tree there, a hill, a stream, or a huge bowlder at other places—and he gets to know that he should pass each one of them at a given time going in one direction or the other. He also knows that a certain curve, a culvert, a siding, or a bridge lies one mile, a half-mile, or a quarter-mile beyond one or the other of his landmarks and by these indications he knows it is time for him to perform certain of the duties already described.

Block Signals. Many roads, especially in the older portions of this country where the traffic is heavy, use a double track extending for 80 or 90 miles outside some of the large cities and often all the way between important cities. Wherever double track is used, the block system of signals is installed, thus relieving the engine driver of many of the anxieties connected with running trains on a single track road and making the road safe for traffic.

It is not within the province of this article to discuss block signals except as to their effect on the duties of the man who watches over the destinies of the train committed to his care. Briefly, the right of way is divided into sections called *blocks* and at the commencement and end of every block there is a manually or automatically operated signal over each track; unless the driver sees that his signal shows the way is clear he must not enter a new block. On approaching a station, he must also look for the signals showing *way clear* and on arriving at a station must observe the semaphore arm projecting from the front of the station over the track; it may be that orders are awaiting him, which it is his duty to read and follow.

It will readily be seen from the above description of a portion of a locomotive driver's duties why it is essential to the proper performance of his work that he should *know the road* thoroughly.

CARE OF LOCOMOTIVE

Watching His Engine. While the engineer is attending to the matters just enumerated he must not neglect his engine. It would be a difficult matter to decide which of the numerous features to be watched are the most important but it goes without saying that the steam pressure and the water in the boiler are those which will require the most constant watching because they are liable to change, in fact are constantly changing unless foresight is used to keep them normal. In addition to these points, he must be eternally on the lookout for the condition of the working parts of the machine he is operating. To give a clear idea of the the conditions under which his machine is working, we will assume that he is running a passenger train and that his average speed between stations is 50 miles per hour and that the driving wheels are 5½ feet in diameter.

Oiling Parts. Now at a speed of 50 miles per hour the engine would have to make 260 revolutions per minute and all the reciprocating parts of the engine, such as the crossheads, the rock shaft, the pistons and rods, the valve stems and valves, the links and lifters, would vibrate just twice this number of times. This is very rapid motion for such heavy parts and there is a liability of great wear in these parts unless they are kept properly lubricated. The only time the engine man can get the opportunity of supplying them with oil is while his engine is standing, and usually the stops are short. Hence, he must see that these parts are provided with large oil cups holding a good supply of oil and feeding oil to the working parts of the machine in an exact and very regular manner. Lack of space will not permit a description here of the various devices in use, but whether the cups are made to feed through the medium of a spring, of reciprocating parts, or of capilliary attraction, the engineer must be thoroughly familiar with their operation; in his leisure time in the roundhouse he should see to it that the oiling devices are so adjusted that they will perform their required functions while the engine is on the road. Some of the moving parts require more oil than others and the feed of the various oil cups must be set to suit the requirements; if any cup should feed too fast, it will waste the lubricant and probably will run out of oil too soon, or if too slow the moving part will run dry and cut.

All engines are provided with two oils, one of a heavy body for such places as the pedestal boxes in which the axles of the driving wheels run and on the journals of which there is an enormous pressure, and the other a light oil for the connecting rods, guides, links, lifters, eccentrics, rock and tumbling shafts. The pedestal boxes have a large reservoir called a *cellar* and a means of keeping the oil always against the lower part of the journal and hence these parts do not require such constant watching. The other parts mentioned, however, have to be watched constantly and the amount of watchfulness required is not always the same for the different parts at all times, for weather conditions frequently influence them. For instance, certain parts—such as the eccentric straps, the guides, the links, and lifters—in ordinary weather or on damp cool days will run very smooth and cool while on a hot dry dusty day they will need careful watching; the dust raised from the roadbed by the rapid motion of the engine over it will be quite considerable and a large amount of it will settle on these parts in the form of grit which will cut the parts badly unless the oil feed is liberal and frequently replenished. For all these reasons, the careful man will, when his train stops at a station for a minute or two, jump down from his cab with his oil can and walk round his engine, touching the ends of the driving axles, the crank pins, etc., with the back of his left hand to ascertain if their temperature is normal and at the same time replenishing the oil cups if found necessary. He does not oil every part in this way each time but divides them up mentally into groups, oiling one group at one stopping place and another at some future time; nor does he go through the oiling process at every station unless these are quite far apart. Experience teaches him about how often to do it, a good maxim being to oil too often rather than sparingly until he has learned just how much is needed and how often. The back of the hand is used to try the temperature of the bearing because it is considered more sensitive than the palm or the ends of the fingers owing to the absence of calloused skin.

Very few engineers travel without a supply of flour of sulphur to use in case of a hot box.

On the Road. *Starting.* On starting out from a station the reverse lever is thrown forward into or nearly to the last notch in the quadrant. The cylinder cocks are opened and, when the signal comes to start, steam is admitted to the cylinders and the engine starts slowly. After running a short distance so that the train has acquired some momentum and the cylinders have become warmed, the cylinder cocks are closed and the reverse lever is pulled up several notches on the quadrant. This has the effect of making the travel of the valve shorter, of giving more lead to the valve, and of cutting off the supply of steam to each end of the cylinders before the end of the stroke; at the same time the throttle is opened a little wider. The effect of all this is to cause the steam to impinge on the pistons at the beginning of each stroke with more force and in greater volume, with the result that the engine picks up, or increases its speed; when this condition has been attained, the reverse lever is pulled up a few more notches and the throttle opened a little wider until the desired speed has been attained.

Running at Speed. Now while this is being done the engine man does not for one moment take his eyes off the right of way; he is watching the track, the semaphores, and everything before him. Having gotten safely away from the station yard and out on the main track, he then has time to look at the pressure and water gages, etc., a glance being sufficient to show him if everything is as it should be. He may seat himself or he may stand on the foot board, as suits his convenience, but the careful man will, in either position, keep his hand almost constantly on the reverse lever; this is his means of knowing if his *motion* is working right. By this term is meant that part of the mechanism which operates the cylinder or distributing valves, such as the eccentric rods, the links, the lifters, etc. Should anything happen to any of these parts it can be instantly detected if his hand is on the reverse lever. In addition to this, the engineer's attention is directed to the main and side rods on his side of the engine and to the beat of the exhaust steam as it escapes from the smokestack. An experienced engine man, listening to the exhaust of his own engine or of an engine at a distance, can tell at once whether the valves are working square. He can discern at once by the pulsations of the engine he is riding on, if all the parts are working in unison.

The attentive and careful man never allows his mind to wander for a moment from these symptoms for it is imperative, in case of emergency, that he act quickly. To this end he devotes a portion of his leisure time to thinking up what will be the best course of action in certain emergencies, going over carefully every possible occurrence that might take place and what should best be done under the circumstances. These matters he commits carefully to memory so that when the emergency arises he will act instantly without reflection, for when the time arrives to act there is no time to reflect or consider, and unless he is prepared beforehand he will be lost. Consequently, whenever a fellow craftsman meets with a casualty he is interested to learn all the details, including the course of action taken under the circumstances and the criticisms of those who are experienced in such matters. This gradually educates his mind to such a point that when anything happens to his engine he acts automatically much more quickly than anyone can think.

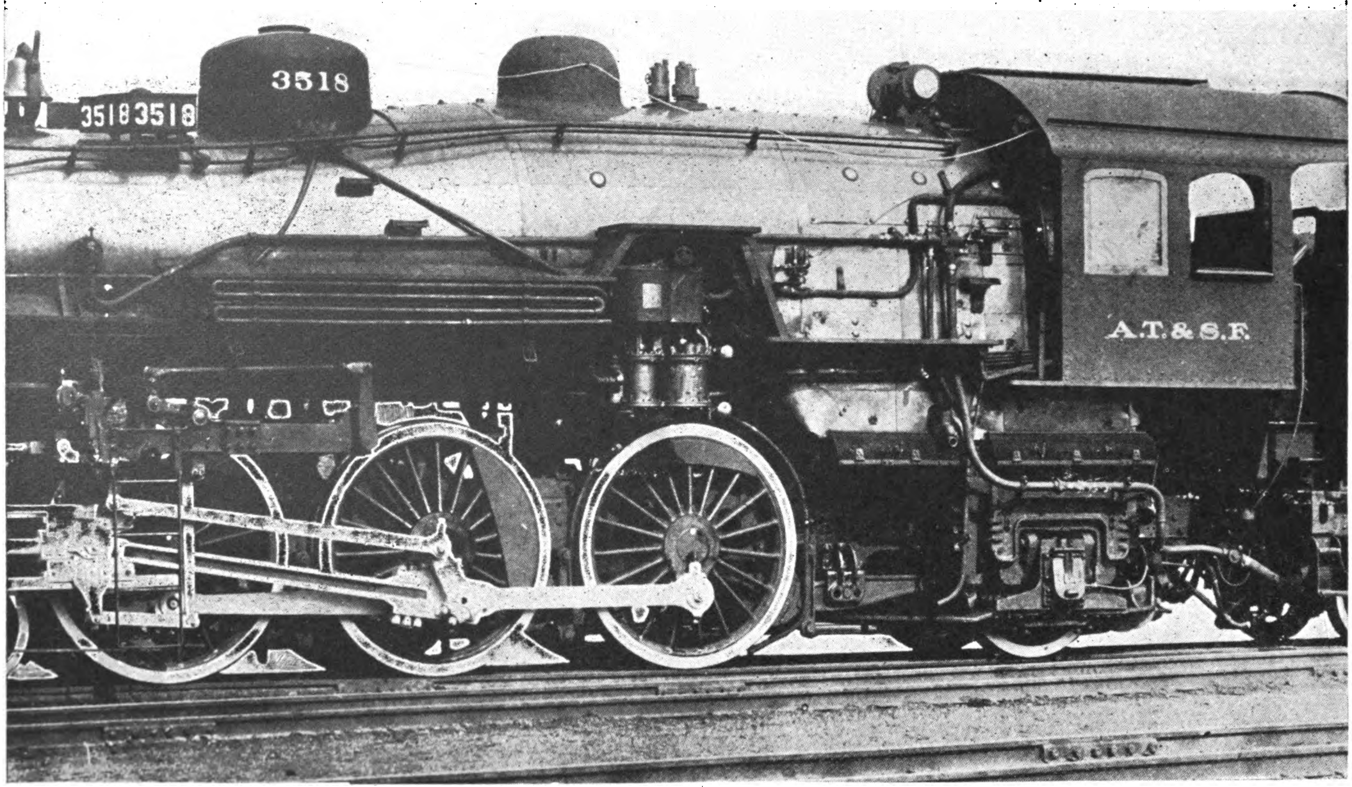
Making Adjustments En Route. The pedestal boxes, brasses on the connecting rods, eccentric straps, and other moving parts are usually adjusted by the engineer while *en route* because these matters cannot be attended to in the shop. A knocking connecting or side rod must be tightened up a very little at a time until the knock is all taken out; if tightened up all at once it would heat, so it is adjusted a little at a time until it runs quietly. The side, or parallel, rods can never be made to run as closely keyed up as the connecting rods because they do not need to be and because a certain amount of looseness is desirable. These rods are always fitted with about $\frac{1}{16}$-inch side play between the collars on the pins because in rounding a curve, the driving and trailing wheels are not exactly in line and if the brass boxes in these rods fitted snug between the collars on the pins they would jam and become sprung. Hence, when the engine is standing and he sees that on one side of the engine the pins of these wheels are in a horizontal position, he takes hold of the rod in the middle and tries it to see if it will move freely sidewise.

The proper length of a side rod, between center and center of boxes, should be identical with the distance between center and center of the axles of these wheels and if a little adjustment is required for the pedestal boxes, the centers of both rod and axles should be *trammed* to see if they agree. But this is a job for the shop man.

Any other derangements noticed by the engineer are reported by him to the shop foreman for attention by his staff.

End of Run. At the termination of his run the engineer should come into his last station with a thin fire on his grates and just enough steam to make the roundhouse. Whether he leaves his engine at this point depends on the relative locations of the depot and roundhouse. In some localities the engineer must take his train into the yards and shunt it into a siding before he leaves it; in others his engine is taken charge of by a man from the roundhouse, called a *hostler,* who takes the engine direct to the roundhouse while a switching engine does the shunting of the train.

When, however, the engineer returns to take out his train again he carefully looks the engine over to see that everything is in adjustment—all oil cups filled and working, fire in good shape, steam and air pressures right, and the hose couplings properly connected. He should also look into his sand box (this should really be done in the roundhouse) to see that his supply of sand is sufficient and dry enough to run out if required. When he has tried his air to see if the brakes are working, he is ready for another start.



CHARACTERISTIC AIR-BRAKE EQUIPMENT FOR PASSENGER LOCOMOTIVE
Courtesy of Baldwin Locomotive Works, Philadelphia, Pennsylvania

AIR BRAKES

PART I

INTRODUCTION

Braking an Outgrowth of Speed. The development of the many accessory appliances with which the rolling stock of our railways is fitted has been the subject of a great deal of study and investigation. Of the many appliances which have received careful and systematic study, the braking apparatus is one of the most important.

The time when the question of braking first received attention dates back farther than the time when highways became sufficiently well made and well maintained to permit of vehicles being drawn at a moderate rate of speed. When wheeled vehicles, drawn at speeds of ten or fifteen miles per hour, first made their appearance, it was found necessary to provide means by which they could be easily and quickly stopped in case of emergency. The first carts and wagons, built for agricultural purposes, were of such construction that the resistance of the earth and axle were sufficient to bring them to rest in a reasonable length of time on ordinary roads. In cases of steep grades, the motion was retarded by one or both wheels being locked with chains, or by a stone or piece of timber being chained to the axle and dragged along the ground behind the vehicle.

It is interesting to note that the question of braking has steadily increased in importance as the demand for higher speed has increased. This applies equally well to all classes of vehicles, including railway trains, street and interurban cars, automobiles, and wagons. The first forms of braking apparatus adopted have formed the basis of almost all brake appliances since employed for the same vehicles.

Early Forms of Brake. *Stagecoach Type.* Perhaps one of the first forms of brake used was that found on the early stagecoach. It consisted of an iron shoe which was chained to the fore part of the coach, and it was used only on steep grades. To apply this brake, the shoe was removed from its hook under the carriage and placed on the ground in front of the rear wheel in such a position that the wheel would roll on it. As the wheel rolled on the shoe, the chain became taut, with the result that both the shoe and wheel slid over the surface of the ground.

First Railroad Type. A railroad is known to have existed as early as 1630, although it would hardly be called by that name today. The construction of the track, as well as that of the cars, was almost entirely of wood. Even with this crude construction it was found necessary to provide a brake to control the speed of the cars on the slight grades. The form of brake devised to meet the conditions consisted of a wooden lever pinned to the frame of the car at one end in such a manner as to permit of its being pressed against the tread of the wheel by hand. When not in use, the lever was held off the wheel by means of a chain. The principle employed here in resisting the motion of the car is the same as that employed today on all railroads, namely, of applying the braking or resisting force to the periphery of the wheel.

Developments Due to Steam Locomotive. As railroads increased in number and their construction improved, braking apparatus became more and more a necessity. As a result, inventors brought out a number of simple braking appliances. The question of braking, however, did not become a very important or a very serious one until the advent of the steam locomotive. Previous to its coming, the cars were small and were drawn by animals, and the speeds were low; but, with the steam locomotive in existence, an efficient brake became an absolute necessity.

This problem received the close attention of inventors and investigators; and, at the close of 1870, the automatic, electro-magnetic, steam, vacuum, and air brakes were found in use on the railroads in the United States. These types of brakes differed chiefly in the manner in which the braking power was obtained. Other devices were invented, but could not stand the test of actual practice and did not come into prominence.

Cramer Spring Type. It might be interesting to note briefly one or two rather unique types of brakes not included in any class yet mentioned. The Cramer brake, brought out in 1853, might be mentioned as one of these. Its principal feature consisted of a spiral spring, which was connected to the brake staff at the end of each car. This spring was wound up by the brakeman before leaving the station, and the brake apparatus on each car was under the control of the engineer through the medium of a cord. This cord was connected to the mechanism of the several brakes and passed through the cars, terminating in the cab on the engine. The engineer, desiring to stop his train, would shut off the steam and give the cord a pull, which action resulted in releasing the coil springs on the various cars and applied the brakes by winding up the brake chains.

Loughridge Chain Type. The Loughridge chain brake, another unique brake, was introduced in 1855. This brake consisted of a combination of rods and chains which extended from a winding drum under the engine throughout the entire length of the train. This continuous chain joined other chains under each car, which, in turn, were connected to the brake levers. The winding drum located under the engine was connected by a worm gear to a small friction wheel. In operating the brake, a lever in the cab was thrown which brought the small friction wheel in contact with the periphery of one of the driving wheels, thereby causing the drum to rotate and wind up the chain. The movement of the chain, which was experienced throughout the entire length of the train, served to actuate levers and rods under each car which, in turn, applied the brake shoes to the treads of the wheels.

Hand Types. The early types of hand brakes underwent many changes as years went on and as experience suggested improvements. Although during many years of early railroading, the braking on all trains was done by hand, nevertheless there was a constant desire and demand for a practical automatic brake. The rather crude and inefficient types already referred to were obtained only after a great many failures. Since about 1870, all forms of brakes have differed chiefly in but one respect, that is, in the appliances which are used in operating the foundation brake gear. The foundation brake gear is made up of the rods, levers, pins, and beams located under the frame of the car, the operation of which causes the brake shoes to be pressed against the periphery or tread of the wheel. The present scheme of applying the brake shoe to the periphery of the car wheel—which was in use long before the first locomotive made its appearance—later experience has proved to be the most practicable.

Many forms of brakes were devised prior to the year 1840, but, at that time, few locomotives were equipped with braking apparatus. About this period, however, when the locomotive tender began to take on some definite form, we find the tender fitted with braking appliances. Previously, when brakes were provided, they were usually found fitted to the cars only. It is only within the last thirty-five years that locomotives have been built with brakes fitted to the drivers. Today it is not uncommon to find all wheels on both the locomotive and the tender equipped with braking apparatus.

First Westinghouse Air Type. In 1869, the first Westinghouse air brake made its appearance. This brake is now referred to as the "straight air brake". It was not an automatic brake. It consisted chiefly of a steam-driven air compressor and storage reservoir located on the engine; a pipe line extending from this reservoir throughout the length of the train, a brake cylinder on each car, and a valve located in the cab for controlling the brake mechanism. The train line was connected between cars by means of flexible rubber hose with suitable couplings. Each car was fitted with a simple cast-iron brake cylinder and piston located underneath the frame, the piston rod of which connected with the brake rigging in such a manner that, when air was admitted into the cylinder, the piston was pushed outward and the brake thereby applied. In operating the brake, air was admitted into the train line from the storage reservoir by means of a three-way cock located in the cab. The air was conducted to the brake cylinder under the various cars by means of the train pipe. The release of the brakes was accomplished by discharging the air in the various brake cylinders and the train pipe into the atmosphere through the three-way cock in the cab. This was the simplest and most efficient brake invented up to the time of its appearance, and was adopted by many railroad companies in this country.

Westinghouse Plain Automatic. The straight air-brake system, however, possessed three very objectionable features: *First,* in case of a break-in-two or of a hose bursting, the brake at once became inoperative; *second,* it was very slow to respond in applying and releasing the brakes; and, *third,* the brakes on cars nearest the engine were applied first, causing jamming and surging of the cars, which sometimes proved destructive to the equipment. In order to overcome these undesirable qualities, Mr. George Westinghouse invented the Westinghouse automatic air brake in 1872. This form of brake, which has since gone out of service on steam railroads, was known as the "plain automatic air brake". This brake retained the principal features of the straight air brake, but in addition, each car was provided with an air reservoir, which supplied the air for operating its particular brake cylinder. The charging of this auxiliary reservoir with air, the admitting of this air into the brake cylinder, and the discharge of the air from the brake cylinder to the atmosphere, were accomplished by an ingenious device known as the triple valve. A detailed description of this valve will be given later.

Vacuum Brake. The vacuum brake was also invented in the year 1872, but, on account of its many undesirable features, it never gained very great prominence in this country. This brake was spoken of as the "plain vacuum brake", and was followed later by the "automatic vacuum brake". The principal parts of the air brake were, in general, embodied in the vacuum brake. One marked difference existed, however, in that, instead of an air compressor, an ejector was installed on the locomotive, which exhausted the air from the train pipe when the system was in operation.

At the close of the year 1885, there could be found in use on the railroads of the United States a number of different types of brakes. These could be grouped into two general classes: continuous, or air brakes, and independent, or buffer brakes. In the buffer brake, the brake shoes were actuated by rods and levers, which in turn received their motion from the movement of the draw-bar. It is easily seen that, with such a variety of different forms of braking apparatus, it would be impossible to control a train properly if it were made up of cars from different railroads having different brake systems.

Work of Master Car Builders' Association. *Interchangeable Brake System.* The one agency which has had an important part in bringing the braking appliances of our railroads to the present high standard of perfection is the Master Car Builders' Association. This association, realizing the increasing demand for the interchange of cars, saw the need of interchangeable brake systems. It was principally through the research of their committees that the brake systems of today are interchangeable and efficient.

The first experiment conducted by the committee in 1886 clearly showed that any further attempt to use the independent or buffer brake was not desirable, on account of the severe shocks resulting when stopping the train. The effect of the report of the committee was the withdrawal of this type of brake from the attention of the railroad officials. This left almost the entire field open to the continuous or air-brake system. The committee continued its work the following year and, from the results of a large number of tests, reported that the best type of brake for long freight trains was one operated by air in which the valves were actuated by electricity. This type of brake stopped the train in the shortest possible distance, reduced all attending shocks to a minimum, was released instantaneously, and could be applied gradually. Although the results of tests pointed to the superiority of the air brake in which the valves were operated by electricity, yet it is only recently that a successful system has been adopted.

From the time of these tests, the different brake companies turned their attention to the style of brake represented by the Westinghouse "automatic air-brake" system. In this system, the most important parts are the triple valve, located on the brake cylinder of each car, and the controlling, or engineer's brake valve, located in the cab. By the year 1893, a number of triple valves and engineer's brake valves had been placed on the market and representative ones were exhibited at the Columbian Exposition in Chicago in that year.

Triple-Valve Tests. The committee of the Master Car Builders' Association, being conscious of the fact that the actions of the valves made by the different companies were so widely different, proposed a series of tests of triple valves and asked the different companies to submit valves for the said tests. The object of the proposed tests was to obtain data from which a code of tests for triple valves could be formulated which would be satisfactory to all parties concerned. The ultimate aim of the committee was to secure triple valves which would operate with the same ultimate effect when subjected to identical conditions, and which would operate successfully when intermingled with each other in a train.

Such tests were conducted on a specially constructed air-brake testing track in the year 1894. Five companies responded with valves for the series of tests, of which the valves representing the Westinghouse and New York companies gave the best results. From the results obtained the committee prepared a code of tests for triple valves, which code was soon after adopted by the association

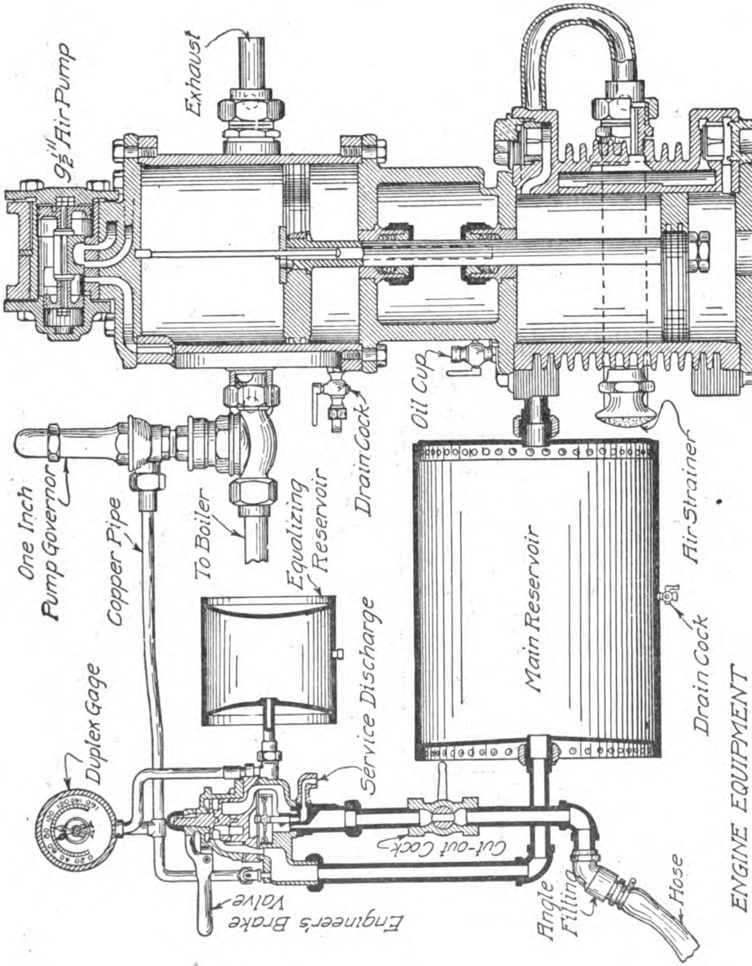
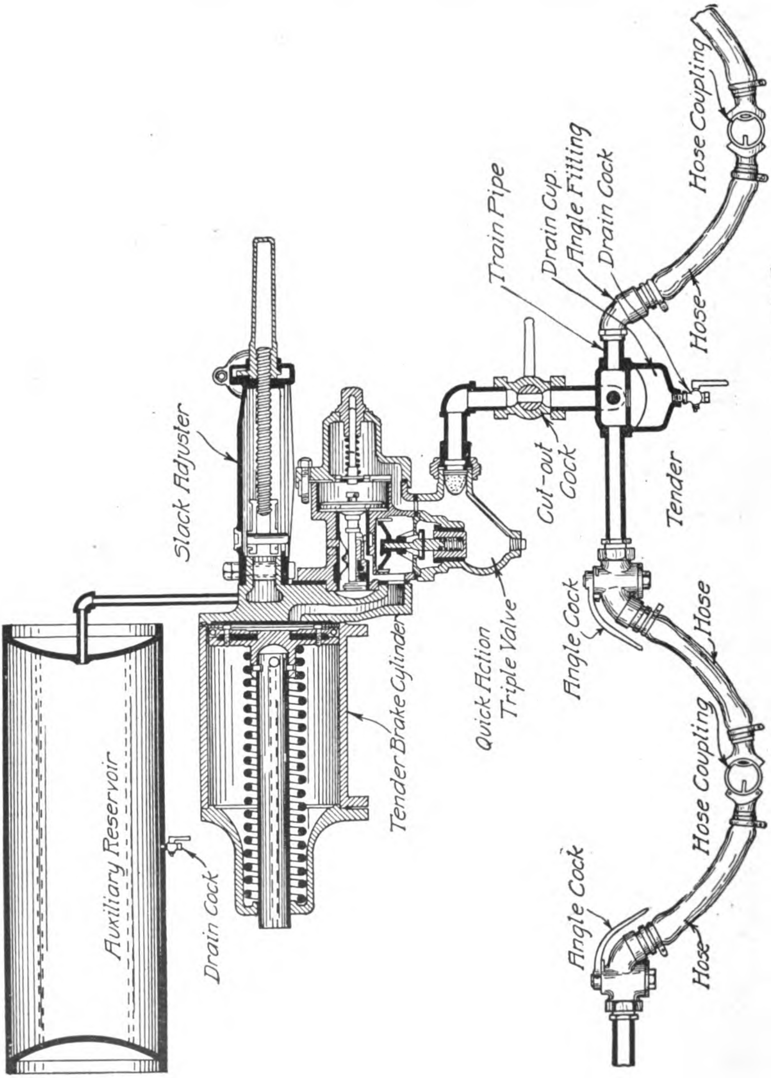


Fig. 1. Diagram Showing Basic Air-Brake Equipment for Locomotive under Westinghouse System

as standard. As a result of this action, makers of air-brake apparatus endeavored to produce triple valves which would give results as specified in the code. This naturally led to interchangeable air-brake systems—one of the objects which the committee hoped to attain. Many triple-valve tests have since been made, and the code has been changed from time to time to meet new conditions which have developed.

Studying the Air Brake. Air-brake study should be carried on



TENDER EQUIPMENT

Fig. 2. Diagram Showing Basic Air-Brake Equipment for Locomotive Tender under Westinghouse System

from two standpoints, namely, the theoretical and the practical, keeping them as closely associated as possible.

First, the name of every complete part of the air-brake apparatus and its connections on the engine, tender, and car should be learned. The next thing to be taken up is the function of each part, but neglecting the interior mechanism, ports, passages, etc. In other words, one should learn how the air brake looks on the outside and

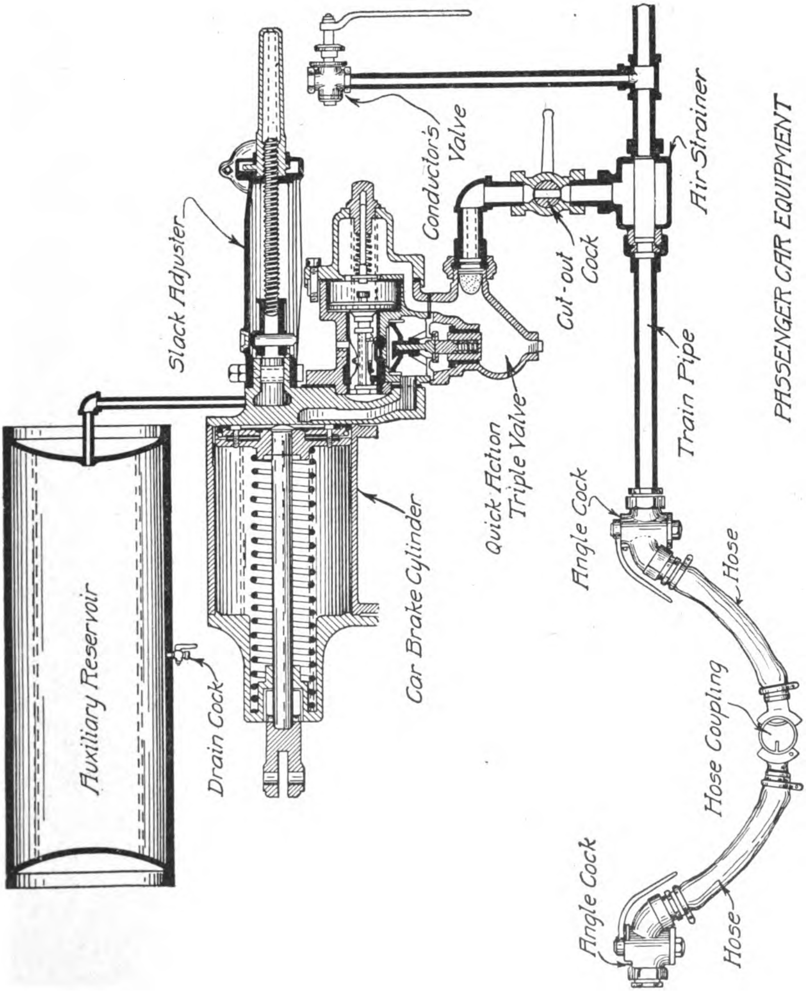


Fig. 3. Diagram Showing Basic Passenger-Car Air-Brake Equipment under Westinghouse System

how it is connected, as shown in Figs. 1, 2, and 3, as this is the basic principle of installation of all automatic railway air brakes now in service. Until this is so well learned that it can be pictured in the mind without reference to the engine, car, or illustration, the student is not ready to study the interior construction and operation of any part.

Today there are mainly two air-brake systems in general use on steam railroads in this country, namely, the *Westinghouse* system and the *New York* system. A few years ago the two systems were quite different, the construction and operation of the different valves being worked out on entirely different principles. Today the various parts comprising the two systems are so much alike in both appearance and principle of operation that the layman cannot distinguish any difference. For this reason it seems advisable to confine the work entirely to a discussion of the Westinghouse system.

WESTINGHOUSE AIR-BRAKE SYSTEM*

GENERAL CHARACTERISTICS OF SYSTEM

Brakes are used to prevent the movement of cars or engines when at rest and, when in motion, to control the speed while descending grades or to stop when it is desired to do so. These results are obtained through friction resulting from pressing the brake shoes against the wheel faces or treads. An air brake is one in which compressed air instead of hand power is used to cause the brake-shoe pressure.

Essential Elements. The automatic air brake has the following ten important parts which, with their connections, are shown in Figs. 1, 2, and 3.

1. A *steam-driven air pump or compressor* located on the engine to compress the air for use in the brake system and signal system when used.

2. A *main reservoir* located somewhere on the engine or tender for the following purposes: (a) to receive and store the air compressed by the pump or compressor; (b) to act as a cooler for the compressed air and to catch the moisture and oil which are precipitated from the air by cooling; (c) to act as a storage chamber for excess pressure or backing volume for the purpose of releasing the brakes and recharging the air-brake system.

3. An *engineer's brake valve*, located in the cab in easy reach of the engineer, with feed valve attachment, through which (a) Air from the main reservoir may be admitted to the brake pipe either (1) direct, as when charging the train or releasing the brakes; and (2) through the feed valve, as when running over the road and maintaining pressure in the system. (b) Air from the brake pipe

*In presenting the discussion and description of the Westinghouse system, free use has been made, where necessary, of literature on the subject published by the Westinghouse Company.

may be allowed to escape to atmosphere when applying the brakes. (c) The flow of air to or from the brake pipe and brake system may be prevented, as when holding the brakes applied.

4. A *double-pointed air gage,* so connected that one hand indicates the main-reservoir pressure and the other indicates the brake-pipe pressure.

5. An *air-pump or compressor governor* to control the operation of the pump by automatically decreasing or closing off the steam supply to the pump to prevent the accumulation of more than the predetermined main-reservoir pressure.

6. A *brake pipe,* including branch pipe, flexible hose, and couplings, which connects the engineer's brake valve and the conductor's valve, with the triple valve on each car. Angle and cut-out cocks are provided in the brake pipe on each car, the former for opening or closing the brake pipe at any desired point in the train, and the latter to cut out, or in, individual triple valves.

7. A *triple valve* on each vehicle, to which the brake pipe, the auxiliary reservoir, and the brake cylinder are connected by separate openings and which, by connecting these openings, control the flow of air between these parts so as to enable the auxiliary reservoir to be charged and the brakes to be applied and released. The functions of the triple valve may be briefly stated as follows: (a) When charging and maintaining the pressure in the brake system (1) to permit air to flow from the brake pipe to the auxiliary reservoir; (2) to prevent air from flowing from the auxiliary reservoir to the brake cylinder; and (3) to keep the brake cylinder open to the atmosphere. (b) When applying the brakes (1) to close communication from the brake pipe to the auxiliary reservoir; (2) to close communication from the brake cylinder to the atmosphere; and (3) to permit air to flow from the auxiliary reservoir to the brake cylinder. (c) When holding the brakes applied, to close all communications between the brake pipe, auxiliary reservoir, brake cylinder, and atmosphere. (d) When releasing the brakes and recharging the system: (1) to keep the brake cylinder open to the atmosphere; (2) to permit the air to flow from the brake pipe to the auxiliary reservoir; and (3) to prevent air from flowing from the auxiliary reservoir to the brake cylinder.

8. An *auxiliary reservoir,* in which the compressed air is stored for applying the brake on its individual car.

9. A *brake cylinder* provided with a leather-packed piston and piston rod connected with the brake levers in such a manner that when the piston is moved by the air pressure the brakes are applied.

10. A *pressure-retaining valve,* not shown in either Figs. 1, 2, or 3, but connected to the exhaust or discharge port of the triple valve. In its ordinary or cut-out position it permits the brake-cylinder pressure to be freely discharged to the atmosphere, but when cut in, as required when descending heavy grades, it retards the discharge of air from the brake cylinder down to a predetermined amount, and then retains that amount when the triple valve is in its release position.

The operation of these parts referred to above will be described in detail under the proper heading later in the work.

The triple valve performs its various functions by variations between brake-pipe and auxiliary-reservoir pressures. If the brake-pipe pressure is made the higher of the two, then the triple valve will move to a position for releasing the brake and charging the auxiliary reservoir. But if the auxiliary-reservoir pressure is made higher than that in the brake pipe—a condition obtainable only through reducing the brake-pipe pressure by the engineer's brake valve or conductor's valve, burst hose or pipe, or train parting—then the triple valve will move to a position for brake application.

Definition of Terms. *Increase in Brake-Pipe Pressure.* Whenever air is passing into the brake pipe more rapidly than it is escaping so as to produce a raise in pressure, it means a brake-pipe pressure increase, and will cause the triple valves to release the brakes and recharge the brake system; but the student must bear in mind that there are two sources of drain on the brake pipe which will operate to prevent an increase in pressure, namely, leakage from the brake pipe through any of its many connections, and also by feeding into the auxiliary reservoirs. All of these losses must be overcome before a raise in brake-pipe pressure can be obtained.

The brake-pipe pressure is maintained by a piece of apparatus known as a feed valve, which forms a part of the engineer's brake valve. This feed valve automatically supplies the brake-pipe losses as fast as they take place through any source whatever, provided the handle of the engineer's brake valve is kept in running position.

Brake-Pipe Reduction. The term "brake-pipe reduction" means that air is escaping or being discharged from the brake pipe faster than it is being supplied. Therefore, it must be understood that losses from the brake pipe which are not supplied will constitute a brake-pipe reduction and will cause the triple valves to move toward application position.

Lap. The term "lap" is used to designate the position of the engineer's brake valve, triple valve, or distributing valve, in which all operative ports are closed to the air in any direction.

Brake Application. By brake application is meant a sufficient reduction of brake-pipe pressure, no matter how made, to cause the triple valves to move to application position and, if made through the service position of the engineer's brake valve, may consist of one or more brake-pipe reductions.

Service Application. Service application is accomplished by a gradual reduction of brake-pipe pressure, so as to cause the triple valves to assume this position and produce the desired result, such as is made by operators for a known train stop or slow down.

Emergency Application. Emergency application is accomplished by a quick, heavy reduction of brake-pipe pressure which will cause the triple valves to assume the emergency position and produce quick action, such as is made by operators with the brake valve, or by train men with the conductor's valve, for the purpose of saving life or property. It is also made automatically whenever the brake pipe is broken or the train parts.

Operation of Westinghouse Air Brake. When the brakes are in operating condition, the pump governor is usually set to maintain a pressure of 90 pounds in the main reservoir. The feed valve is set to maintain a pressure of 70 pounds in the brake pipe when the engineer's brake valve is in running position. The operation of the brake is controlled by the engineer's brake valve, which has five fixed positions for its handle. These positions named in order, beginning from the left, are: *release*, *running*, *lap*, *service*, and *emergency*.

To make a service application of the brakes, the handle of the engineer's brake valve is placed in *service* position, thereby closing connection between the main reservoir and the brake pipe and permitting air to escape from the brake pipe to the atmosphere through ports in the valve. The handle of the engineer's brake valve is left in this position for a short time only, when it is placed in the lap position.

In the *lap* position, all working ports are closed and the brakes are held applied.

When it is desired to release the brake after either a service or an emergency application, the handle of the engineer's brake valve is placed in *release* position. In this position, direct connection is made between the main reservoir and the brake pipe. The handle of the brake valve is left in this position only long enough to insure the release of all of the triple valves and then it is placed in running position. This is done to prevent an overcharged brake pipe. The brakes will release when the engineer's brake valve is placed in *running* position, but they will do so very slowly.

When it is necessary to make an emergency application, the handle of the engineer's brake valve is placed in *emergency* position and direct connection is made between the brake pipe and the atmosphere. This causes a sudden reduction of pressure in the brake pipe and gives a higher pressure in the brake cylinder than is obtained in service applications. If the handle of the engineer's valve is left in the emergency position until a brake-pipe pressure reduction of from 20 to 25 pounds is obtained and it is then placed in lap position, the maximum braking power is obtained. This will be made clear when the study of the quick-action triple valve is taken up.

AIR COMPRESSORS

Single-Stage Type. The Westinghouse single-stage air compressor consists of an air cylinder, in which the air drawn from the atmosphere is compressed; a steam cylinder, located above the air cylinder, the two being connected by a center piece; and a steam cylinder valve motion which for the most part is contained in the upper steam cylinder head.

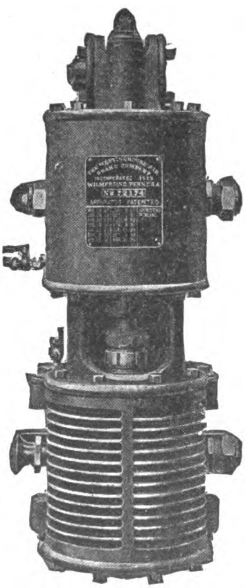


Fig. 4. 9½-inch Steam-Driven Air Compresser
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

The compressor is of the double-acting direct-connected type, steam being admitted alternately to the under and to the upper side of the steam piston, causing it to move up and down. As the air piston is directly coupled to the steam piston by the piston rod, it moves up and down with the steam piston. On the upward stroke of the air piston, the air above it is compressed and discharged into the main reservoir while the space below it is being filled with air drawn from the atmosphere. On the down stroke this operation is reversed. The exhaust steam is usually piped to the smokestack.

Sizes. The compressor is built in different sizes. Table I gives the principal dimensions, actual air delivery, and weight of the single-stage compressors.

All of the sizes of single-stage air compressors now being built operate on the same principle. Fig. 4 illustrates the general appear-

TABLE I

General Dimensions, Capacity, and Weight of Westinghouse Standard Steam-Driven Air Compressors

Diameter of Steam Cylinder	8 in.	$9\frac{1}{2}$ in.	11 in.
Diameter of Air Cylinder	8 in.	$9\frac{1}{2}$ in.	11 in.
Stroke	10 in.	10 in.	12 in.
Steam Admission Pipe	1 in.	1 in.	1 in.
Steam Exhaust Pipe	$1\frac{1}{4}$ in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.
Air Admission Pipe	$1\frac{1}{2}$ in.	$1\frac{1}{2}$ in.	$1\frac{1}{2}$ in.
Air Delivery Pipe	$1\frac{1}{4}$ in.	$1\frac{1}{4}$ in.	$1\frac{1}{4}$ in.
Nominal Speed, single strokes per minute	120	120	100
Actual capacity in cu. ft. of free air per min. actually delivered when operating continuously, at above speed, against 100 pounds pressure	20 cu. ft.	28 cu. ft.	45 cu. ft.
Over-all Dimensions: (Approximate) Height	$42\frac{1}{4}$ in.	$42\frac{1}{4}$ in.	$51\frac{1}{4}$ in.
Width	18 in.	$18\frac{1}{4}$ in.	22 in.
Depth	$13\frac{3}{4}$ in.	$14\frac{1}{2}$ in.	16 in.
Average Net Weight	450 lb.	525 lb.	850 lb.

ance of the $9\frac{1}{2}$-inch size. Views of the compressor, with steam and air cylinders and valve mechanism in section, are shown in Figs. 5 and 6. Figs. 7 and 8 are distorted or "diagrammatic" illustrations designed to show as clearly as possible the connections of the various ports and passages but not the actual construction of the parts.

Method of Action in Steam End of Compressor. Considering first the steam end of the compressor, and referring to the above-mentioned figures, steam from the supply enters at the connection marked "from boiler", Fig. 6 (or "steam inlet", Figs. 7 and 8), and flows through the passageways a and a^2 (see also Fig. 5), to the chamber A, above the main valve *83* and between the pistons *77* and *79*, and through passage e to chamber C, in which is reversing valve *72*. The supply and exhaust of steam to and from the steam cylinder is controlled by the main valve *83*, which is a **D** type of slide valve. It is operated by the two pistons, *77* and *79*, of unequal diameters and connected by the stem *81*. The movement of these two pistons and the main valve is controlled by the reversing valve *72*, which is in turn operated by the main steam piston *65*, by means of the reversing rod *71* and the reversing plate *69*. As will be seen from the following description, the duty of the reversing valve *72* is to alternately admit or discharge steam from chamber D

at the right of piston *77*, thus alternately balancing or unbalancing this piston. The reversing valve is operated by the reversing rod *71*. This rod is alternately moved up and down by reversing plate *69*, which engages reversing shoulder *j* on the upward stroke of the steam piston and button *k* at the end of the rod, on the downward stroke.

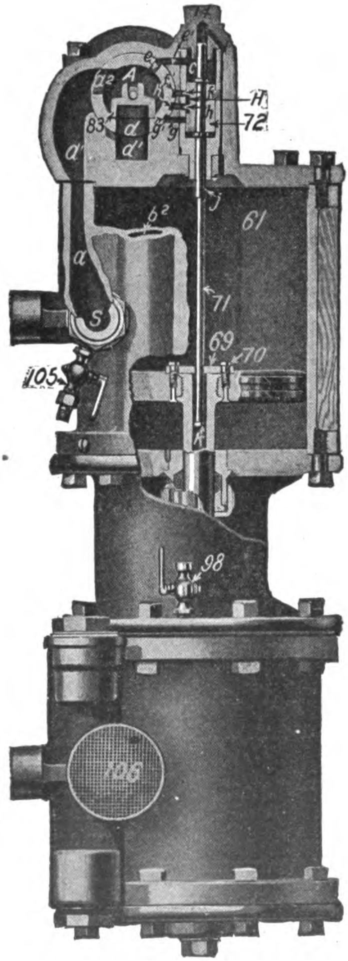


Fig. 5. Section of Air Compressor through Reversing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Chambers *A* and *C* are always in free communication with each other and with the steam inlet through port *e*, e^1 as shown in the figures. Live steam is therefore always present in these chambers *A* and *C*. Chamber *E*, at the left of small piston *79*, is always open to the exhaust passage *d* through the ports *t* and t^1, shown in the main valve bushing, Fig. 5, and diagrammatically in Figs. 7 and 8. Exhaust steam, practically at atmospheric pressure, is therefore always present in chamber *E*.

A balancing port *s* runs diagonally to the right in the reversing-valve cap nut and meets a groove down the outside of the reversing valve bush, where it enters the upper end of the cylinder through a small port in the head. The object of this is to assure the same pressure above as below the reversing rod, whether there is live or exhaust steam in the upper end of the cylinder, thus balancing it so far as steam pressure is concerned.

When the reversing slide valve *72* is in its lower position, as shown in Figs. 5 and 7, chamber *D* is connected (through ports *h*, h^1, reversing-valve exhaust-cavity *H* and ports *f* and f^1) with main exhaust passage *d*, d^1, d^2, and there is, therefore, only atmospheric pressure at the right of piston *77*.

Therefore, as chamber *E*, at the left of piston *79*, and chamber *D*, at the right of piston *77*, are both connected to the exhaust,

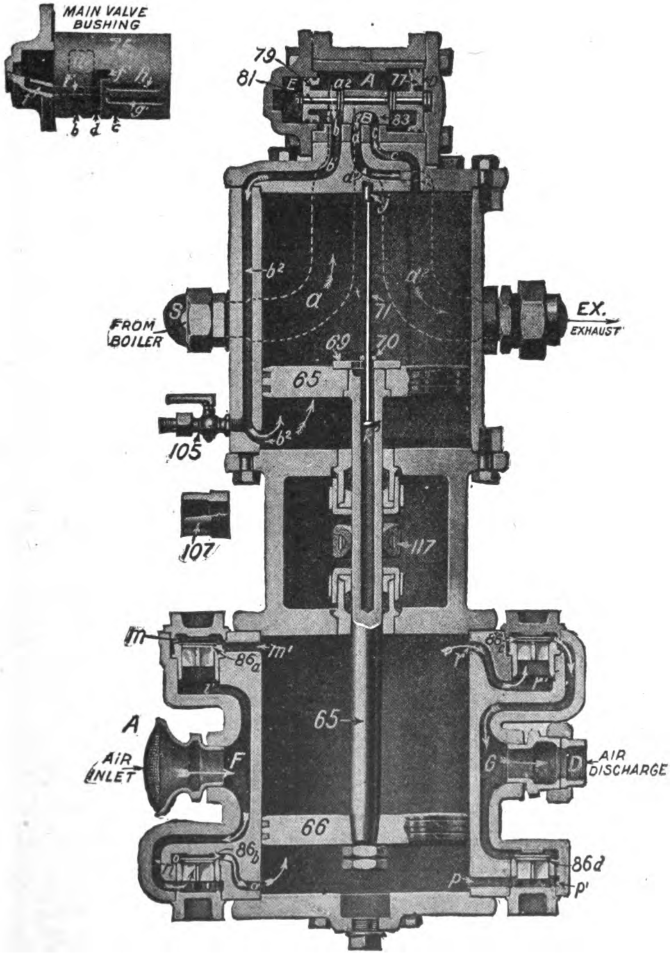


Fig. 6. Section of Air Compressor through Main Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

as already explained, the pressure of the steam in chamber *A* has driven the large piston *77* to the right, and it has pulled the smaller piston *79* and the main valve *83* with it to the position in Figs. 6 and 7. The main valve *83* is then admitting steam below piston

65 through port *b*, b^1, b^2. Piston *65* is thereby forced upward, and the steam above piston *65* passes through port c^1, *c*, exhaust cavity *B* of main valve *83*, port *d*, and passage d^1, d^2 to connection *Ex*, at which point it leaves the compressor and discharges through the exhaust pipe into the atmosphere.

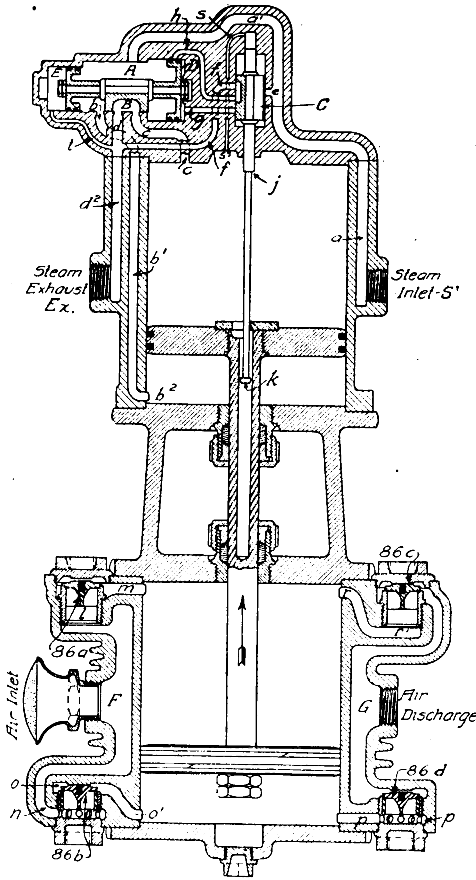


Fig. 7. Diagram of Westinghouse Compressor for the Up-Stroke

When piston *65* reaches the upper end of its stroke, reversing plate *69* strikes shoulder *j* on rod *71*, forcing it and reversing slide valve *72* upward sufficiently to open port *g*. Steam from chamber *C* then enters chamber *D* through port *g* and port g^1 of the bushing. The pressures upon the two sides of piston *77* are thus equalized or balanced. Considering piston *79*, the conditions are different. Chamber *E*, as already stated, is always open to the exhaust. As piston *77* is now balanced, the steam pressure in chamber *A* forces piston *79* to the left, drawing with it piston *77* and main valve *83* to position shown in Fig. 8.

With main valve *83* in the position, steam is admitted from chamber *A*, through port *c*, c^1, above piston *65* forcing it down; at the same time the steam below this piston is exhausted to the atmosphere through port b^2, b^1, *b*, exhaust cavity *B* in the main valve, port *d*, d^1, d^2 and the exhaust pipe connected at *Ex*.

When piston *65* reaches the lower end of its stroke, reversing plate *69* engages reversing button *k*, and draws rod *71* and reversing valve *72* down to the positions shown in Figs. 6 and 7, and one complete cycle (two single strokes) of the steam end of the compressor has been described.

Method of Action in Air End of Compressor. The movement of steam piston *65* is imparted to air piston *66* by means of the piston rod *65*. As the air piston *66* is raised, the air above it is compressed and air from the atmosphere is drawn in beneath it; the reverse is true in the downward stroke.

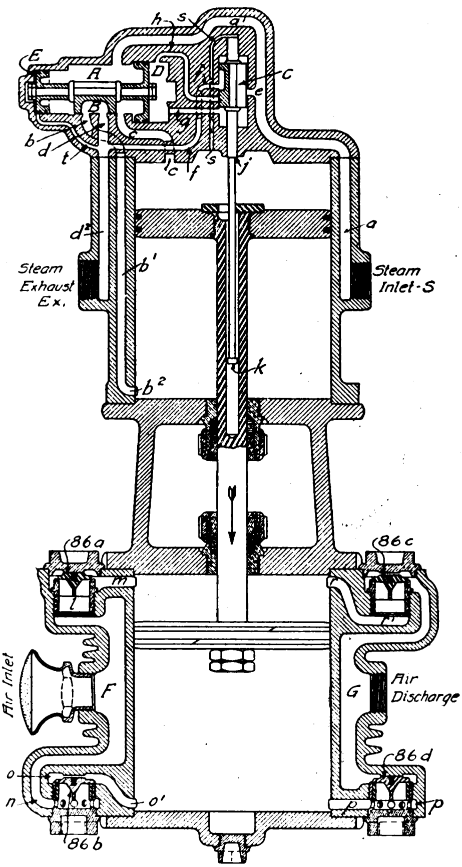


Fig. 8. Diagram of Westinghouse Compressor for the Down Stroke

On the upward stroke of piston *66*, the air being compressed above it is prevented from discharging back into the atmosphere by the upper inlet valve *86a*. As soon as the pressure in ports *r*, r^1 below upper discharge valve *86c* becomes greater than the main reservoir pressure above it, the discharge valve *86c* is lifted from its seat. The air then flows past this valve down through chamber *G*, out at "air discharge" and through the discharge pipe into the main reservoir.

The upward movement of the air piston produces a partial suction or vacuum in the portion of the cylinder below it. The air pressure below piston *66* and on top of the lower left-hand inlet valve *86b* becomes, therefore, less than that of the atmosphere in port *n* underneath this valve. Atmospheric pressure, therefore, raises valve *86b* from its seat, and atmospheric air is drawn through strainer *106* at "air inlet", into chamber *F*, and port *n* below the inlet valve *86b,* thence past that valve through ports *o* and o^1 into the lower end of the air cylinder, filling same. Air cannot enter this part of the cylinder by flowing back from the reservoir through *D* and *G* and lower discharge valve *86d,* since this valve is held to its seat by the main-reservoir pressure above it. The lower inlet valve *86b* seats by its own weight as soon as the up-stroke of the air piston *66* is completed.

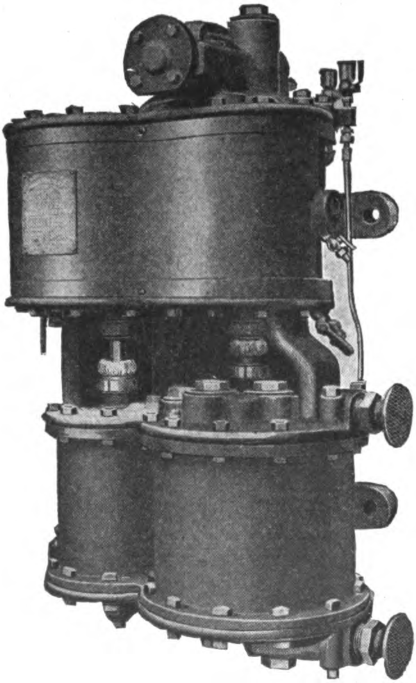


Fig. 9. 8½-Inch Cross-Compound Compressor, Showing Air-Inlet Side
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

On the downward stroke of the compressor, the effect just described is reversed, the air below piston *66* being compressed and forced out through ports *p* and p^1 past lower discharge valve *86d* and through chamber *G* and the air discharge pipe into the main reservoir. At the same time air is being drawn in from the atmosphere through "air inlet" through chamber *F* and port l^1, upper inlet valve *86a* and ports *m* and m^1 into the upper end of the air cylinder above the air piston *66*.

Two-Stage Type. The Westinghouse two-stage air compressor, known as the "8½-inch cross-compound compressor", is controlled or operated by a valve gear quite similar to that used in the single-stage type. The following description covers in a general way the chief differences in the operation of the two types of compressors:

Comparison with Single-Stage Type. The cross-compound pump is coming into use as a result of the growing demand for more air on long freight trains. Its capacity is about three and one-half times that of the $9\frac{1}{2}$-inch pump shown in Fig. 4. As illustrated in Figs. 9 and 10, this pump is of the duplex type, having two steam

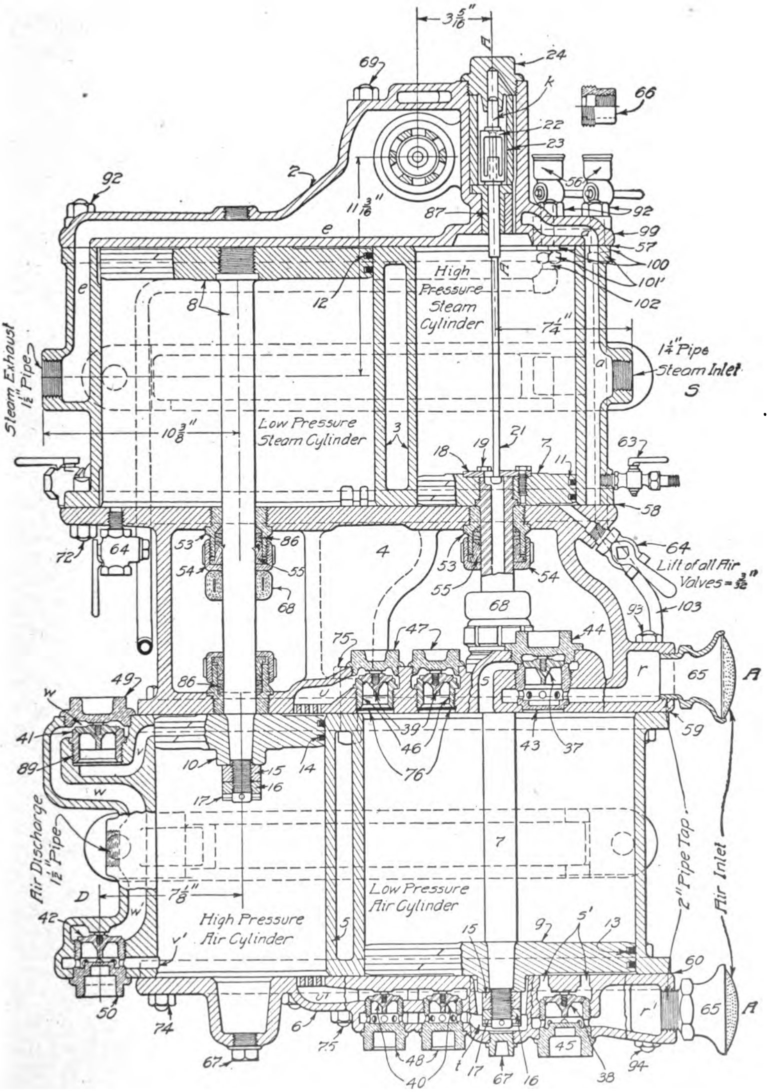


Fig. 10. Vertical Section of Westinghouse 8½-Inch Cross-Compound Compressor

and two air cylinders arranged with the steam cylinders above and the air cylinders below. The high-pressure steam cylinder is $8\frac{1}{2}$ inches in diameter, and the low-pressure $14\frac{1}{2}$ inches in diameter, both having a 12-inch stroke. The low-pressure air cylinder is 14½ inches in diameter, and is located under the high-pressure steam cylinder. The high-pressure air cylinder is 9 inches in diameter and is located under the low-pressure steam cylinder. The valve gear is

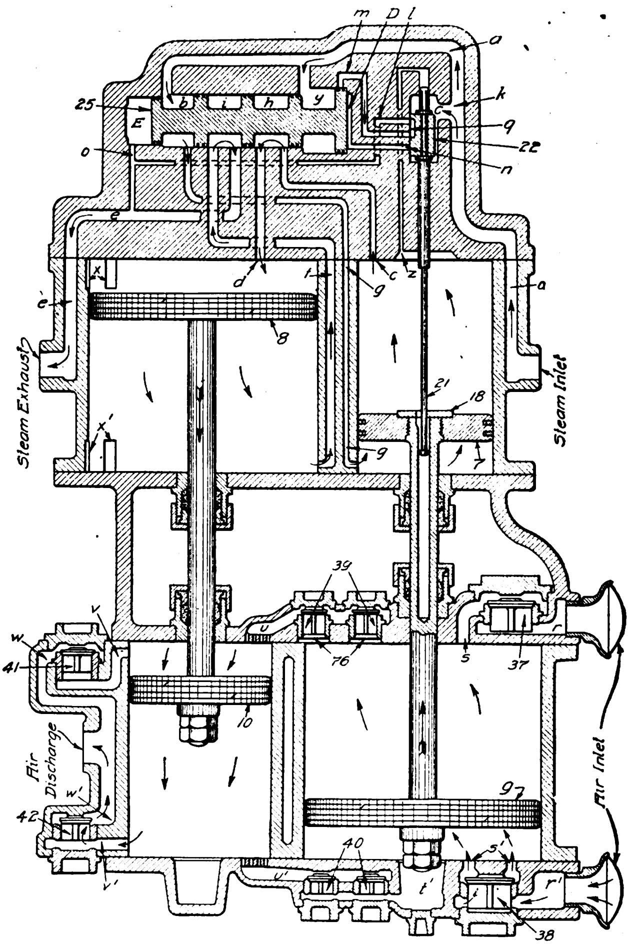


Fig. 11. Diagram of Westinghouse 8½-Inch Cross-Compound Compressor, Showing High-Pressure Steam (Low-Pressure Air) Piston on the Up-Stroke

located on the top head of the high-pressure steam cylinder and is very similar to that of the 9½-inch pump already described. Figs. 11 and 12 show diagrammatically a cross section through the pump, Fig. 11 showing the parts during an up-stroke of the high-pressure steam side, and Fig. 12 during a down-stroke of the high-pressure steam side. The high-pressure steam piston is shown on the right and the low pressure on the left. The high-pressure steam piston, with its hollow rod, contains the reversing-valve rod and operates

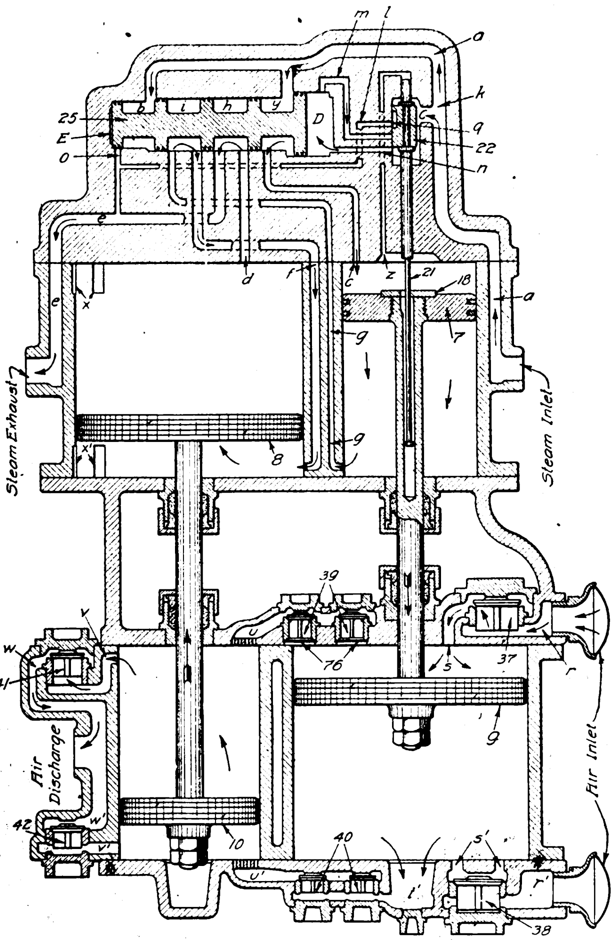


Fig. 12. Diagram of Westinghouse 8½-Inch Cross-Compound Compressor, Showing High-Pressure Steam (Low-Pressure Air) Piston on the Down Stroke

the reversing valve in the same manner as that of the 9½-inch pump. This valve operates the main valve in the same manner as that described in the case of the 9½-inch pump. The main slide valve controls the steam admission to, and the exhaust from, both the high- and the low-pressure steam cylinders. It is provided with an exhaust cavity and, in addition, has four steam ports in its face. The two outer and one of the intermediate ports communicate with cored passages extending longitudinally in the valve, which serve to make the connection between the high- and the low-pressure cylinders during the expansion of steam from one to the other. The other port controls the admission of steam to the high-pressure cylinder.

The valve seat has five ports. Of these, the two outside, shown in Figs. 11 and 12, lead to the upper and to the lower ends of the high-pressure steam cylinder. The second and fourth from the right lead to the upper and to the lower ends of the low-pressure steam cylinder; and the middle one leads to the exhaust. By following the arrows in Figs. 11 and 12, the flow of air and steam through the pump can be easily traced.

The principle of compounding employed in this pump enables it to compress air much more economically than is possible with the simple, or single-stage, compressor.

Special Air Strainer. The air strainer ordinarily furnished with compressors is simple and in many respects is entirely satis-

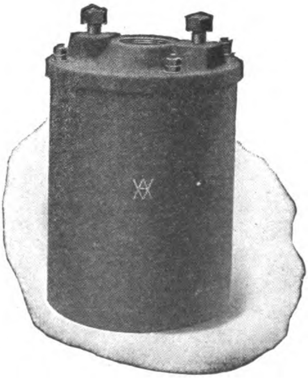


Fig. 12a. Westinghouse Special "Fifty-Four" Air Strainer

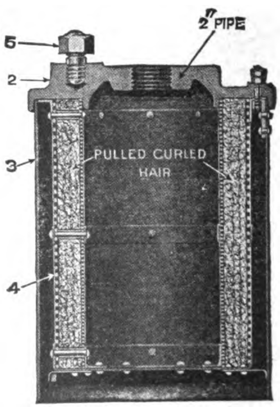


Fig. 12b. Sectional View of Westinghouse Special "Fifty-Four" Air Strainer

factory. But when a strainer of great capacity and efficiency is desired, the special "Fifty-Four" air strainer can be secured. This strainer is named from its relatively large suction area of 54 square inches. The outward appearance and general construction of this air strainer are illustrated in Figs. 12a and 12b.

The large capacity of this strainer permits the free passage of air at a low velocity without imposing additional work on the compressor. The dust, dirt, etc., are caught and held at the outer surface of the strainer proper and much of the foreign matter thus collected is jolted out as the locomotive moves along the track. The over-all dimensions are approximately 10 inches by 14 inches. It consists of an inner strainer of perforated galvanized sheet steel and an outer strainer of coarse galvanized wire mesh, the space between being well packed with curled hair. A galvanized sheet-iron shell *3*, Fig. 12b, surrounds the strainer proper and prevents clogging due to oil, water, etc., coming directly in contact with it. It is easily and quickly removed for cleaning and repairs without disturbing any of the pipe connections. This strainer should be installed in a vertical position with the open end downward. It can be bolted under the running board at some protected point where it can receive clean dry air. It should never be installed where a steam leak would saturate the intake air.

Air-Cylinder Lubrication. *Method.* Proper lubrication of the air cylinder is often neglected. However, for efficient operation this should receive careful attention. In ordinary installations to oil the air cylinder, open the oil cock (see oil cock *98*, Fig. 5) to blow out any dirt which may have collected, then close it and fill with valve oil and, on the down stroke of the piston, open the cock to allow the oil to be drawn into the cylinder. The cock should be closed before the beginning of the up stroke. This operation can be most easily carried out when the speed of the pump is moderate and the air pressure low. Valve oil only should be used in the air cylinder, as a lighter oil will not last and may prove dangerous. The use of a very heavy oil soon clogs and restricts the air passages and causes the compressor to labor and heat unduly. The amount of oil to use and at what intervals must be left to the judgment of the operator.

Non-Automatic Oil Cups. If too much oil is used, trouble may be experienced due to the oil passing into the system. To overcome this difficulty, the equipment furnished with the cross-compound compressors includes two non-automatic oil cups, one being connected to each air cylinder by means of suitable piping. The location and connection of these oil cups are shown in Figs. 9 and 10. A section of one of these cups is represented by Fig. 12c.

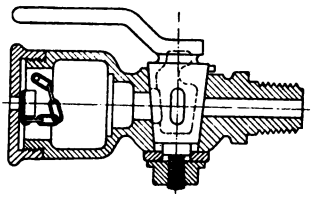


Fig. 12c. Non-Automatic Oil Cup

In the construction of this oil cup, a screen is provided, located in the bottom, which prevents any dirt in the oil from entering the cylinder. The oil cup is closed by a tight-fitting screw cap. When the handle is turned, a cavity in the plug cock which normally forms the bottom of the oil cup deposits a definite amount of oil in the air cylinder, at the same time preventing air pressure from reaching the oil chamber. To oil the cylinder, then, it is only necessary to fill the oil cup with valve oil, screw on the cap, and turn the handle up. With the handle turned up a small quantity of oil enters the cavity in the plug cock. Now, if the handle is turned down, the oil in the cavity finds its way into the cylinder. If more oil is desired, turn the handle up again to fill the cavity, then turn down to empty, and repeat as often as desired. A well-oiled swab on the piston rod is very essential.

Sight-Feed Lubricators. The great length of trains now being handled by many railroads calls for sustained performance on the part of the air compressors. For this reason many roads consider sight-feed lubricators for the air cylinders very essential. These are conveniently located in the cab and connected in the piping leading from the oil well of the locomotive lubricator to the compressor air cylinder. They are provided for single-compressor, two-compressor, and cross-compound-compressor installations.

In Fig. 12d is illustrated the scheme of attaching a double sight-feed lubricator. Such an installation gives the engineer complete control of the air-cylinder lubrication and reduces the amount of oil required to a minimum. In order to prevent compressed air from entering the oil pipe between the air cylinder and the lubricator, a ball check-valve connection is provided. The oil-delivery pipe from the lubricator to the air cylinders should run direct without any trap existing. The lubricator shown is of the non-self-closing type. When desired, a self-closing lubricator can be furnished which automatically closes as soon as the engineer removes his hand from the operating lever.

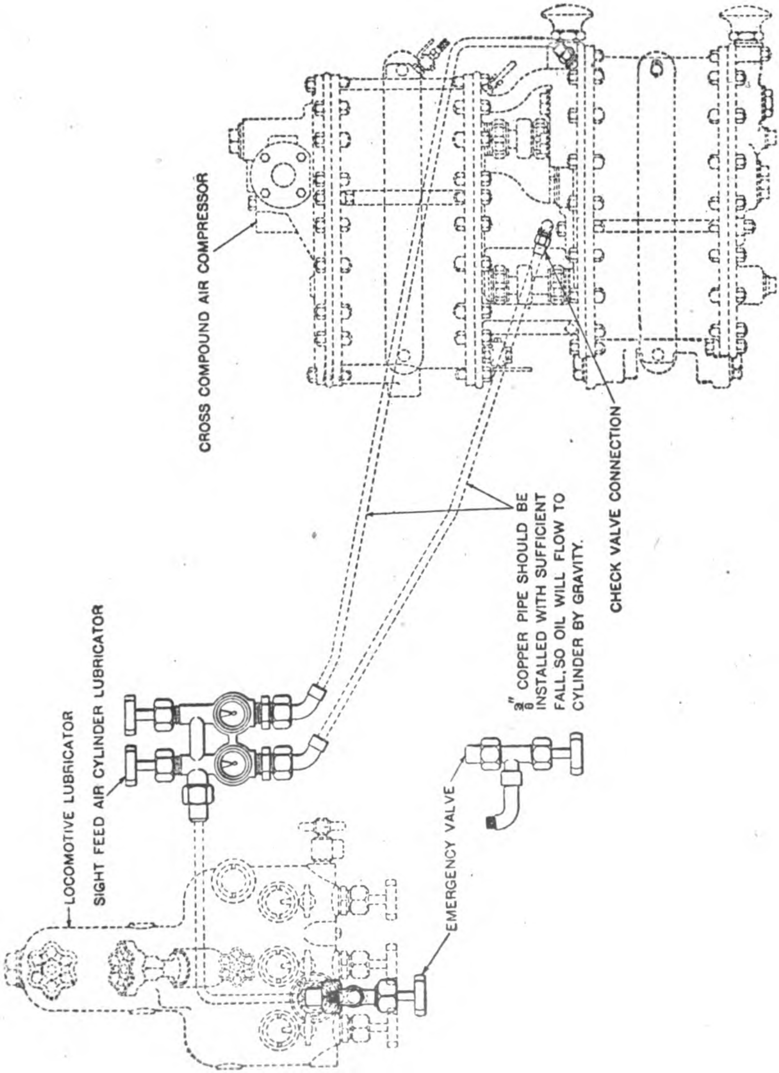


Fig. 12d. Diagram Showing Scheme of Connections for Sight-Feed Air-Cylinder Lubricator

Shop and Road Tests. *Test of Capacity of Compressors.* A recent ruling of the Interstate Commerce Commission for the inspection and testing of steam locomotives and tenders requires that the compressor or compressors shall be tested for capacity by means of the orifice method as often as conditions may require, but not less than once every three months. The $9\frac{1}{2}$-inch single-stage compressor must make not more than 120 single strokes per minute in maintaining a pressure of 60 pounds in the main reservoir against a $\frac{11}{64}$-inch orifice. The 11-inch single-stage compressor must make not more than 100 single strokes per minute in maintaining a main-reservoir pressure of 60 pounds against a $\frac{3}{16}$-inch orifice. The $8\frac{1}{2}$-inch cross-compound two-stage compressor must make not more than 100 single strokes per minute in maintaining a main-reservoir pressure of 60 pounds against a $\frac{9}{32}$-inch orifice. For altitudes of over 1000 feet, the speed of all types of compressors may be increased 5 single stokes per minute for each 1000 feet increase in altitude.

In making these tests the main reservoir should be drained and, after all valves are properly set, depending on the equipment being used, its connections tested for leakage. The pressure in the reservoir should be bled down to 62 or 63 pounds and sufficient time given for the temperatures to become equalized and the pressure to reduce to 60 pounds. From this point the time and pressure drop should be taken. The drop in pressure should not exceed 2 pounds during one minute. If it exceeds this amount, the test should not be made until the leakage has been reduced to this limit.

The small disc containing the orifice can be used with any suitable holder, which can conveniently be attached to the main-reservoir drain cock with as short a connection as possible. The gage for indicating the pressure on the orifice should be connected between the orifice and reservoir. When all is in readiness the compressor should be started and the pressure in the main reservoir raised to slightly below 60 pounds. At this point the drain cock to the orifice should be opened and the steam supply to the compressor regulated until the pressure on the gage near the orifice reads 60 pounds. The single strokes per minute made by the compressor should then be counted. If the number of single strokes per minute do not fall within the limit specified by the Interstate Commerce Commission for the particular type of compressor being used, then the compressor should be rejected and returned to the shop for repairs.

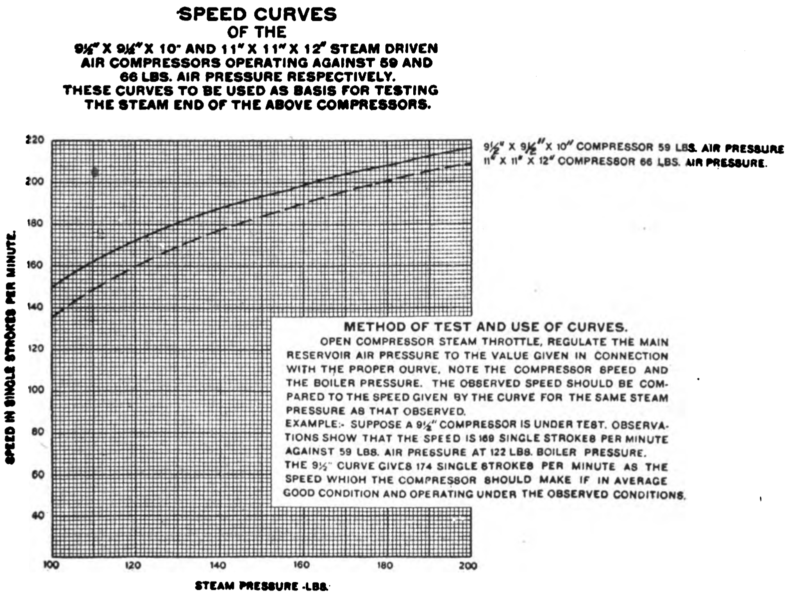


Fig. 12e. Test Curves of 9½-Inch and 11-Inch Single-Stage Compressors

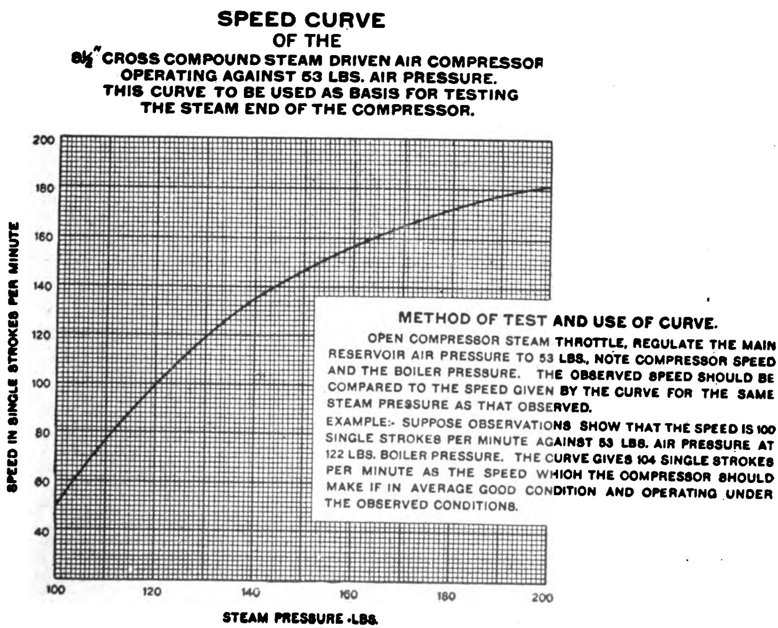


Fig. 12f. Test Curve of 8½-Inch Cross-Compound Two-Stage Air Compressor

Steam Economy Tests. The Interstate Commerce Commission makes no ruling concerning tests of the steam end of the compressor In many cases the steam end needs investigating to determine whether or not the efficiency of the compressor as a whole is lower than warrants continuing it in service or, after having received repairs, if it is in proper condition to be returned to service.

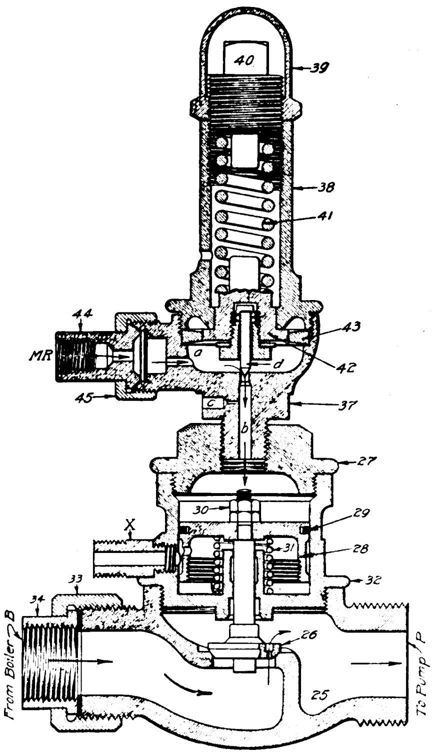


Fig. 13. Westinghouse Type "S" Single-Top Steam Compressor Governor Closed

It is not always convenient in repair shops to conduct steam economy tests on compressors and as a substitute the Westinghouse Air Brake Company offers the method as explained in Figs. 12e and 12f. The test results given in these curves were secured from a number of compressors considered to be in good average operating condition. The Westinghouse Company states that if the condemning limit for the steam end has been set at 75 per cent of the performance of a compressor in good average condition, then the speed of the compressor should be not less than 75 per cent of the speed called for by the curve at a point corresponding to the particular condition of steam pressure under which the compressor was tested. The curves referred to above are self-explanatory.

Steam Compressor Governors. The steam compressor governor, sometimes called the air-pump governor, is used, as the name implies, for governing the air pump or compressor, causing it to stop operation when it has compressed the air in the main reservoir to a certain predetermined pressure and to resume operation when the pressure has dropped below this point.

Single Top "S" Type. This governor is located in the steam supply pipe close to the air compressor. Figs. 13 and 14 show the governor in closed and open positions. When in operation steam enters at *B* and flows past the steam valve *26*, when open, to the pump at *P*. The governor is operated by air pressure from the main reservoir, which is always open to the connection *MR* and the underside of the diaphragm *46* through a small pipe leading from the main reservoir pipe near the engineer's brake valve shown in Fig. 1. As long as the main-reservoir pressure in chamber *a* below diaphragm *46* is not able to overcome the pressure of spring *41*, acting on the top of the diaphragm, spring *41* holds the diaphragm *46* down and thereby holds the small pin valve *d* to its seat. The chamber above the governor piston *28* is open through passage *b* and the small relief port *c* to the atmosphere, which permits spring *31* below piston *28* to hold the latter and the attached steam valve *26* in the open position.

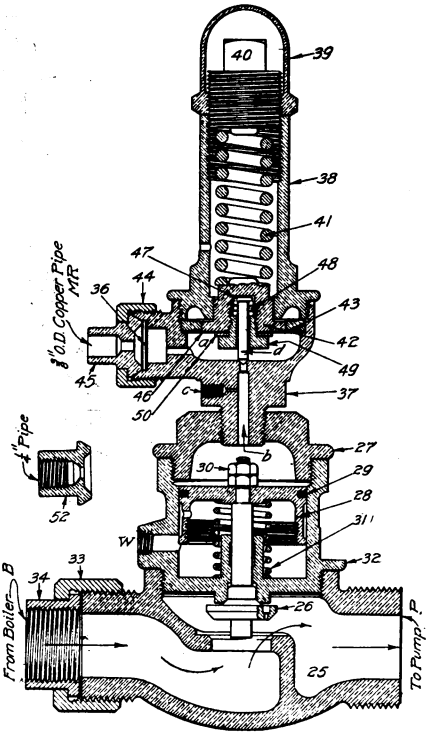


Fig. 14. Westinghouse Type "S" Single-Top Steam Compressor Governor Open

When the main-reservoir pressure in chamber *a* below diaphragm *46* becomes slightly greater than the spring pressure above the diaphragm, the diaphragm is raised, unseating pin valve *d* and allowing air from chamber *a* to flow through passage *b* to the chamber above piston *28*. This forces piston *28* down to the closed position, compressing piston spring *31* and seating steam valve *26*, thus cutting off the supply of steam to the air compressor, except for the slight amount which can pass through the small port shown in steam valve *26*. This is just sufficient to keep the compressor operating slowly so as to supply the air leakage and avoid troubles from steam condensation.

The chamber below piston *28* is open to the atmosphere through the drip-pipe connection on the left. This is to permit

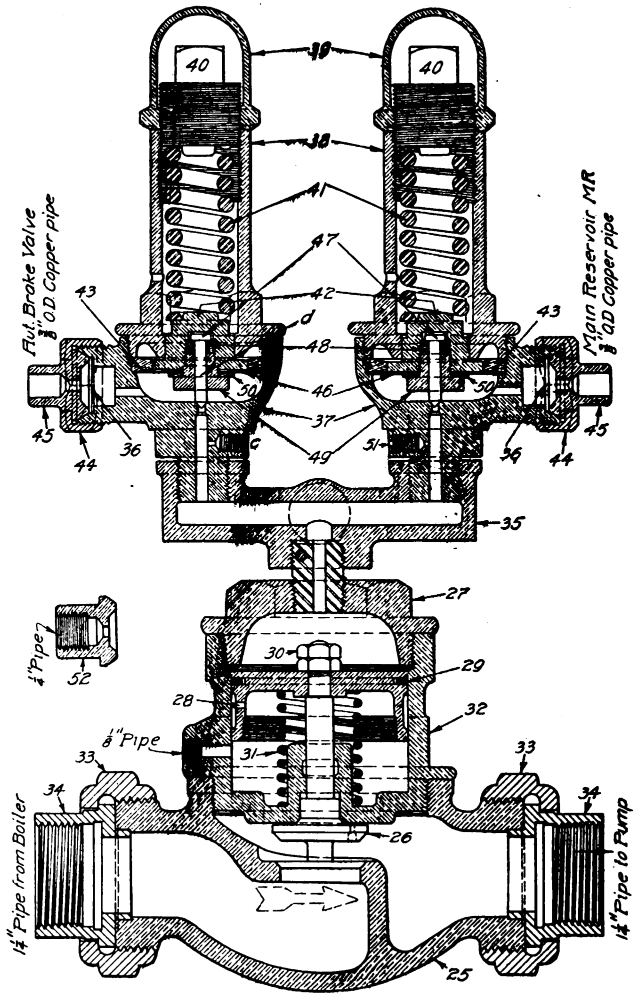


Fig. 15. Westinghouse Type "SD" Duplex Steam Compressor Governor Shown in Section

the escape of any steam that may leak past the stem of valve *26* or air that may leak past piston *28*. To avoid troubles from freezing and stopping up, the drip pipe should be as short as practicable.

The governor is adjusted by means of adjusting nut *40*, which regulates the pressure of spring *41* upon the diaphragm. To change the adjustment of the governor, remove cap nut *39* and screw down or back off regulating nut *40* to increase or lower the main-reservoir pressure, replacing nut *39* after making this adjustment. The governor is usually set to cut off at 90 pounds main-reservoir pressure.

For years the "S" governor was the standard but it has practically been superseded by governors of improved design.

Double-Top or Duplex "SD" Type. This type of governor has been developed to operate in connection with the engineer's brake valve, permitting the air pump to anticipate demands upon the main reservoir and to have an excess pressure stored there for releasing brakes and charging trains of greater length than the usual main-reservoir capacity will permit. It is arranged to obtain what is known as "duplex main-reservoir regulation". As shown in Fig. 15, the "duplex" governor is the same as the "S" type of governor except that two regulating portions or "tops" are used, with a **T** or "Siamese" fitting to connect them to the steam portion of the governor. The adjustment of the two heads varies according to local conditions, but is usually 90 pounds for the "low-pressure" and 120 pounds for the "high-pressure" top.

The low-pressure top, on the left, is connected to a port in the brake valve through which air from the main-reservoir port flows to the feed valve when the brake-valve handle is in *running* position. When running over the road, therefore, with the brakes released, the low-pressure top of the governor controls the operation of the air compressor in the same manner as has been described for the "S" type of governor, and the high-pressure top does not operate at all. When an application of the brakes is made, however, the relation of the brake-valve ports is changed so as to shut off the supply of air to the underside of the diaphragm of the low-pressure governor top, and its pin valve *d* remains held to its seat. Meanwhile, air from the main-reservoir pipe can flow direct to the connection marked *M R* of the high-pressure governor top and to the chamber beneath its diaphragm. This governor top will consequently control the operation of the air compressor as described for the "S" type of governor until the brakes are released and the brake-valve handle again placed in *running* position. Only one vent port *c* should be open, the other being plugged by a small screw *51*, as shown in Fig. 15. This arrangement permits

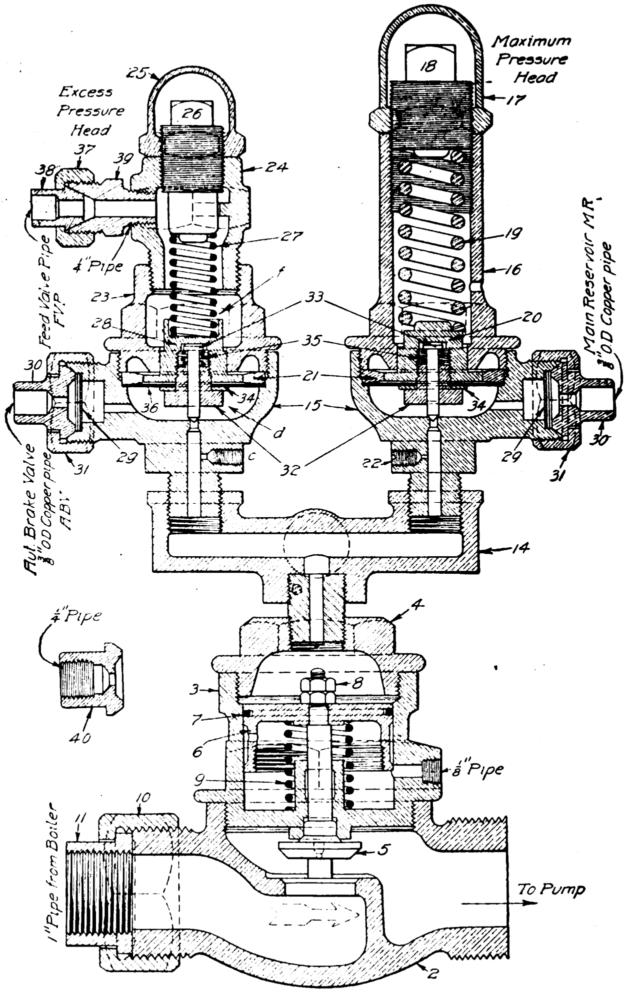


Fig. 16. Westinghouse Type "SF" Duplex Steam Compressor Governor Shown in Section

the compressor to operate while the brakes are released against a comparatively low but ample main-reservoir pressure. This requires it to operate against the maximum main-reservoir pressure only during the time that the brakes are applied.

Double-Top "SF" Type. The principal difference between the "SD" and "SF" types is in the arrangement of the low-pressure head, or, as it is called in the "SF" governor, the "excess-pressure" head, Fig. 16. The low-pressure head of the "SD" governor is arranged to maintain a fixed main-reservoir pressure during the times that the brakes are released, while the excess-pressure head of the "SF" governor maintains a fixed "excess" of main-reservoir pressure over the brake-pipe pressure under the same conditions. The high- or maximum-pressure heads of both types are alike.

The excess-pressure head of the "SF" governor has two air connections. That marked *ABV* corresponds to the similar connection of the "SD" governor. That marked *FVP* leads from the feed-valve pipe, so that air, at whatever pressure the feed valve is adjusted for, is always present in chamber *f* above diaphragm *28*. The total pressure on the top of diaphragm *28* is, therefore, the pressure in the feed-valve pipe plus the pressure of spring *27*, which is usually adjusted for 20 pounds. The main-reservoir pressure in chamber *d* below diaphragm *28* will, therefore, not be able to raise the diaphragm and its pin valve, and thus shut off the compressor, until it has risen about 20 pounds above the pressure determined by the feed-valve setting. Consequently, whether the setting of the feed valve be changed by accident or design, the same excess pressure, 20 pounds, is always maintained. In the operation of the steam and air pistons of the governor, the total pressure on top of diaphragm *28* is always feed-valve pressure plus 20 pounds instead of a fixed pressure, as in the former types. With the feed valve set for 70 pounds, about 90 pounds main-reservoir pressure would be maintained.

Main Reservoir. The use of the main reservoir is for storing an abundant air supply to be used in charging and releasing the brakes. The main reservoir should have a capacity of not less than 35,000 cubic inches on passenger engines and not less than 50,000 cubic inches on freight. The main reservoir is usually placed on the engine but sometimes on the tender, the latter necessitating two extra pipe connections between the engine and the tender, which is not good practice. To divide the main reservoir and place half on each side under the running board is better.

The air is then delivered to one side and taken out of the other, the two reservoirs being connected. This system has two decided advantages over the others, one being that the air is cooled, thus causing the moisture to be collected in the reservoir. The other advantage is that the distance between the inflow and out-take prevents much of the dirt and oil from being carried into the brake pipe. The main reservoir should always be drained after each trip is completed.

VALVES AND VALVE APPLIANCES

AUTOMATIC BRAKE VALVES

Several types of automatic brake valves, or engineer's brake valves, have been developed and are now in use on American railroads. The one most commonly met with is that known as the "G-6" type. It is now found in use on most locomotives not equipped with what is known as the "ET" equipment.

"G-6" Automatic Brake Valve. The general construction of the "G-6" brake valve is illustrated in Figs. 17, 18, and 19. It is of the rotary type, and is connected as shown in Figs. 1, 2, and 3. Air from the main reservoir flows to the chamber above the rotary valve and, by means of a pipe leading from the brake-valve connections, to the duplex air gage (red hand) and compressor governor. It has pipe connections to the main-reservoir pipe, brake pipe, equalizing-reservoir pipe, gage (red hand, main reservoir) and governor pipe, and gage (black hand, brake pipe) pipe. All of these connections are clearly shown in Figs. 18 and 19. There are five different positions of the brake-valve handle as indicated in Fig. 19. Beginning from the left and naming them in order they are as follows: *release*, *running*, *lap*, *service-application*, and *emergency-application* positions.

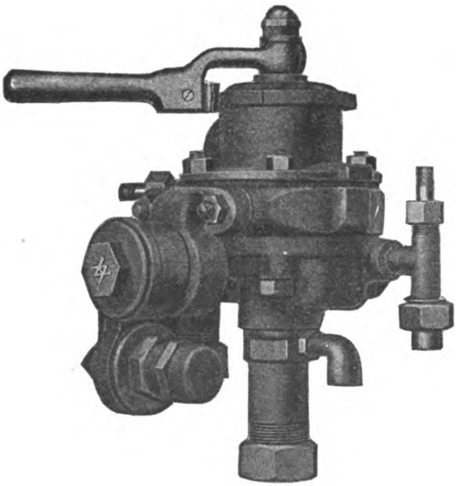


Fig. 17. "G-6" Automatic Brake Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

In describing the operation of the brake valve when the handle is placed in any of the five different positions, reference will be made to the diagrammatic views shown in Figs. 20, 21, 22, 23, and 24.

Running Position. In charging the system, compressed air flows from the main reservoir to the brake valve, entering it through passage *A*, Fig. 20, and flowing to chamber *A* above the rotary valve (see cross section of brake valve, Fig. 18). Port *j* through

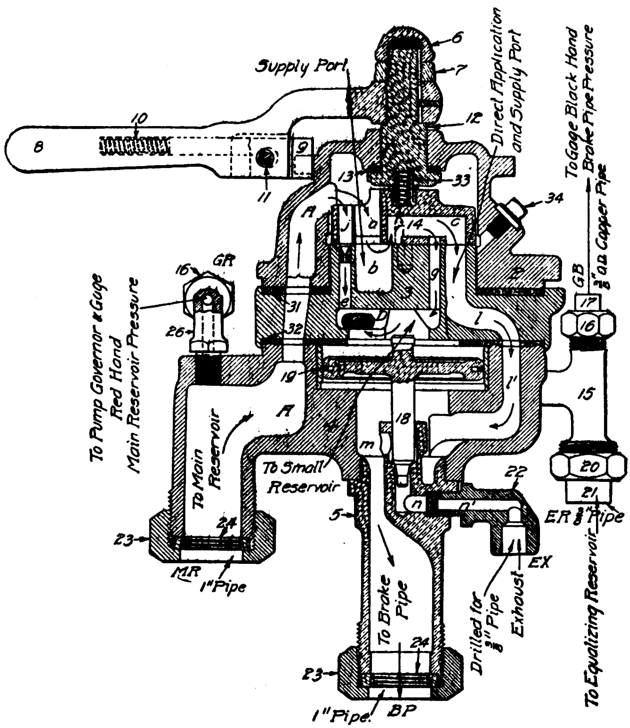


Fig. 18. Westinghouse "G-6" Brake Valve in Release Position

the rotary valve registers with port *f* in the seat, allowing air to flow to the feed valve, which is attached directly to the brake valve as shown. The feed valve reduces the pressure of the air from that carried in the main reservoir to that which is to be carried in the brake pipe. From the feed valve the air re-enters the brake valve through port *i*, which has two branches.

One branch leads to port *l* in the seat through which the air flows to the cavity *c* in the rotary valve, thence to the equalizing port g in the seat, and through this to the chamber D above the equalizing piston in the lower part of the brake valve.

Chamber D is connected through port s and pipe connections, as shown, to the qualizing reservoir.

The purpose of the equalizing reservoir is to furnish a volume to chamber D above the equalizing piston larger than could be permissible within the brake valve proper.

From the equalizing-reservoir pipe a connection is made to

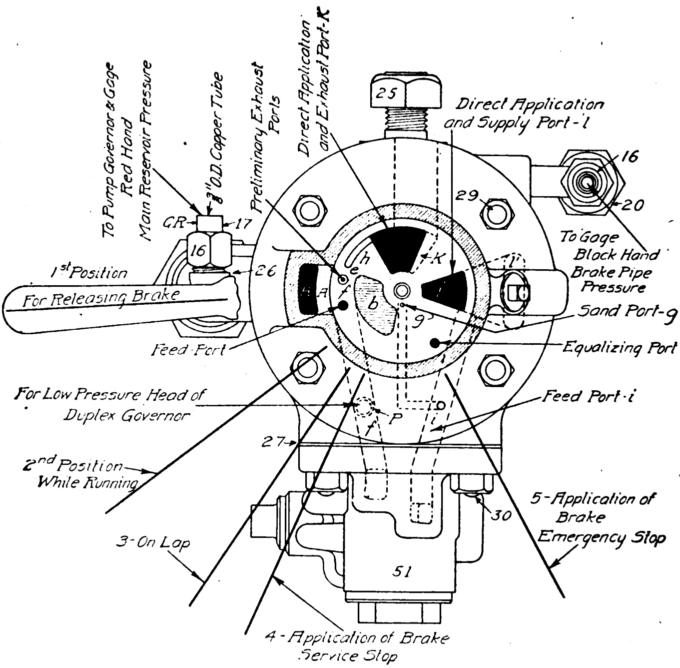


Fig. 19. Westinghouse "G-6" Automatic Brake Valve, Shown in Plan

the *black hand* of the duplex air gage, which registers the pressure in chamber D and the equalizing reservoir.

The other branch of port i leads from the feed valve to the brake-pipe connection at Y and to the underside of the equalizing piston. With the brake handle in *running* position, the feed valve maintains a constant pressure—usually 70 pounds is carried in freight service—in the brake pipe and on the underside of the equalizing piston as well as the same pressure in chamber D and the upper side of the piston. The equalizing-discharge valve m is kept on its seat, due to the fact that, while the pressure on the opposite sides of the piston is equal, the area of the upper side is greater by an amount equal to the area of the equalizing-discharge valve spindle.

During the time the brake-valve handle is in *running* position, air flows from the main reservoir through the brake valve and the

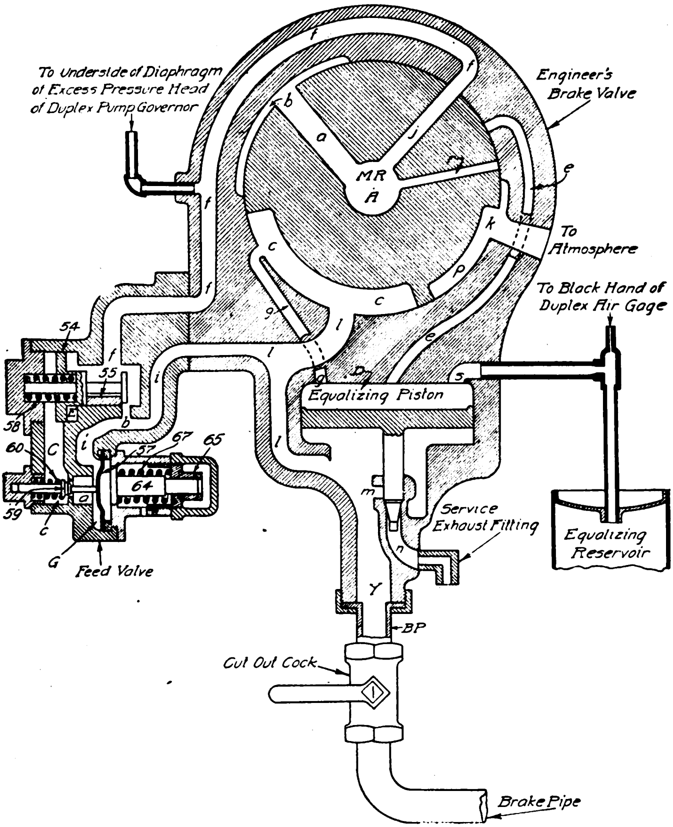


Fig. 20. Horizontal Section of Westinghouse Brake Valve, Showing Running Position

feed valve into the brake pipe, keeping the train charged, which is the normal condition of the brake system while a train is running over the road and the brakes are not being used.

Application Position. To apply the brakes in service, the brake-valve handle is moved to *service-application* position, which will permit of a brake-pipe reduction. This cuts off all air supply to the brake pipe and equalizing reservoir, as shown in Fig. 21, and opens the small port *e* called the preliminary exhaust port, leading to chamber *D* and the equalizing reservoir. This permits air to escape from above the equalizing piston through port *e* in

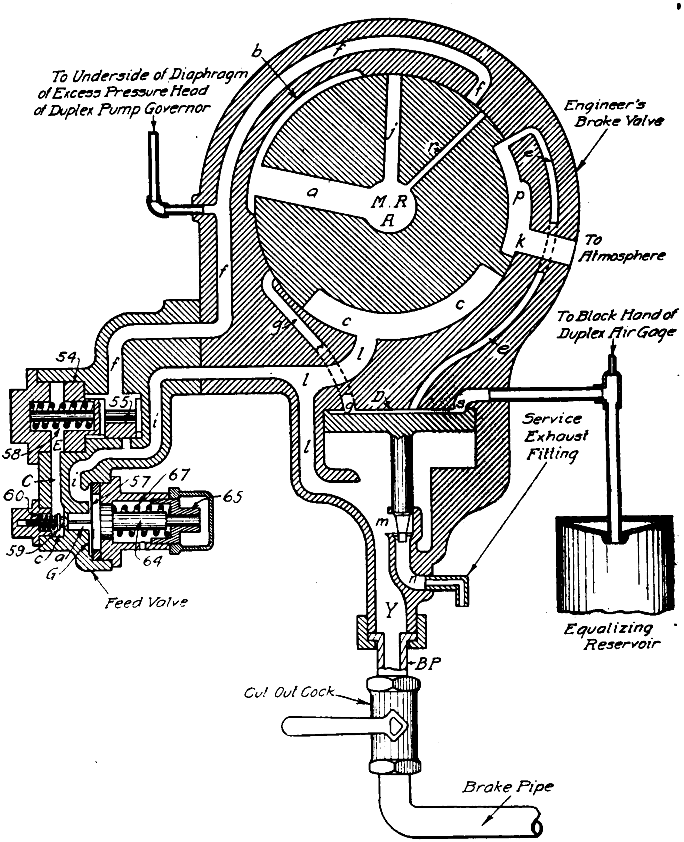


Fig. 21. Horizontal Section of Westinghouse Brake Valve, Showing Service Position

the rotary valve seat, cavity *p* in the rotary valve, and the direct application and exhaust port *k* to the atmosphere. This reduces the pressure of the air on top of the equalizing piston below the pressure of the air in the brake pipe under the piston. This condition causes the piston to lift, carrying the equalizing-discharge valve from its seat and allowing air from the brake pipe to escape through the opening m past the valve and thence through passage n and service exhaust fitting into the atmosphere.

Without the equalizing reservoir the pressure in chamber D would drop almost instantly to zero, and consequently it would be nearly impossible to make a moderate brake-pipe reduction. With an

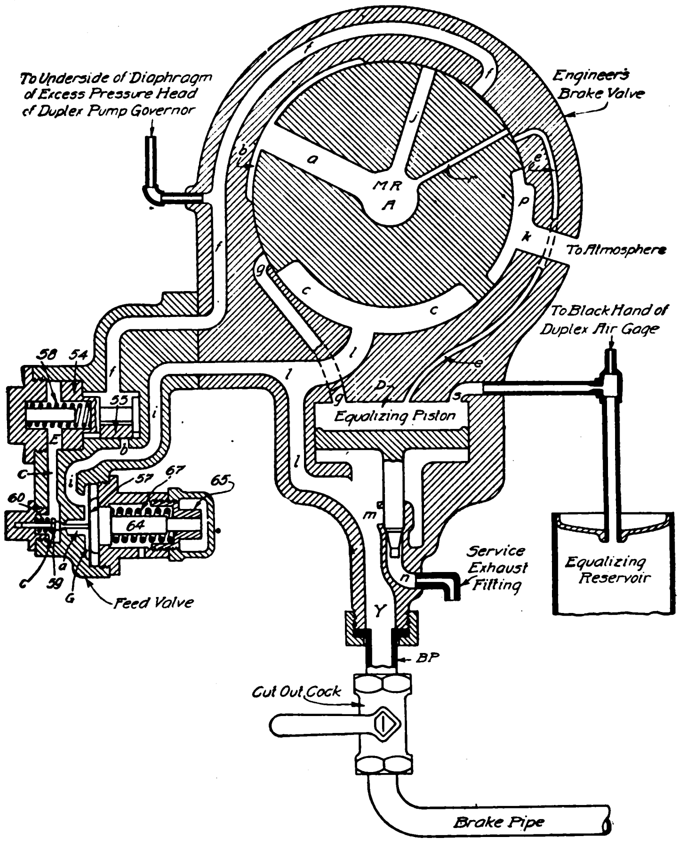


Fig. 22. Horizontal Section of Westinghouse Brake Valve, Showing Lap Position

equalizing reservoir of sufficient capacity, it takes 6 to 7 seconds to make a reduction of 20 pounds, which is slow enough to permit of the reduction to be stopped at any desired point as indicated by the air gage by moving the brake-valve handle to *lap* position.

When the equalizing-discharge valve lifts, the discharge of air from the brake pipe is rapid, decreasing in amount slowly as the pressure in the brake pipe approaches the pressure in chamber *D*, and the equalizing piston causes the equalizing-discharge valve to close, stopping further discharge of air from the brake pipe. This gradual stopping of the brake-pipe discharge prevents the air from surging in the brake pipe, a condition which tends to cause

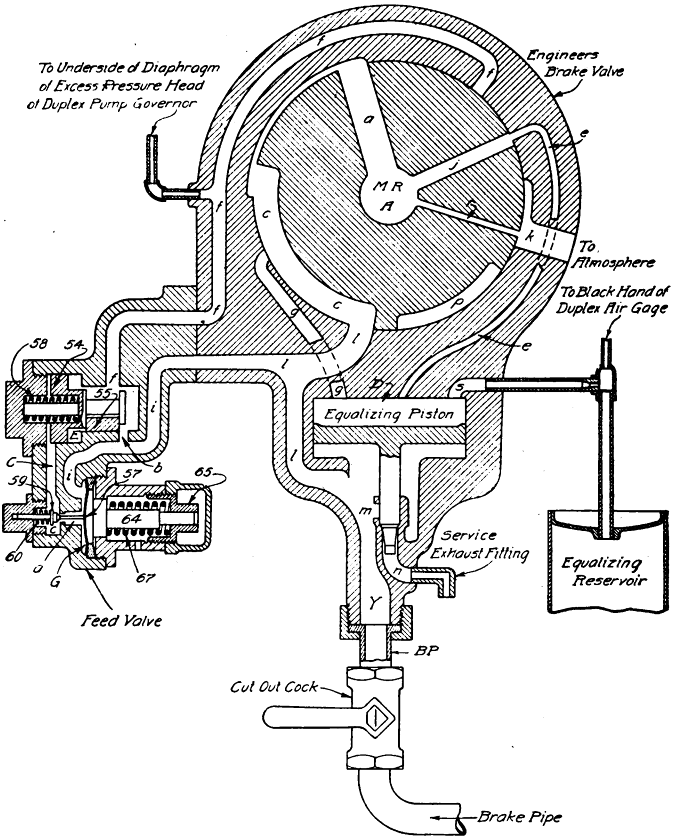


Fig. 23. Horizontal Section of Westinghouse Brake Valve, Showing Release Position

an undesired movement of the triple-valve pistons, which might cause some of the head brakes to release.

The length of time that the air will continue to discharge from the brake pipe after the brake-valve handle has been placed in *lap* position depends upon whether the train is a long or short one. With a short train, the brake-pipe volume is small and will not take as long to discharge as in the case of a long train where the brake-pipe volume is great. It can be readily seen that the equalizing reservoir, together with the equalizing piston, is nothing more than an automatic means of measuring the amount of air to be discharged from the brake pipe and to govern the rate of flow to the atmosphere.

Lap Position. Lap position of the brake valve, as illustrated in Fig. 22, prevents the movement of air to or from any part of the brake equipment through the brake valve.

This position of the brake-valve handle on locomotives equipped with either type of governor previously described causes the low-pressure, or the under, side of the diaphragm in the excess-pressure head to become inoperative, due to the feed valve being cut off from the main reservoir. What air under pressure is left in the feed valve escapes through the vent port in the governor. This permits the compressor to pump up a supply of air under high pressure in the main reservoir to insure a quick release and recharge of the brake pipe.

Lap position is the holding position—the position used when it is desired to hold the brake applied for any considerable length of time.

Release Position. The brakes in the train are released by placing the brake-valve handle in *release* position. This opens direct communication through the brake valve between the main reservoir and the brake pipe, increasing the pressure in the brake pipe and releasing the brakes throughout the train.

When the brake valve is in *release* position, as shown in Fig. 23, air from the main reservoir flows through port *a* in the rotary valve to cavity *b* in its seat, then through cavity *c* in the rotary valve to port *l*, and thence directly into the brake pipe. At the same time, air in cavity *c* also flows through the equalizing port *g*, to chamber *D* above the equalizing piston and to the equalizing reservoir. Air also flows from the main reservoir through port *j* in the rotary valve into the preliminary-exhaust port *e* and to chamber *D*.

While in the *release* position, air from the main reservoir flows through the warning port *r* in the rotary valve to the direct application and exhaust port *k* and the atmosphere with considerable noise. This loud exhaust indicates to the engineer that the handle of the brake is in *release* position and attracts his attention in case the handle is left in that position by mistake.

After the handle has been in *release* position the proper length of time, it is moved to the *running* position, which closes the warning port, stops the direct flow of air from the main reservoir to the

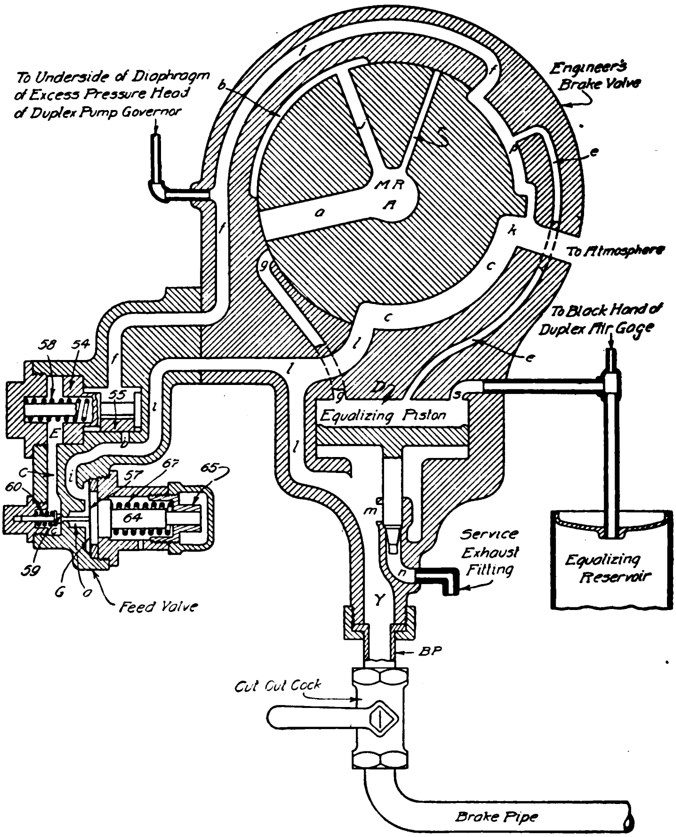


Fig. 24. Horizontal Section of Westinghouse Brake Valve, Showing Emergency Position

brake pipe, chamber *D*, and the equalizing reservoir, and opens the supply of air to these parts through the feed valve. In this position, the brake pipe, chamber *D*, and the equalizing reservoir are charged up and maintained at the standard pressure by the feed valve.

The brakes can be released and the brake pipe and system re-charged by placing the brake-valve handle in *running* position directly without first being placed in *release* position, but a much longer time will be required.

Emergency-Application Position. When it is desired to make the shortest possible stop, the brake-valve handle is placed in *emergency* position, as illustrated in Fig. 24. In this position the brake pipe is opened directly to the atmosphere through the large port *l*, cavity *c*, and port *k*, causing a sudden and rapid drop in brake-pipe pressure. In this position, cavity *p* in the rotary valve connects

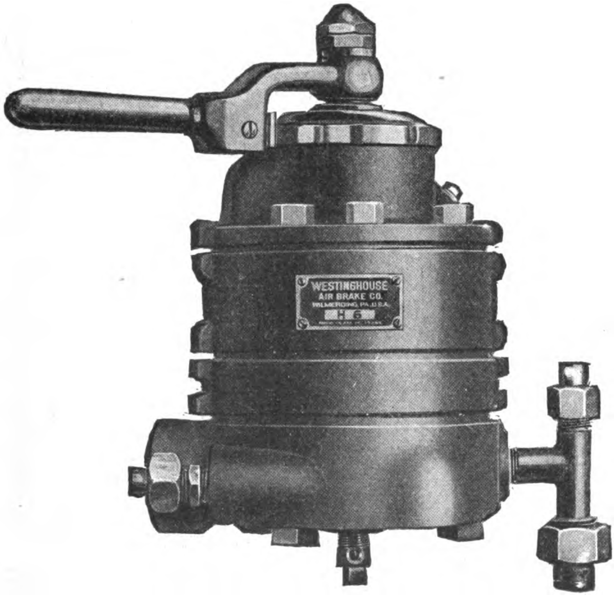


Fig. 25. "H-6" Automatic Brake Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

the feed port *f* and the preliminary exhaust port *e* to the exhaust port *k*, thus allowing the air in the feed port, chamber *D*, and the equalizing reservoir to escape to the atmosphere. The whole *emergency-application* action depends solely upon the suddenness of the brake-pipe reduction.

"H-6" Automatic Brake Valve. The "H-6" automatic brake valve not only performs the functions of the "G-6" brake valve but has some additional features necessary for its use in connection with the "No. 6" distributing valve and the "S-6" independent brake valve of the "ET" locomotive-brake equipment. In this brake valve, the feed valve is not directly attached to the body of the valve but is located elsewhere in a convenient place and connected by suitable pipes. Its general appearance is shown in Fig. 25, while Fig. 26 shows two views, the upper one being a horizontal section through the top case, showing the rotary valve seat, also showing the different positions of the handle, the lower one being a vertical section.

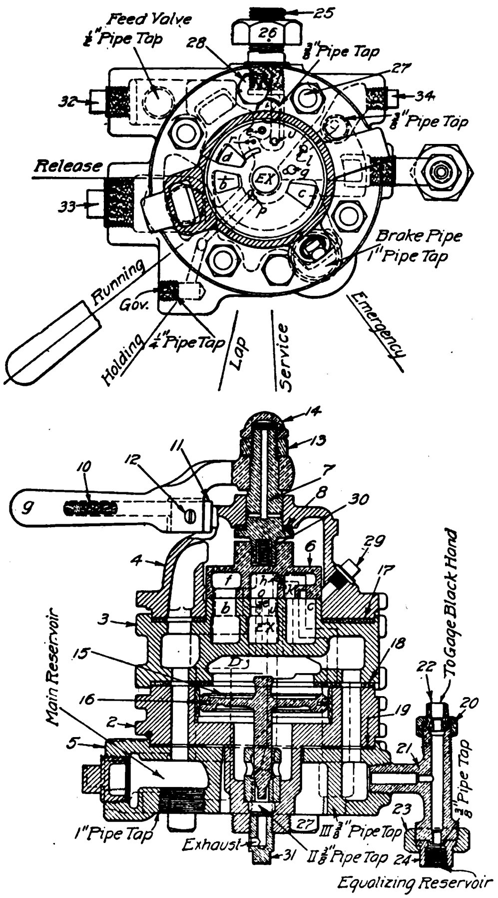


Fig. 26. Plan and Sectional Elevation of Westinghouse "H-6" Automatic Brake Valve

In describing the operation of the brake valve, the different positions will be taken up in the order in which they are most generally used. As shown in Fig. 26, there are six positions for the brake-valve handle. Beginning from the extreme left, they are: *release, running, holding, lap, service,* and *emergency.* In the operation of the valve the air flows through ports in a manner quite similar to that of the "G-6" brake valve. For this reason, the flow of air through the "H-6" brake valve, with the handle in its different positions, will not be traced.

Release and Charging Position. The purpose of this position is to provide a large and direct passage from the main reservoir to the brake pipe, to permit a rapid flow of air into the latter (1) to charge the train brake system; (2) to quickly release and re-charge the brake; but (3) not to release the locomotive brakes if they are applied. If the handle is allowed to remain in this position, the brake system would be charged to main-reservoir pressure. To avoid this, the handle must be moved to *running* or holding position. To prevent the engineer from forgetting this, a small port discharges feed-valve-pipe air to the atmosphere in release position.

Running Position. This is the proper position of the brake-valve handle (1) when the brakes are charged and ready for use; (2) when the brakes are not being operated; and (3) to release the locomotive brakes. This position affords a large direct passage from the feed-valve pipe to the brake pipe, so that the latter will charge up to the pressure for which the feed valve is adjusted.

If the brake valve is in *running* position when uncharged cars are cut in, or if, after a heavy brake application and release, the handle of the automatic brake valve is returned to *running* position too soon, the governor will stop the compressors until the difference between the hands on duplex gage No. 1, Fig. 92, is less than 20 pounds. The stopping of the compressor from this cause calls the engineer's attention to the seriously wrong operation on his part, as *running* position results in delay in charging and is liable to cause some brakes to stick. *Release* position should be used until all brakes are released and nearly charged.

Service Position. This position gives a gradual reduction of brake-pipe pressure to cause a *service application.* The gradual reduction of brake-pipe pressure is to prevent quick action, and the gradual stopping of this discharge is to prevent the pressure at the head end of the brake pipe being built up by the air flowing from the rear, which might cause some of the head brakes to "kick-off".

Lap Position. This position is used while holding the brakes applied after a service application until it is desired either to make a further brake-pipe reduction or to release the brakes. All ports are closed and the excess-pressure head of the governor is made inoperative, permitting the pump to increase the main-reservoir pressure to the pressure at which the high-pressure head will cause it to stop.

Release Position. This position is used for releasing the train brakes after an application without releasing the locomotive brakes.

When the brake-pipe pressure has been increased sufficiently to cause this, the handle of the brake valve should be moved to either *running* or *holding* position; the former when it is desired to release the locomotive brakes, and the latter when they are to be still held applied.

Holding Position. This position is so named because the locomotive brakes are held applied while the train brakes are being released and their auxiliary reservoirs recharged to feed-valve pressure. The only difference between the *running* and *holding* positions is that in the former the locomotive brakes are released, while in the latter they are held applied.

Emergency Position. This position is used (1) when the most prompt and heavy application of the brakes is required, and (2) to prevent loss of main reservoir air and insure that the brakes remain applied in event of a burst hose, a break-in-two, or the opening of a conductor's valve. Plug *29*, Fig. 26, is placed in the top of the case at a point to fix the level of an oil bath in which the rotary valve operates. Valve oil should be used.

"S-6" Independent Brake Valve. The general appearance of this valve is shown in Fig. 27. Fig. 28 shows two views of the "S-6" brake valve; the lower one being a vertical section through the center of the valve, and the upper one a horizontal section through the valve body, showing the rotary valve seat and the different positions of the valve handle. There are five positions of the brake-valve handle which, beginning from the extreme left, are: *release, running, lap, slow application,* and *quick application.*

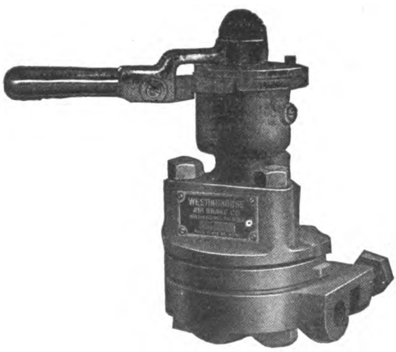


Fig. 27. Westinghouse "S-6" Independent Brake Valve

This brake valve is used in connection with the "H-6" automatic brake valve and is to permit the engineer to operate the locomotive or independent brakes through the distributing valve independently of the train brakes.

Running Position. This is the position that the independent brake valve should occupy at all times when the independent brake is not in use. It can be noted that if the automatic brake valve is in running position and the independent brakes are being operated, they can be released by simply returning the independent valve to

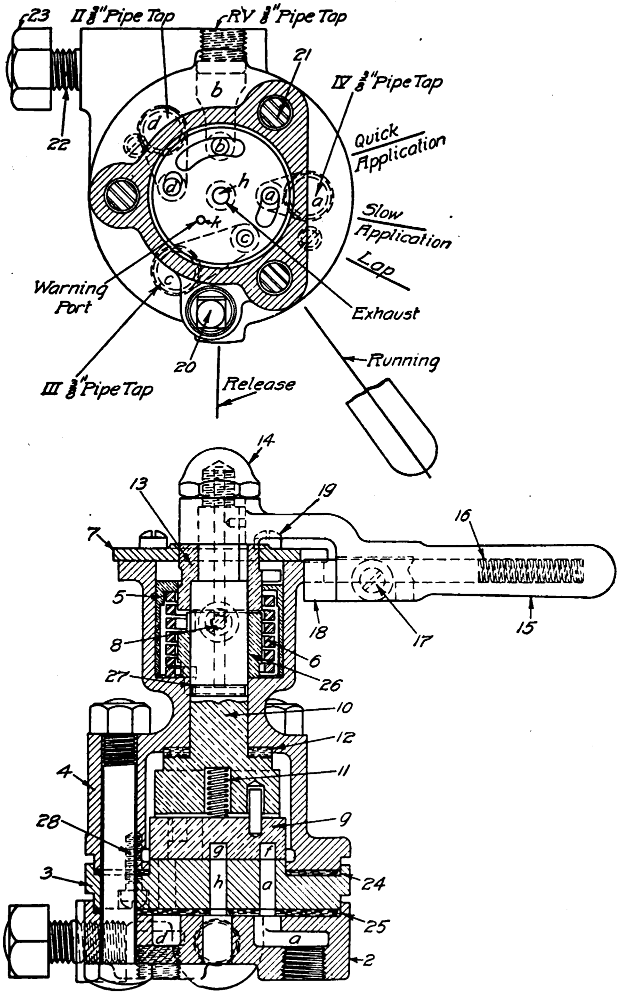


Fig. 28. Plan and Sectional Elevation of Westinghouse "S-6" Independent Brake Valve

running position, as the application-cylinder pressure can then escape through the release pipe and the automatic brake valve.

Slow-Application Position. This position is used for light or gradual applications of the independent or locomotive brake.

Quick-Application Position. This position is used for quick applications of the independent or locomotive brake.

Lap Position. This position is used to hold the independent or locomotive brake after the desired cylinder pressure is obtained. In this position all communication between ports is closed.

Release Position. This position is used to release the pressure from the application cylinder when the automatic brake valve is not in *running* position.

The supply pressure in the independent brake valve is limited by a reducing valve to 45 pounds. Connected to the handle of

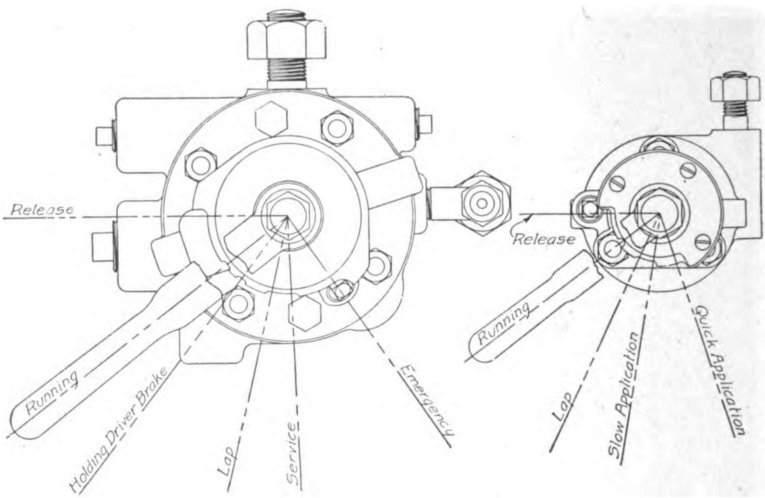


Fig. 29. Diagrams Showing Positions of Valve Handles for Westinghouse Automatic and Independent Brake Valves

the independent brake valve is a return spring, the purpose of which is to return the handle from the *release* to the *running* position, or from the *quick-application* to the *slow-application* position. The automatic return from *release* to *running* is to prevent leaving the handle in that position and make it impossible to operate the independent brake by the automatic brake valve. The spring return from *quick application* to *slow application* is to give a resistance to unintentional moving of the valve handle to *quick-application* position when only a slow application is desired.

The operation of the "H-6" and "S-6" brake valves will be studied further in connection with the study of the "ET" equipment.

The plan view of both the "H-6" and "S-6" brake valves shown in Fig. 29 presents a little more clearly the different positions of the brake-valve handles.

Duplex Air Gage. The duplex air gage previously referred to is located on a convenient place in the cab in plain view of the engineer. In the ordinary equipment only one gage is required. In the "ET" equipment two are provided. The gage, see Fig. 30, is of the Bourdon type and has two pipe connections to the brake valve, one of which is in constant communication with the main reservoir (red hand) and the other is in constant communication with the equalizing reservoir (black hand). The second gage furnished with the "ET" equipment has one of its two pipes connected to the brake cylinder (red hand) and the other to the brake pipe (black hand).

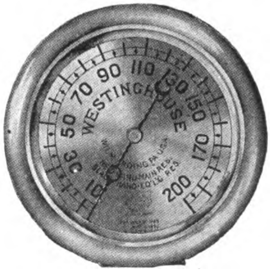


Fig. 30. Westinghouse Duplex Air Gage

FEED VALVES

The function of the feed valve has already been explained. In the "G-6" brake valve it forms a part of the valve. The two forms most commonly found in service are the single-pressure and double-pressure types.

"C-6" Single-Pressure Feed Valve. This feed valve is of the slide-valve type and consists of two portions, the supply and regulating portions. Its appearance detached from the brake is shown in Fig. 31. Figs. 32 and 33 show actual sections taken through the spring box and through the slide valve. Figs. 34 and 35 are diagrammatic sections illustrating the operation of the valve and will be referred to in the description of its action when in service.

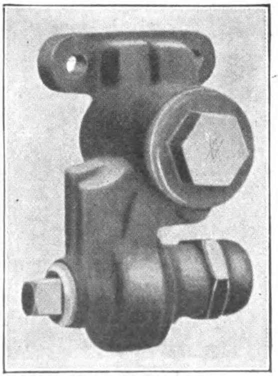


Fig. 31. Westinghouse "C-6" Feed Valve

The supply portion consists of a slide valve *7* and a piston *6*. The slide valve *7* opens or closes communication from the main reservoir to the brake pipe, and is moved by the piston *6*, which is operated by main-reservoir air entering through passage *a* on one side or by the pressure of the piston spring *9* on its opposite side.

The regulating portion consists of a brass diaphragm *17*, on one side of which there is the diaphragm spindle *18*, held against the diaphragm by the regulating spring *19*, and on the other side a regulating valve *12*, held against the diaphragm or its seat, as the case may be, by spring *13*. Chamber *L*, on the face of the diaphragm, is open to the brake pipe through passage *e* and *d*.

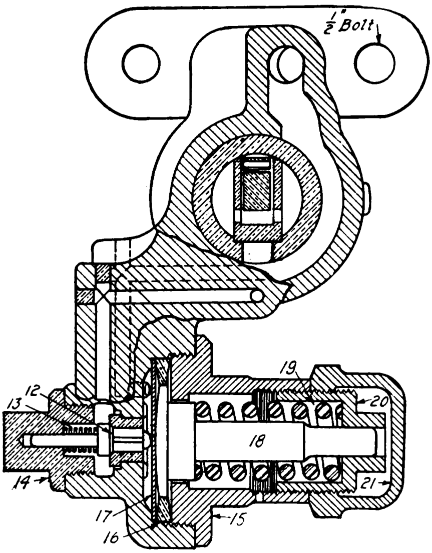


Fig. 32. Section of Westinghouse "C-6" Feed Valve through Spring Box

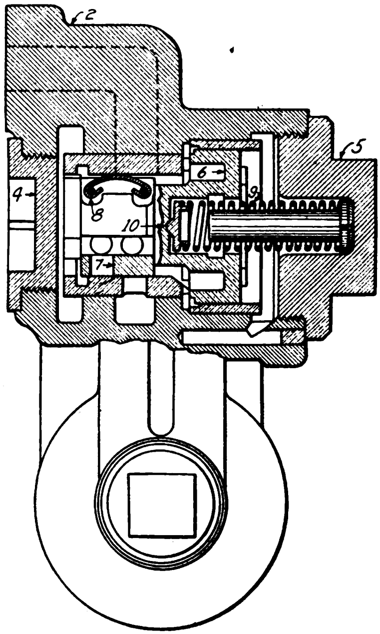


Fig. 33. Section of Westinghouse "C-6" Feed Valve through Slide Valve

The feed valve is adjusted by screwing regulating nut *20* in or out, thus increasing or decreasing the pressure exerted by the spring on the diaphragm.

This feed valve, when applied to the "G-6" brake valve, is usually adjusted for 70 pounds brake-pipe pressure. Suppose spring *19* to be compressed so as to exert a force equivalent to a 70-pound air pressure on the opposite side of the diaphragm. Then, as long as the air pressure in the brake pipe and chamber *L* is less than 70 pounds, the spring holds the diaphragm over as far to the left as possible, as shown in Fig. 35. This holds the regulating valve *12* off its seat, thus opening port *K*, which permits air to flow through port *K* and from passage *H* to chamber *G* at the back of the supply piston *6*. Consequently, as long as the air pressure in *G*, *h*, *e*, and *d* is less than 70 pounds, the higher main-reservoir pressure on the opposite side of piston *6* forces it to the extreme left, compressing spring *9* and opening port *c*, as shown in Fig. 35. Air, therefore, continues to flow from the main reservoir through *a*, *c*, and *d* to the brake pipe, increasing its pressure and the pressure in chamber *L*, acting on diaphragm *17*, until it reaches 70 pounds.

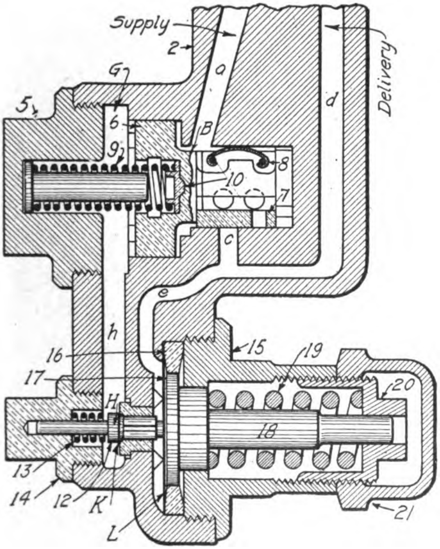


Fig. 34. Diagrammatic Section of Westinghouse "C-6" Feed Valve in Closed Position

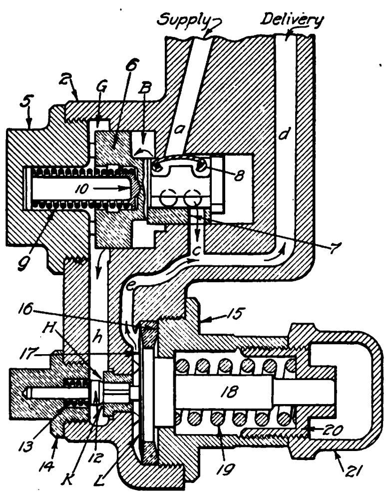


Fig. 35. Diagrammatic Section of Westinghouse "C-6" Feed Valve in Open Position

The air pressure on the diaphragm is then able to overcome the spring pressure on the opposite side and force the diaphragm to the right by "buckling" it slightly in that direction. This allows the regulating-valve spring *13* to return the regulating valve *12* to its seat, which closes port *K*. Chambers *G* and *H* are then no longer open to the brake-pipe passage *d* at 70 pounds pressure and, being small, are instantly raised to main-reservoir pressure by the slight leakage of air past the supply piston, which is made loose-fitting for this purpose. As the air pressures become nearly equal on the opposite sides of the supply piston, the piston spring

9 forces the piston and its slide valve to closed position, Fig. 34, which prevents further flow of air from the main reservoir to the brake pipe. The operation of the valve as described, after the pressure in the brake pipe has reached 70 pounds is almost instantaneous, so that the brake-pipe pressure is held constant at 70 pounds until it is slightly reduced by leakage, so that its pressure on diaphragm *17* is no longer able to withstand the pressure of the regulating spring, which then forces the diaphragm back, lifting the regulating valve from its seat and again opening port *K*.

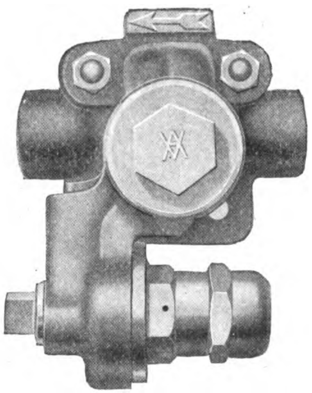


Fig. 36. Westinghouse "C-6" Reducing Valve

The feed valve acts as a maintaining valve in this manner, keeping the brake-pipe pressure constant at the amount for which the regulating valve is adjusted as long as the brake-valve handle is in proper position for the feed valve to be operative.

When the "C-6" type feed valve is fitted for pipe connections to be used in connection with the distributing valve of the "ET" equipment, it is called a *reducing* valve. It is usually adjusted to reduce to 45 pounds pressure. The arrangement used is illustrated in Fig. 36.

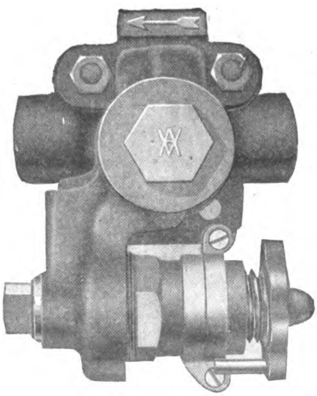


Fig. 37. Westinghouse "B-6" Feed Valve, Showing Valve and Pipe Bracket Complete

"B-6" Double-Pressure Feed Valve. The "B-6" feed valve is furnished with the high-speed and double-pressure control apparatus, and also with the "ET" equipment, to permit the use of either low- or high-brake pipe pressure. The features of this feed valve are the same as for the "C-6" feed valve with the exception of having a *regulating handle* in place of a regulating nut. The extreme movement of the regulating handle is controlled by stops, as shown in Fig. 37. To adjust this valve, slacken the screw which allows the stops to turn around the spring box. The regulating handle should then be turned until the valve closes at the lower brake-pipe pressure desired, the stop should then be brought in contact with the handle pin, at which point it should be securely fastened by the tightening screw. The regulating handle should then be turned until the higher brake-pipe pressure is obtained and the stop is brought in contact with the handle pin and securely fastened. The usual and recommended pressures for low and high pressures are 70 pounds and 110 pounds, respectively.

The "B-6" feed valve, like the "C-6" feed valve, is also used

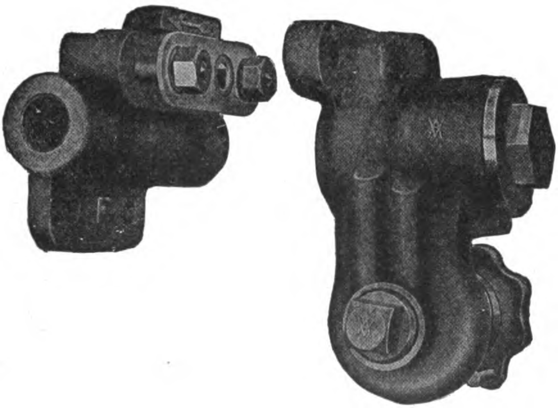


Fig. 38. "B-6" Feed Valve, Showing Valve Removed from Pipe Bracket
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

as a reducing valve. When used in this capacity it is fitted to a pipe bracket as illustrated in Fig. 38.

TRIPLE VALVES

In the study of the triple valve it is well to keep in mind that its essential parts consist of a cylinder fitted with a piston, the movement of which operates a slide valve. As long as the pressure remains the same on each side of the piston it cannot move, but when the pressure on one side is changed the piston will move toward the side having the least pressure. It is of vital importance that this principle be thoroughly understood, as practically all automatic devices of the air brake are constructed along this line. This principle, as stated by the Westinghouse Company, is as follows:

The devices used in connection with the air brake, which are automatic in their action, and of which the triple valve is one, depend for their operation upon the movements of one or more diaphragms or pistons. The piston or diaphragm is a movable partition separating two sources of pressure. As long as these pressures are equal no movement occurs, but as soon as the equality of pressure is destroyed, and the pressure on one side becomes higher than that on the other, the piston or diaphragm tends to move toward the lower pressure and, as soon as the balance of pressure is again restored, the tendency to move ceases. This condition holds true whether the pressures involved are due to compressed air or to springs, or to a combination of the two.

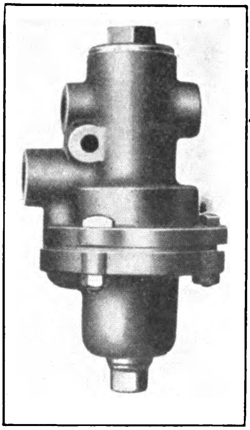


Fig. 39. Plain Triple Valve for Air Brake Equipment
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

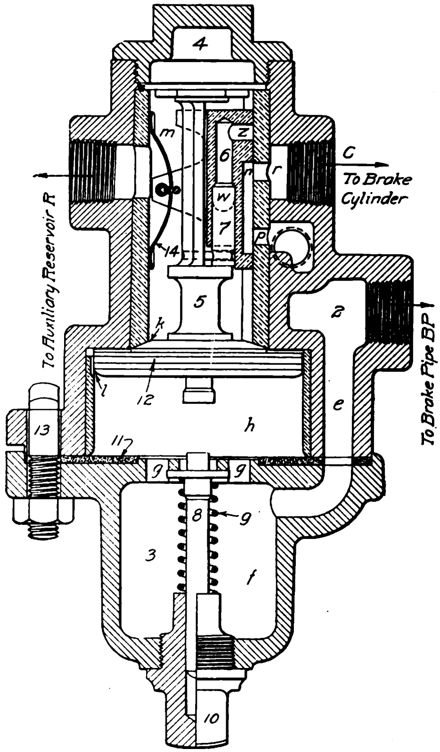


Fig. 40. Section through Westinghouse Plain Triple Valve

In the case of the triple valve, the variations in pressure necessary to cause it to operate are due to the increase or decrease in brake-pipe pressure caused by movements of the engineer's brake valve, burst hose, opening of conductor's valve, etc., on one side of the triple-valve piston, or on the other side of the piston by a decrease in the auxiliary-reservoir pressure caused by a flow of air into the brake cylinder from the auxiliary reservoir.

As previously stated, the triple valve forms one of the most important parts of the air-brake equipment. The different Westinghouse air-brake equipments make use of the following types of triple valves: plain, quick-action, "K", and "L". The first two types mentioned are rapidly passing out of service and those of later development are taking their place.

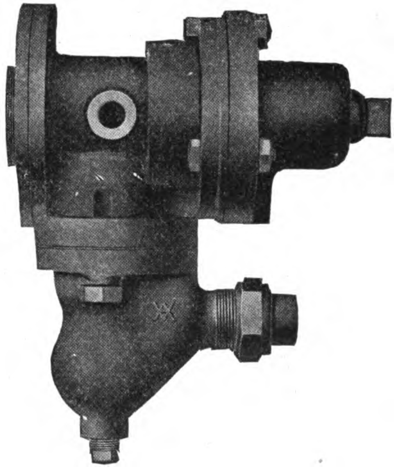


Fig. 41. Westinghouse Quick-Action Triple Valve

Plain Triple Valve. The plain triple valve, the general appearance of which is shown in Fig. 39 and in vertical section in Fig. 40, has a cast-iron body with pipe connections to the brake pipe *BP*, to the auxiliary reservoir *R*, and to the brake cylinder *C*, and has an outlet to the atmosphere shown by dotted and full lines to the right of port *p*.

The operating parts consist of a slide valve *6*, in which the graduating valve *7* moves, the piston *5*, and the graduating stem *8*, with its spring *9*. The graduating valve is attached to the stem of piston *5* by a pin shown in dotted lines.

Quick-Action Triple Valve. The quick-action triple valve, Fig. 41, is shown in vertical section in Fig. 42. Its constructional features are quite similar to those of the plain triple valve, one of the noticeable differences being that the operating piston and slide valve occupy a horizontal position, while in the plain triple valve they have a vertical position. It also differs from the plain triple valve in having additional quick-

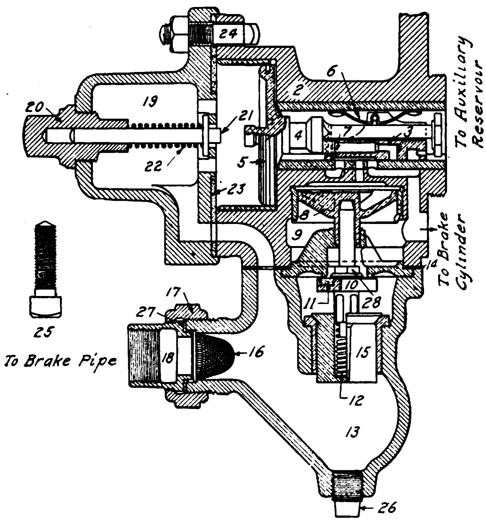


Fig. 42. Westinghouse Quick-Action Triple Valve Shown in Section

action parts, consisting of an emergency piston *8*, emergency valve *10*, and check valve *15*. This triple valve is arranged so as to be bolted to the pressure head of the brake cylinder in passenger equipments or to the cast-iron auxiliary reservoir in freight equipments, thus making the brake-pipe connection the only pipe connection necessary to the triple valve.

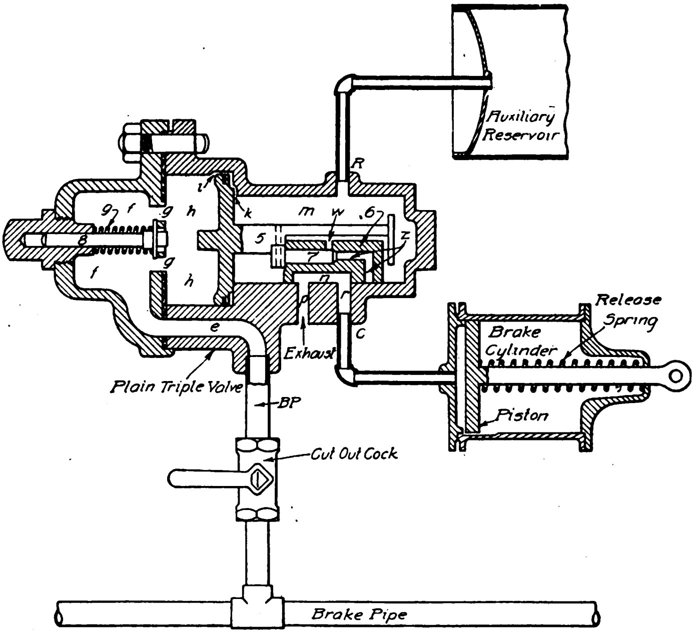


Fig. 43. Diagram of Westinghouse Plain Triple Valve, Showing Running and Release Position

The plain triple valve was developed to overcome the defects of the straight air brake, chief among which may be mentioned the following: a brake that was inoperative in event of a train parting; a brake that could not be used successfully in trains of over ten cars in length; and a brake requiring considerable time to operate.

The plain triple valve overcame these defects in a large measure but soon had to give way to a more refined type of triple valve, a valve whose action was more rapid and did not give such severe shocks between cars in long trains—say 50 cars—when an emergency application of the brakes was made.

The quick-action triple valve overcame the defects of the plain triple valve. The general operation of these two valves is so much alike that a description for either type will apply to the other with the exception of the quick-action or emergency feature.

It will be remembered that the brake pipe extends from the engineer's brake valve on the locomotive throughout the train, the connections between the locomotive and cars being made by a hose and coupling. The essential pipe equipment on each car

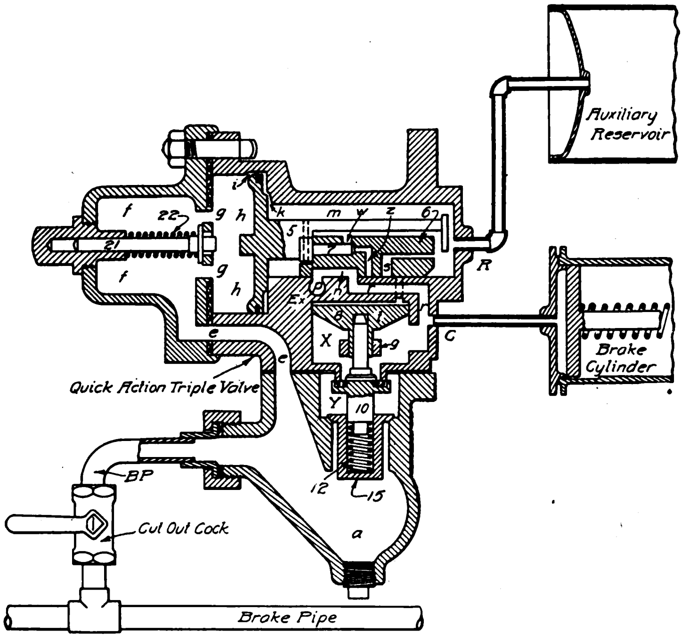


Fig. 44. Diagram of Westinghouse Quick-Action Triple Valve, Showing Running and Release Position

is the brake pipe, and a branch pipe which connects the triple valve to the brake pipe through a cut-out cock. In giving the description of the action of both the plain and the quick-action triple valves, reference will be made to diagrammatic views shown in Figs. 43 to 48. Like the engineer's brake valve, the triple valve is spoken of as having certain definite positions, such as running or release, service, service-lap, and emergency positions.

Running Position. Air enters the triple valve through port *e*, Figs. 43 and 44, to chamber *f* and through passages *g* to chamber *h*, in which the triple valve piston *5* moves. The air pressure in chamber *h*, acting on the face of the piston, forces it to its extreme position to the right, which is *release* and *charging* position. In this position air can flow from chamber *h* around the piston through feed groove *i* in the bushing and *k* in the piston seat into chamber *m*, and thence through the pipe connection at *R*, as shown, to the auxiliary reservoir.

From the figures it will be seen that the triple-valve piston *5* has a stem on which are two collars. Between these two collars is a slide valve *6*, shorter than the distance between the collars on the piston stem, so that there is a certain amount of clearance or "lost motion" between the piston stem and the slide valve.

The function of this slide valve *6* is to make proper connections between the space *m* (auxiliary-reservoir pressure) and the brake-cylinder port *r* in the seat of the valve; or between the brake-cylinder port *r* and the exhaust port *p*, also in the seat; or to close these ports—according to the positions to which the slide valve is moved by the triple-valve piston in order to perform certain functions. In the *release* position shown, air at auxiliary pressure is acting above and on all sides of the slide valve, but cannot flow past or through it since all ports through the valve are closed. The exhaust cavity *n* in the face of the valve, however, makes an opening across from the brake cylinder port *r* in the seat to the exhaust port *p*, so that the brake cylinder is then connected through the pipe connection to the triple valve and the ports named to the exhaust opening and atmosphere. Any compressed air contained in the brake cylinder will flow to the atmosphere, thus permitting the release spring acting on the opposite side of the piston to force it back to the *release* position and release the brake shoes from the wheels.

The normal condition of the triple valve when the train is running over the road and the brakes are not being used is with the triple-valve pistons and slide valve in *release* position, the brakes released, and the auxiliary reservoirs charged and maintained at the pressure for which the feed valve—engineer's brake valve—is adjusted.

Service Position. As the brake pipe is connected to the chamber *h*, Fig. 45, of each triple valve. a reduction in brake-pipe pressure will lower the pressure on the brake-pipe side of the triple-valve piston below that of the auxiliary reservoir on the opposite side. The higher auxiliary-reservoir pressure will then cause the piston to move in the direction of the weaker pressure, thereby closing communication between chamber *h* and the auxiliary reservoir through feed groove *i*. Attached to the piston stem is a pin valve *7* called the "graduating valve", which when seated, Fig. 46, closes communication between port *w* leading from chamber *m* to the

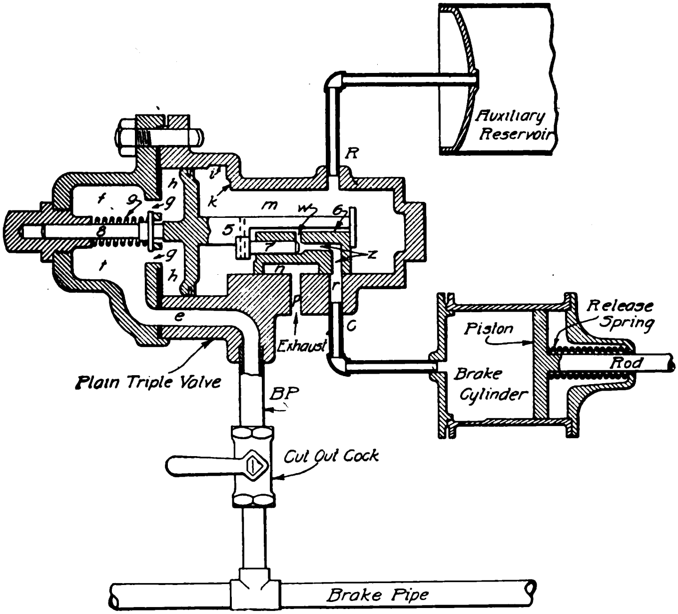


Fig. 45. Westinghouse Plain Triple Valve, Showing Service Position

graduating-valve seat in the slide valve and the service port *z* leading from the graduating-valve seat to the face of the slide valve. The first movement of the triple-valve piston unseats the graduating valve *7*, so that the air in chamber *m*, entering port *w*, flows to the service port *z*.

There is a small amount of clearance between the slide valve *6* and the collar, or "spider", on the end of the triple-valve piston stem, so that the first movement of the piston, which closes the feed groove *i* and opens the graduating valve *7*, does not move the slide valve but brings the spider on the stem against the end of the valve. Further movement of the piston causes the slide valve to move until it has closed communication between the brake-cylinder port *r* and the exhaust port *p* and opened port *r* to the auxiliary reservoir through port *z* and *w*, as shown in Fig. 45. The piston then comes into contact with the graduating stem and the resistance of the graduating spring, combined with the reduction in the auxiliary-reservoir pressure then taking place, prevents further movement of the parts. The valve is then in *service* position

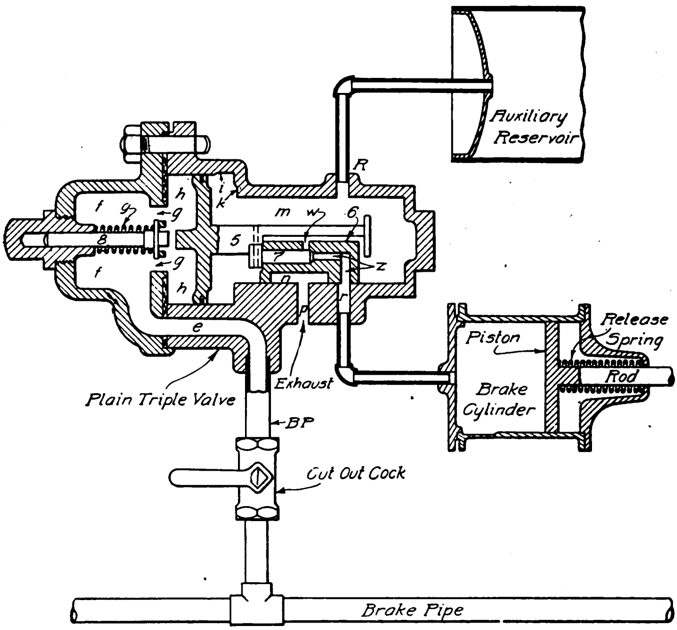


Fig. 46. Westinghouse Plain Triple Valve, Showing Service Lap Position

and air from the auxiliary reservoir flows through the service port to the brake cylinder, forcing its piston outward and applying the brake. While the brake-cylinder pressure rises, that in the auxiliary reservoir falls and tends to become lower than that in the brake pipe. As soon, however, as the pressure on the auxiliary-reservoir side of the triple-valve piston falls slightly below that on the brake-pipe side, the higher pressure causes the piston to move back—toward *release* position—until the graduating valve is seated, closing communication between ports *w* and *z*. This further flow of air from the auxiliary reservoir—the pressure in which is then practically equal to that in the brake pipe—prevents further movement of the triple-valve piston toward *release* position, because the slightly higher pressure on the brake-pipe side of the piston, which was able to move the piston and graduating valve alone, is not sufficient to move the slide valve. The triple valve is then in *service-lap* position.

If a further reduction in brake-pipe pressure is made, the reduction in pressure on the brake-pipe side of the triple-valve piston below that on the auxiliary-reservoir side causes the piston and its attached graduating valve to move to the same position as for the first *service* application of the brakes. The slide valve, however, is already in service position, consequently as soon as the graduating valve is opened air from the auxiliary reservoir flows to the brake cylinder and increases the pressure therein, thus increasing the pressure of the brake shoes against the wheels. If the brake-pipe reduction is continued indefinitely, the auxiliary-reservoir pressure will continue to fall and the brake-cylinder pressure to rise until they become equal, or "equalize". This occurs at about 50 pounds cylinder pressure when carrying 70 pounds brake-pipe pressure with a properly proportioned cylinder and auxiliary reservoir. Nothing is gained in reducing the brake-pipe pressure below the equalization point in *service applications.*

Service-Lap Position. When the triple valve is in *service lap*, Fig. 46, and assuming that there is no leakage, the brake-pipe and auxiliary-reservoir pressures will remain balanced and the brake-cylinder pressure held constant until the brake-pipe pressure is further reduced, in order to apply the brakes harder; or increased in order to release the brakes.

The brake-cylinder leakage, as well as brake-pipe leakage, is generally very severe and it is not good policy to keep brakes applied for too great a period at one time, permitting the pressure in the brake system to leak off.

Release and Recharge. To release the brakes and recharge the auxiliary reservoir, air is admitted to the brake pipe. This increases the pressure on the brake-pipe side of each triple-valve piston above that on the other side, causing the piston and slide valve to move back to release position, which permits the air in the brake cylinder to flow to the atmosphere through the triple-valve exhaust port, thus releasing the brakes. The charging of the auxiliary reservoir has been explained under "Running Position"

Emergency Position. Up to this point, all statements made regarding the operation of the triple valve have applied equally to the plain, or quick-action triple valve, but during an *emergency* application their action is different.

When the piston and slide valve of the plain triple valve move to the *emergency* position, Fig. 47, the brake-cylinder port *r* is uncovered and air from the auxiliary reservoir flows past the end of the valve directly through port *r* into the brake cylinder until the brake-cylinder and auxiliary-reservoir pressures become equalized.

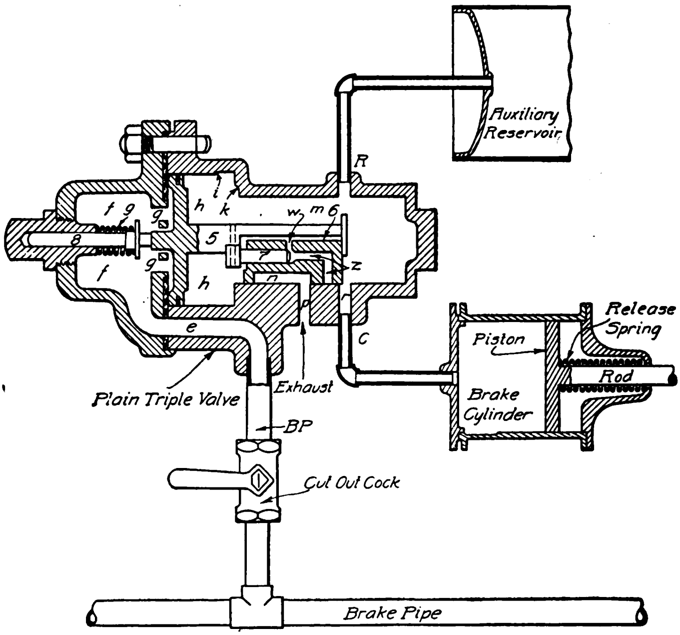


Fig. 47. Westinghouse Plain Triple Valve, Showing Emergency Position

The pressure obtained in the brake cylinder is no higher then when a full-service application is made, but the maximum pressure is obtained more quickly.

When the piston and slide valve of the quick-action triple valve move to the *emergency* position, Fig. 48, port *s* in the slide valve registers with port *r* in the seat, allowing air to flow from the auxiliary reservoir to the brake cylinder. Port *s* is small, however, and in this position the slide valve also opens port *t* in its seat, allowing air to flow from chamber *m* through port *t* to the chamber above the emergency piston *8*. The other side of emergency piston *8* is connected to the brake cylinder, in which there is no air pressure, consequently the emergency piston is forced downward, pushing the emergency valve *10* from its seat and allowing air in chamber *Y* above the check valve *15* to flow past the emergency valve *10* to chamber *X* and the brake-cylinder. Brake-pipe air in *a* below the

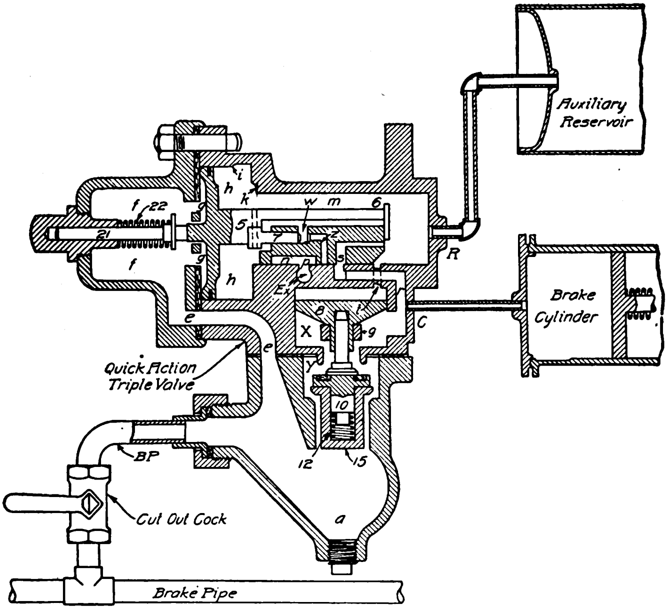


Fig. 48. Westinghouse Quick-Action Triple Valve, Showing Emergency Position

check valve *15*, then raises the check valve and flows to the brake cylinder through the passages mentioned. During an emergency application, therefore, the quick-action triple valve supplies air to the brake cylinder from the brake pipe as well as from the auxiliary reservoir.

Approximately 60-pound brake-cylinder pressure is obtained on emergency applications, the air from the brake pipe increasing the cylinder pressure about 20 per cent above the maximum obtainable with a full-service application.

This "venting" the brake-pipe pressure into the brake-cylinder aids the speed of an emergency application, as each triple valve reduces the brake-pipe pressure sufficiently to set the next triple valve in the train to emergency.

The release after an emergency application is obtained in the same manner as for a service-application release.

The plain triple valve is now only used for locomotives in freight and switching service that are not equipped with the "ET" distributing valve.

Type "K" Freight Triple Valve. The standard form of quick-action triple valve commonly used in freight service has until recently proved very satisfactory. In the last few years, however, with heavier locomotives capable of handling 100-car trains fitted with air-brake equipment, they have failed to meet all the requirements. Realizing the changed conditions and the importance of meeting them, the Westinghouse Company has developed and perfected the "K" triple valve.

Objections to Other Valves Overcome by "K" Type. Some of the undesirable features of the standard quick-action triple valve, which the "K" triple overcomes are as follows:

(a) The failure of a portion of the brakes in a long train to apply.

(b) A complete release of the brakes at the forward end of the train before the brake-pipe pressure which has brought this about can reach the triple valves near the end of the train. This action permits the slack to run out hard, and creates excessive strains on the draft gears, often resulting in a break-in-two.

(c) Overcharging the auxiliary reservoirs at the forward end of the train while releasing the brakes. The result of this action is a reapplication of the forward brakes when the brake-valve handle is placed in running position.

The outward appearance of the "K" triple valve when attached to the auxiliary reservoir is so much like the standard quick-action triple that a thin web is cast on the top part of the body as a distinguishing mark. The designating mark "K-1" or "K-2" is also cast on the side of the body. The "K" triple is made in two sizes —the "K-1" for use with the 8-inch freight-car brake cylinder, and the "K-2" with the 10-inch freight-car brake cylinder, Fig. 49.

This "K" triple valve embodies every feature possessed by the standard quick-action triple valve and three additional ones, namely, quick service, uniform release, and uniform re-charge. It operates in perfect harmony with the standard triple and often improves the action of the latter when the valves are mixed in the same train. The two types of valves have many parts in common and are interchangeable. The standard triple may be transformed into the "K" triple by preserving all of the old parts except the body, slide-valve, bush, and graduating valve. This transformation can be done at a minimum cost when the valves are returned to the works for heavy repairs.

The above-mentioned features of quick action, quick service, uniform release, and uniform re-charge have proved so desirable that the valve has been accepted as standard by so many railroads that it can be said to be the "standard" freight triple valve of today.

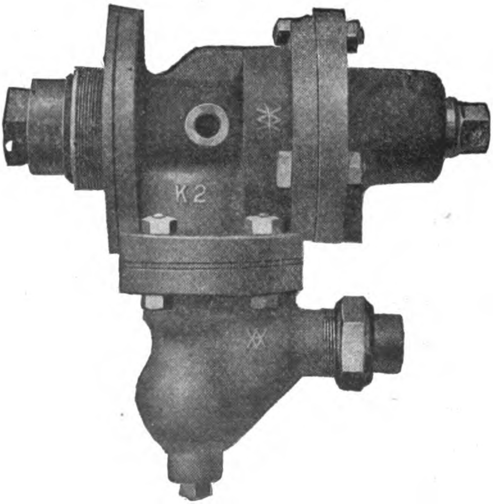


Fig. 49. Westinghouse Type "K" Freight Triple Valve

Quick-Service Feature. The quick-service feature brings about a more uniform and a quicker application of the brakes in a long train during service applications.

The rate of brake-pipe reduction for service applications in the brake system is determined by the exhaust port in the brake valve and by the frictional resistance of the pipe. These being constant, it is plain that the longer the train the slower will be the pressure reduction in the brake pipe, and, as the distance from the head of the train increases toward the rear of long trains, only a very slow reduction, if any, takes place, and consequently a very slow application, if any at all, takes place. This slow rate of brake-pipe reduction not only results in a slow application but many times in the failure of individual brakes to apply. This is due to one of two things, namely, the air from the auxiliary reservoir passing back to the brake pipe through the feed groove; or, in case of a movement of the triple-valve piston, by the air leaking out past the packing leather in the brake cylinder.

The quick-service feature gives a rapid serial operation of all brakes in service application. This is accomplished by using the principle of the standard quick-action triple valve in emergency applications, namely, that of discharging brake-pipe air into the brake cylinder; that is, in service applications some air from the brake pipe passes into the brake cylinder. The result is that the quick-service feature insures the operation of every brake, reduces the amount of air exhausted at the engineer's brake valve and the possible loss of air due to flowing back through the feed groove, and effects a saving of air.

Uniform Release. Uniform release tends to permit the rear brakes to release as soon as those at the head of the train. The rate of increase of brake-pipe pressure takes place more and more slowly as the distance from the head of the train increases; consequently, in long trains the head end brakes are fully released before the rear brakes have commenced to release. The uniform-release feature is accomplished by automatically restricting the exhaust of air from the brake cylinder in the forward portion of the train and allowing the others to release freely. This retarded release of the forward brakes is due to the increased pressure which exists in the forward end of the brake pipe when the brake valve is in release position. The effect is noticeable on about the first thirty cars of a long train.

Uniform Re-Charge. Uniform re-charge permits the auxiliary reservoirs through the entire length of the train to re-charge uniformly. With the ordinary quick-action triple valve, the slowness in brake-pipe pressure increase in long trains permitted the head end auxiliary reservoirs to become overcharged while those at the rear end were undercharged; consequently, when the brake-valve handle was returned to running position the head-end brakes would re-apply. The uniform re-charge of the auxiliary reservoirs is due to the fact that when the valve is in the retarded-release position, the ports connecting the brake pipe with the auxiliary reservoir are automatically restricted. In other words, as long as the exhaust from the brake cylinder is retarded, the recharge is restricted. This feature not only prevents the overcharging of the auxiliary reservoirs on the front end of the train but, by drawing less air from the brake pipe, permits the increase in brake-pipe pressure to travel more rapidly to the rear cars where it is most needed for releasing and re-charging those brakes.

Fig. 50 is a vertical cross section and end view of the "K" triple valve and the names of the various parts are as follows: *2* valve body; *3* slide valve; *4* main piston; *5* piston ring; *6* slide-valve spring; *7* graduating valve; *8* emergency piston; *9* emergency-valve seat; *10* emergency valve; *11* emergency-valve rubber seat; *12* check-valve spring; *13* check-valve case; *14* check-valve case gasket;

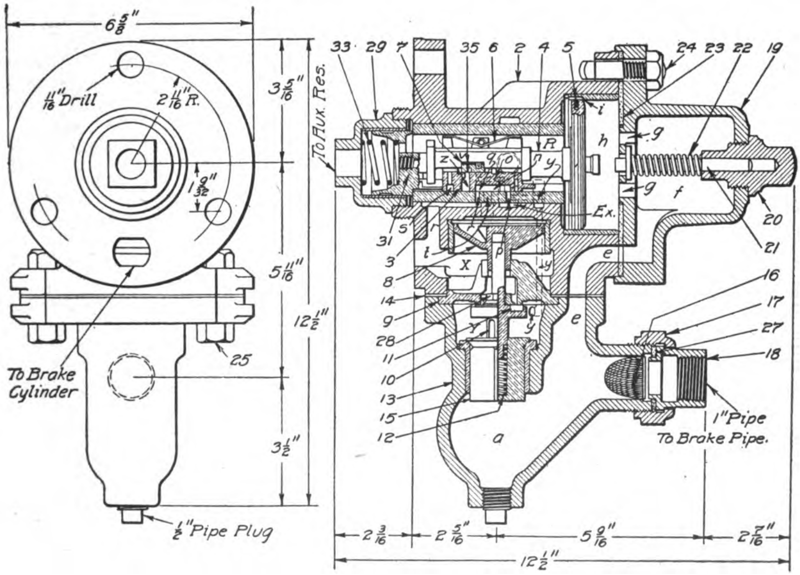


Fig. 50. Westinghouse Type "K" Triple Valve, Shown in End View and Actual Section

15 check-valve; *16* air strainer; *17* union nut; *18* union swivel; *19* cylinder cap; *20* graduating stem nut; *21* graduating stem; *22* graduating spring; *23* cylinder-cap gasket; *24* bolt and nut; *25* cap screw; *27* union gasket; *28* emergency-valve nut; *29* retarding device body; *31* retarding stem; *33* retarding spring; *35* graduating valve spring.

The different recognized positions of the parts of a type "K" triple valve are six in number, namely, full-release and charging, quick-service, full-service, lap, retarded-release and charging, and emergency positions. In explanation of the operation of the valve, reference will be made to the diagrammatic views of this device shown in Figs. 51 to 56 and, for the sake of clearness, the description given in literature published by the Westinghouse Company will be largely made use of.

Full-Release and Charging Position. In this position air from the brake-pipe flows through passage *e*, Fig. 51, cylinder-cap ports *f* and *g* to chamber *h* on the face of the triple-valve piston; thence

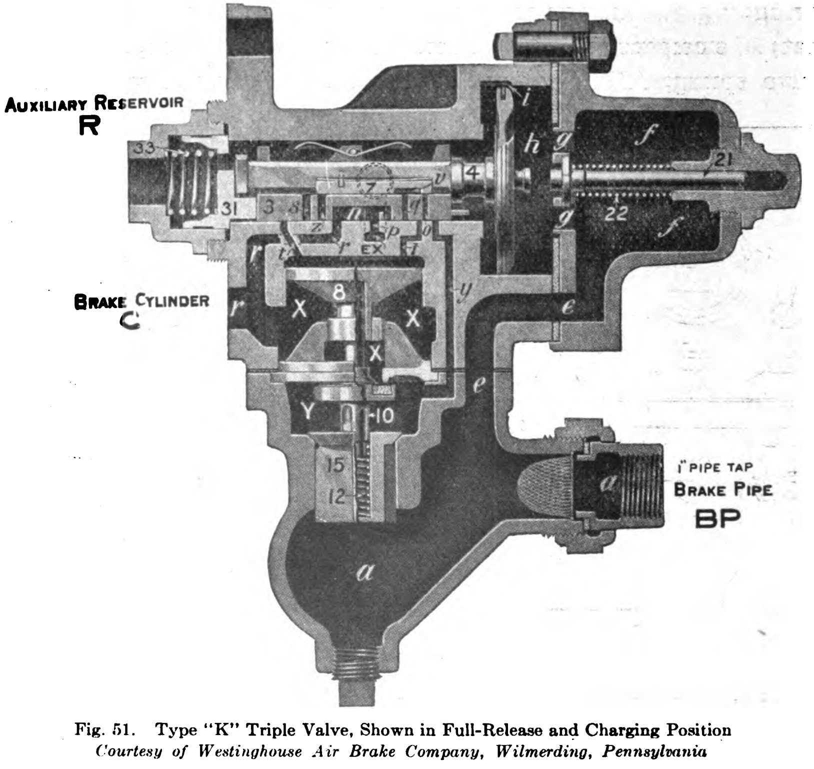


Fig. 51. Type "K" Triple Valve, Shown in Full-Release and Charging Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

through feed groove *i*, now open, to chamber *R* above the slide valve, which is always in free communication with the auxiliary reservoir. In the "K" triple valve, the feed groove *i* is of the same dimension as that of the old standard triple valve. Air flows from the brake pipe to the auxiliary reservoir, as described, until their pressures become equalized.

Quick-Service Position. To make a quick-service application of the brakes, the air pressure in the brake pipe, and thereby in chamber *h*, Fig. 52, is gradually reduced. As soon as the pressure in chamber *h* has been sufficiently reduced below that in chamber *R* on the other side of the triple-valve piston, the higher pressure on the auxiliary-reservoir side of the piston is able to overcome the friction of the piston *4* and its attached graduating valve *7* and to move these parts to the right until the shoulder on the end of the piston stem strikes against the left-hand end of the slide valve.

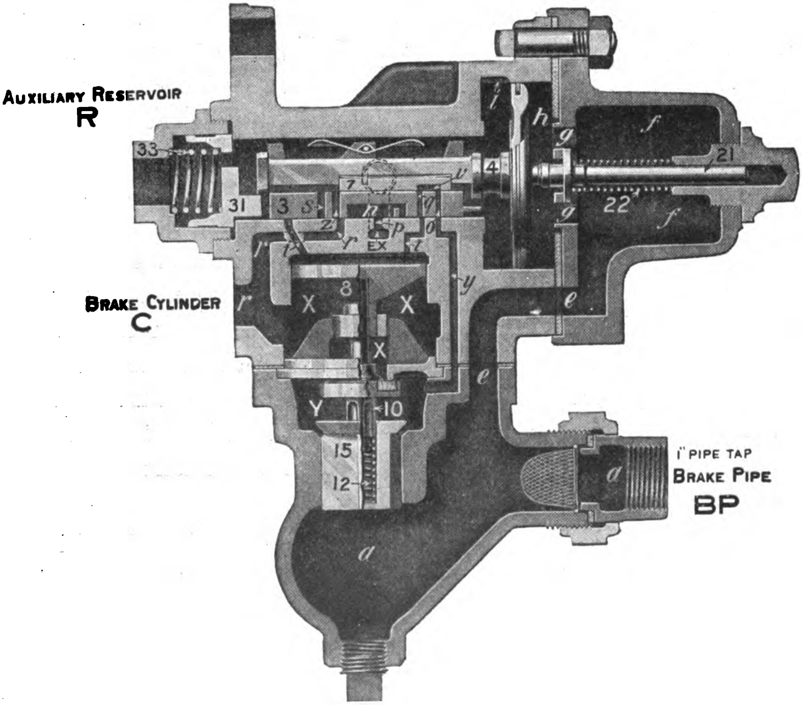


Fig. 52. Type "K" Triple Valve, Shown in Quick-Service Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

The latter is then moved to the right until the piston strikes the graduating stem *21*, which is held in place by the compression of the graduating spring *22*. The parts of the valve are then in the position shown in Fig. 52. The first movement of the piston *4* closes the feed groove *i* and prevents air from feeding back into the brake pipe from the auxiliary reservoir, and at the same time the graduating valve opens the upper end of port *z* in the slide valve. The movement of the latter closes the connection between port *r* and the exhaust port *p* and brings port *z* into partial registration with port *r* in the slide-valve seat. Air from the auxiliary reservoir then flows through port *z* in the slide valve and port *r* in the seat to the brake cylinder.

At the same time, the first movement of the graduating valve connects the two ports *o* and *q* in the slide valve through the cavity *v* in the graduating valve, and the movement of the slide valve brings port *o* to register with port *y* in the slide-valve seat and port *q* with port *t*. Consequently, the air in chamber *Y* flows through ports *y*, *o*, *v*, *q*, and *t*, thence around the emergency piston *8*, which fits loosely in its cylinder, to chamber *X* and the brake cylinder. When the pressure in chamber *Y* has reduced below the brake-pipe pressure remaining in *a*, the check valve *15* is raised and allows brake-pipe air to flow past the check valve and through the ports above mentioned to the brake cylinders. The size of these ports is so proportioned that the flow of air from the brake pipe to the top of emergency piston *8* is not sufficient to force the latter downward and thus cause an emergency application, but at the same time takes enough air from the brake pipe to cause a definite local reduction in brake-pipe pressure at that point, which is transmitted in like manner to the next triple valve, and in turn to the next, thus increasing the rapidity with which the brake-pipe reduction travels through the train.

Full-Service Position. With short trains, the brake-pipe volume being comparatively small will reduce more rapidly for a certain reduction at the brake valve than with long trains. Under such circumstances it might be expected that the added reduction at each triple valve by the quick-service feature would bring about so rapid a brake-pipe reduction as to cause quick action and an emergency application when only a light application was intended, but this is automatically prevented by the triple valve itself. From Fig. 52 it will be noted that in the quick-service position port *z* in the slide valve and port *r* in the seat do not fully register. Nevertheless, when the train is of considerable length, the opening is sufficient to allow the air to flow from the auxiliary reservoir to the brake cylinder with sufficient rapidity to reduce the pressure in the auxiliary reservoir as fast as the pressure is reducing in the brake pipe; but if the brake-pipe reduction is more rapid than that of the auxiliary reservoir, which may be the case on short trains, the difference in pressure on the two sides of piston *4* becomes sufficient to slightly compress the graduating spring and moves the slide valve to the position shown in Fig. 53 called *full service.* In this position, quick-service port *y* is closed, so that no air flows from the brake pipe to the brake cylinder; also, in full-service position ports *z* and *r* are fully open, allowing the auxiliary-reservoir

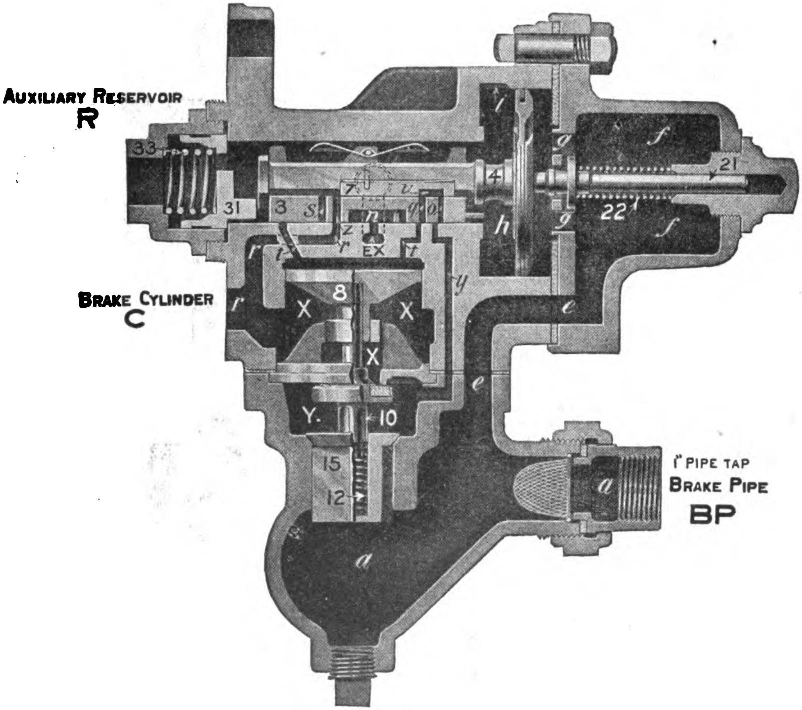


Fig. 53. Type "K" Valve Shown in Full-Service Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

pressure to reduce more rapidly, so as to keep pace with the more rapid brake-pipe reduction.

Lap Position. When the brake-pipe reduction ceases, air continues to flow from the auxiliary reservoir through ports *z* and *r* to the brake cylinder until the pressure in the chamber *R* becomes enough less than that of the brake pipe to cause piston *4* and graduating valve *7* to move to the left until the shoulder on the piston stem strikes the right-hand end of slide valve *3.* As the friction of the piston and graduating valve is much less than that of the slide valve, the difference in pressure which will move the piston and graduating valve will not be sufficient to move all three; consequently, the piston stops in the position shown in Fig. 54. This movement has caused the graduating valve to close port *z*, thus cutting off any further flow of air from the auxiliary reservoir to the brake cylinder and also to port *o*, thus preventing further flow

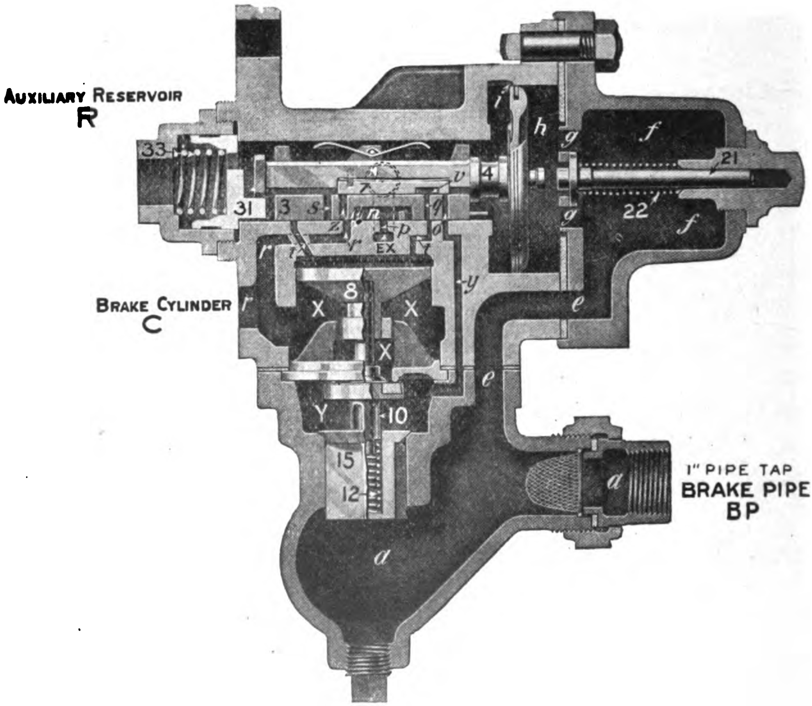


Fig. 54. Type "K" Triple Valve Shown in Lap Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

of air from the brake pipe through the quick-service ports. Consequently, no further change in air pressures can occur, and this position is called *lap* because all ports are *lapped* or closed.

It will be seen that the exact position of the slide valve *3* in *lap* position depends upon whether its previous position was that of *quick service*, Fig. 52, or *full service*, Fig. 53. If the former, the *lap* position assumed would be *quick-service lap* position, as shown in Fig. 54. If the slide valve had previously moved to *full-*

service position, however, the *lap* position assumed would be *full-service lap* position, in which the slide valve would still remain in *full-service* position, Fig. 53, but with the graduating valve moved back so as to blank ports *z* and *o* in the slide valve, and with the shoulder on the piston stem in contact with the right-hand end of slide valve *3*, as shown in Fig. 54. About 20 pounds brake-pipe reduction will give full equalization.

Retarded-Release and Charging Position. The "K" triple valve has two release positions, namely, full release and retarded release. It is well known that in a freight train, when the engineer releases the brakes, those cars toward the front, receiving the air first, will have their brake-pipe pressure raised more rapidly than those in the rear. With the old standard apparatus, this is due to two things: (1) the friction in the brake pipe; (2) the fact that the auxiliary reservoirs in the front begin to re-charge, thus tending to reduce the pressure head by absorbing a quantity of air and holding back the flow from front to rear of the train. The *retarded-release feature* overcomes the second point mentioned, taking advantage of the first while doing so. The friction of the brake pipe causes the pressure to build up more rapidly in the chamber *h* of the triple valves toward the front end of the train than in those at the rear. As soon as the pressure is enough greater than the auxiliary-reservoir pressure remaining in chamber *R*—after the application as above described—to overcome the friction of piston, graduating valve, and slide valve, all three are moved toward the right until the piston stem strikes the retarding stem *31*. The latter is held in position by retarding spring *33*. If the rate of increase of the brake-pipe pressure is small—as, for example, when the car is near the rear of the train—it will be impossible to raise the pressure in chamber *h* three pounds higher than that in the auxiliary reservoir on account of the flow of air which is going on at the same time from chamber *h* through feed groove *i* into the auxiliary reservoir, the triple-valve parts will remain in this position, as shown in Fig. 51, the brakes will release and the auxiliary reservoirs re-charge, as described under "Full Release and Charging". If, however, the triple valve is near the head of the train and the brake-pipe pressure builds up more rapidly than the auxiliary reservoir can re-charge, the necessary excess of pressure in chamber *h* over that in the auxiliary reservoir will be attained quickly and will cause the piston to compress retarding spring *33* and move the triple valve parts to the position shown in Fig. 55.

Exhaust cavity *n* in the slide valve now connects port *r* leading to the brake cylinder with port *p* to the atmosphere, and the brake will release; but, as the small "tail-port" extension of cavity *n* is over exhaust port *p*, the discharge of air from the brake cylinder

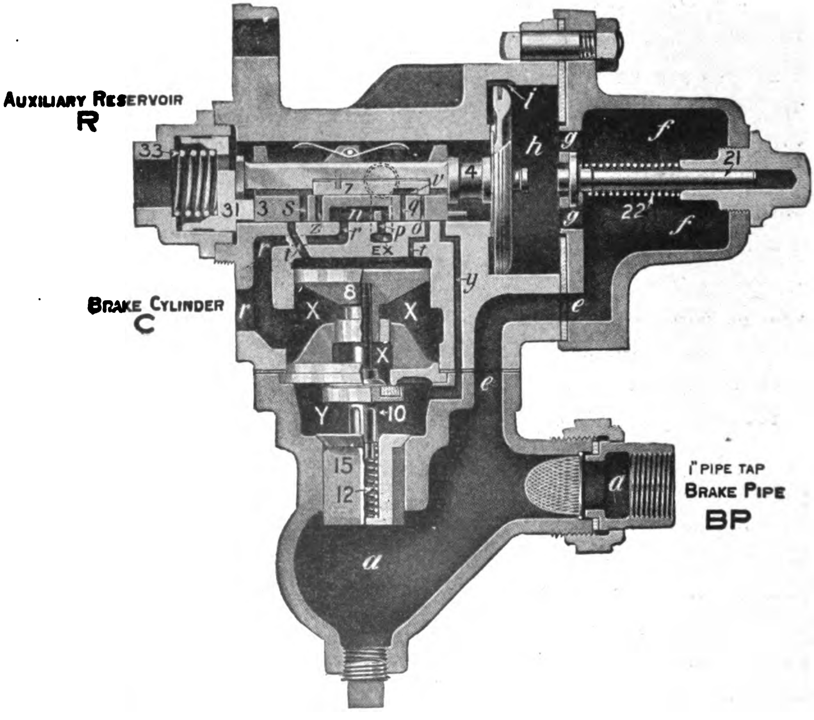


Fig. 55. Type "K" Triple Valve Shown in Retarded-Release and Charging Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

to the atmosphere is quite slow. In this way, the brakes on the front end of the train require a longer time to release than those on the rear. This feature is called the *retarded release*, and, although the triple valves near the locomotive commence to release before those in the rear, as is the case with the standard quick-action triple valve, yet the exhaust of air from the brake cylinder in retarded-release position is sufficiently slow to hold back the release of the brakes at the front end of the train long enough to insure a practically simultaneous release of the brakes on the train as a whole. This permits of releasing the brakes on very long trains at low speeds without danger of a severe shock or break-in-two.

At the same time, the back of the piston is in contact with the end of the slide-valve bush, and, as these two surfaces are ground to an accurate fit, the piston makes a tight "seal" on the end of the bush except at one point, where a feed groove is cut in the

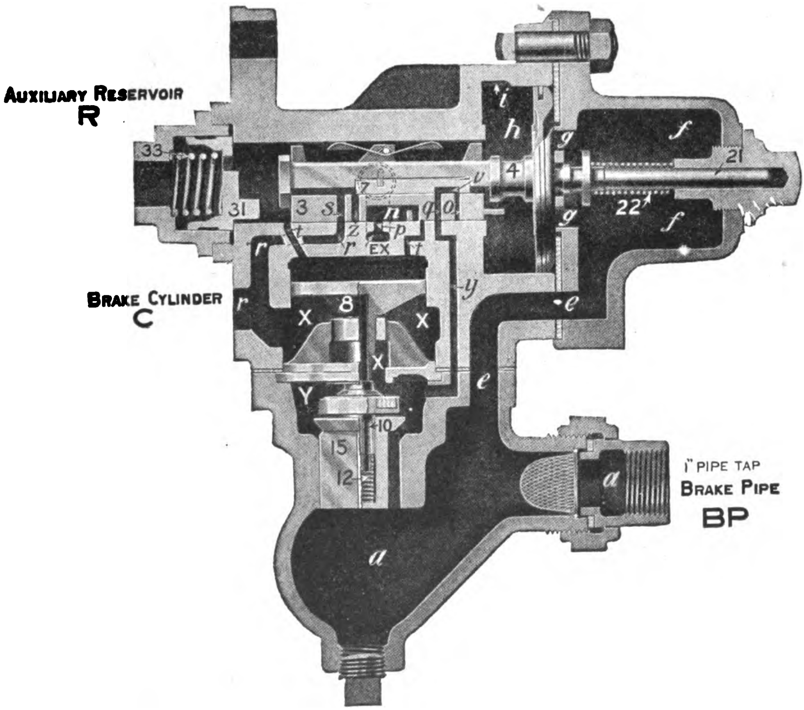


Fig. 56. Type "K" Triple Valve Shown in Emergency Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

piston to allow air to pass around the end of the slide-valve bush into chamber *R* and the auxiliary reservoir, Fig. 55. This feed groove is much smaller than the standard feed groove *i* in the piston bush, so that when the triple-valve piston is in retarded-release position, the re-charge of the auxiliary reservoir takes place much more slowly than when it is in full-release position. This feed groove is larger in the "K-2" than in the "K-1" triple valve so as to maintain the proper rate of recharge of their respective auxiliary reservoirs in retarded-release position.

As the auxiliary reservoir pressure rises and the pressures on the two sides of piston *4* become nearly equal, the retarding spring *31* forces the retarding stem, piston, slide valve, and graduating

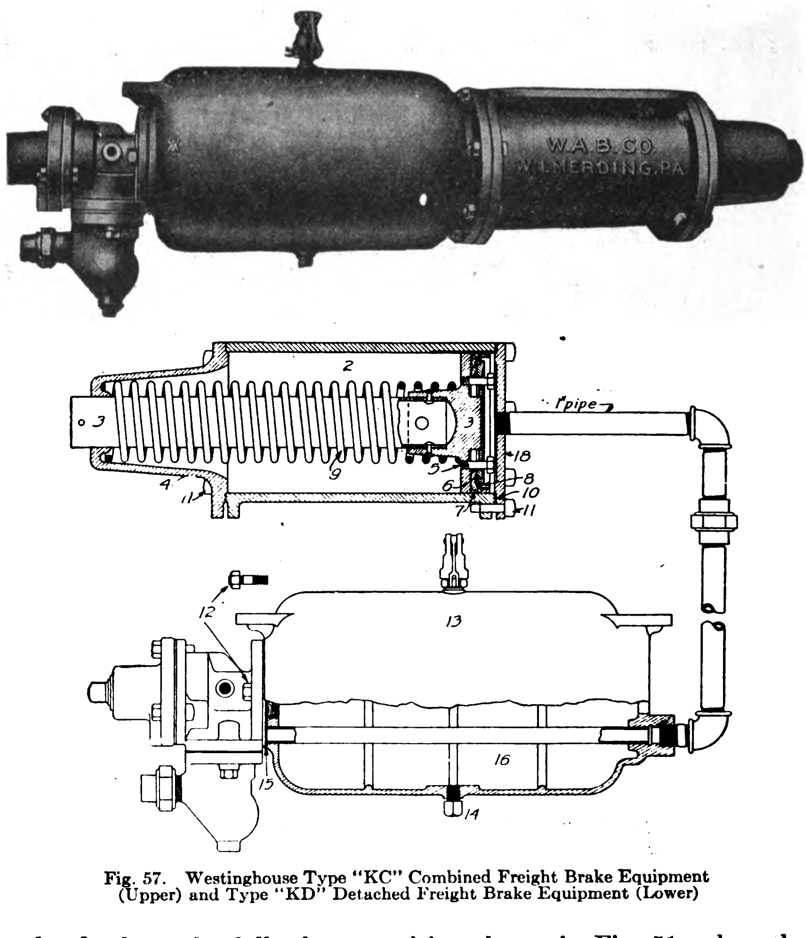


Fig. 57. Westinghouse Type "KC" Combined Freight Brake Equipment (Upper) and Type "KD" Detached Freight Brake Equipment (Lower)

valve back to the full-release position shown in Fig. 51, when the remainder of the release and re-charging will take place as described above under "Full Release and Charging".

Emergency Position. Emergency position is the same with the "K" triple valve as with the standard quick-action type. Quick action is caused by a sudden and considerable reduction in brake-pipe pressure below that in the auxiliary reservoir, no matter how caused. This fall in break-pipe pressure causes the difference in pressure on the two sides of piston *4* to increase very rapidly, so that by the time the piston has traveled to its full-service position, as already explained, there is sufficiently higher pressure on the auxiliary-reservoir side of the triple-valve piston to cause it to compress the graduating spring *22*, forcing back the stem and spring until the piston seats firmly against the gasket *23*, as shown in Fig. 56. The resulting movement of the slide valve opens port *t* in the slide-valve seat and allows air from the auxiliary reservoir to flow to the top of emergency piston *8*, forcing the latter downward and opening emergency valve *10*. The pressure in chamber *Y*, being thereby instantly relieved, allows the brake-pipe pressure to raise the check valve *15* and flow rapidly through the chambers *Y* and *X* to the brake cylinder until brake-cylinder and break-pipe pressures nearly equalize, when the check valve is forced to its seat by the check-valve spring, preventing the pressure in the cylinders from escaping back into the brake pipe again. The emergency valve, being held open by the emergency piston, will consequently return to its seat when the auxiliary-reservoir and brake-cylinder pressures have nearly equalized. At the same time, port *s* in the slide valve registers with port *r* in the slide-valve seat and allows air from the auxiliary reservoir to flow to the brake cylinder. But the size of ports *s* and *r* is such that comparatively little air gets through them before the brake pipe has stopped venting air into the brake cylinder. This sudden discharge of brake-pipe air into the brake cylinder has the same effect on the next triple valve as would be caused by a similar discharge of brake-pipe air to the atmosphere. In this way each triple valve applies the next.

The release after an emergency is effected in exactly the same manner as after a service application, but requires longer time, owing to the high brake-cylinder and auxiliary pressures and lower brake-pipe pressures.

Fig. 57 illustrates two different types of freight-brake equipment in which the type "K" triple valve is used. The lower figure represents the equipment usually found installed on steel hopper-bottom coal and coke cars, while the upper figure shows that usually found on wood box and gondola cars.

Type "L" Triple Valve. The type "L" triple valve is the outcome of a demand for a brake capable of handling heavy fast passenger trains with a greater degree of safety, flexibility, and comfort of passengers than the standard quick-action triple valve could give. It is used in connection with what is known as the L. N. Passenger Car equipment.

In order that trains may be controlled easily and smoothly when running at either high or low speeds, and that stops may

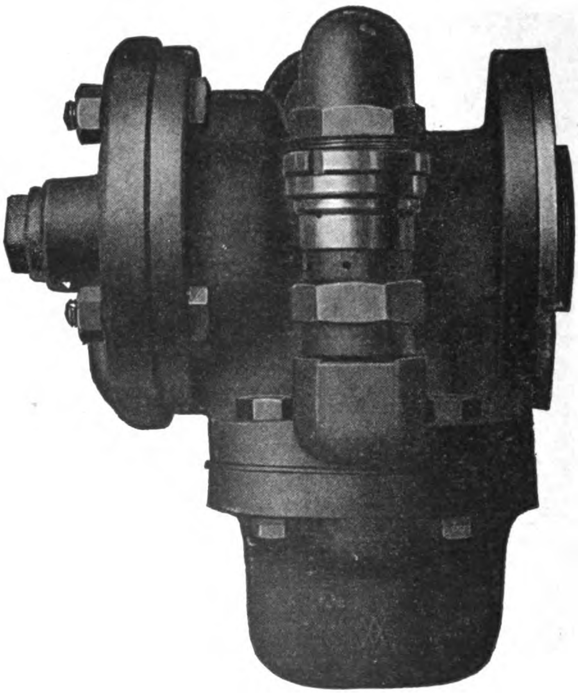


Fig. 58. Type "L" Triple Valve, Showing Safety Valve in Place
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

be made quickly and with the least liability of wheel sliding, the brake apparatus must provide the following essential features of operation:

(a) A small brake-pipe reduction must give a moderate brake-cylinder pressure and a moderate but uniform retardation on the train as a whole.

(b) It must be possible to make a heavy-service reduction quickly but without liability of quick action.

(c) It must be possible to graduate the release as well as the application of the brakes.

(d) To insure the ability to obtain brake applications in rapid succession and to full power, a quick recharging of the auxiliary reservoirs is necessary. This feature also enables the engineer to handle long trains in heavy grade work with a much greater factor of safety than heretofore and eliminates the need for pressure-retaining valves.

For high-speed trains a high brake-cylinder pressure available

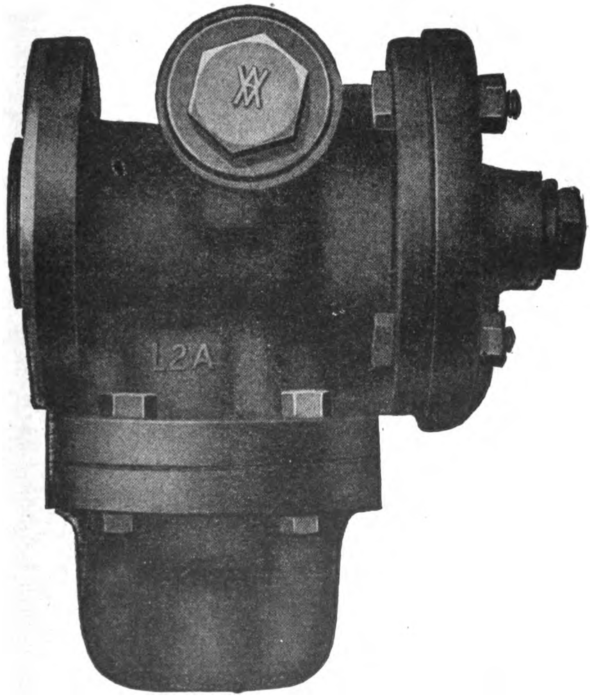


Fig. 59. Type "L" Triple Valve, Showing By-Pass Piston Cap
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

for emergency application is imperative, in order to provide a maximum braking power when the shortest possible stop is required.

New Features in "L" Type. The following new features are incorporated in the new Type "L" triple valve:

(1) *Quick recharge* (of auxiliary reservoirs), making it possible to obtain full braking power almost immediately after a release has been made.

(2) *Quick service*, by which a very quick serial *service* action of the brakes throughout the train is obtained, similar to that in emergency applications but less in degree.

(3) *Graduated release*, which permits of partly or entirely releasing the brakes on the entire train at will. This permits of the best method of braking,

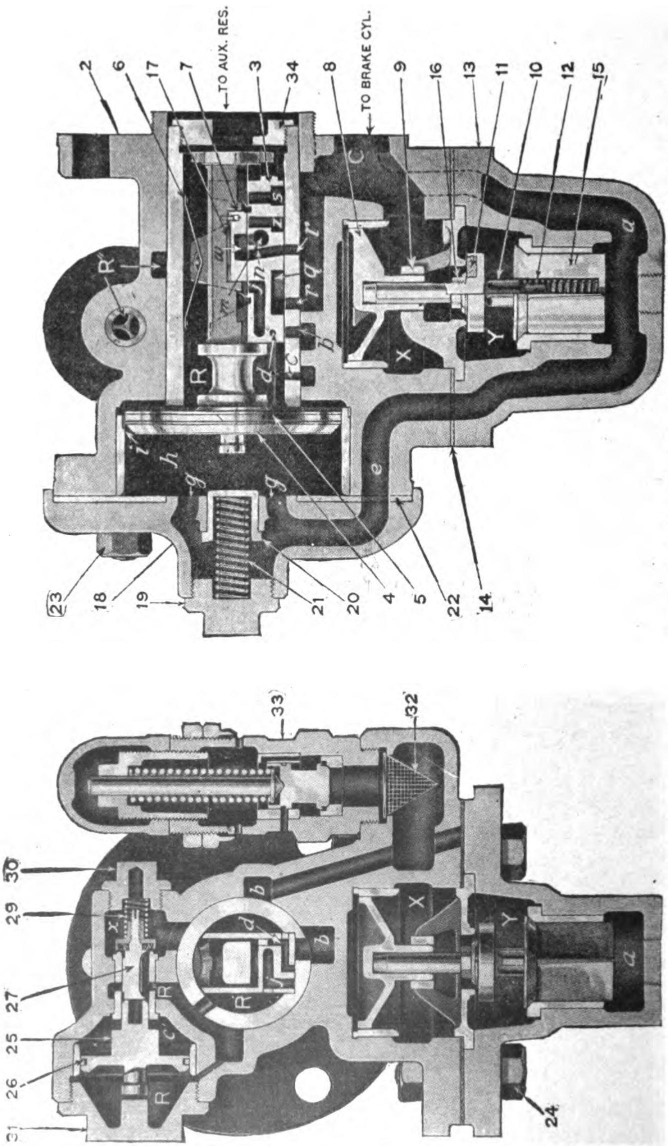


Fig. 60. Vertical Sections through Westinghouse Type "L" Triple Valve—Left, Section at Right Angles to Main Piston; Right, Section along Axis of Main Piston

namely, a heavy application at high speed, gradually reduced as the speed becomes moderate, with just enough brake-cylinder pressure left to complete the stop.

(4) *High emergency-cylinder pressure,* which greatly increases the available braking power over that obtained with a full-service reduction. As with the quick-action triple valve, the brake-pipe air is vented into the brake cylinder. The high emergency-cylinder pressure is made possible by using air from a supplementary reservoir, a reservoir about 2½ times the capacity of the auxiliary reservoir in addition to that from the auxiliary reservoir. The use of the supplementary reservoir also makes possible the graduated-release feature.

Two illustrations of the Type "L" triple valve are given in Figs. 58 and 59. Fig. 58 is a side view showing the safety valve in place. Fig. 59 is the opposite side of the valve showing the by-pass piston cap.

Fig. 60 shows two vertical cross sections of the Type "L" triple valve with all parts numbered, the names of the parts being as follows: *2* valve body; *3* slide valve; *4* piston; *5* piston ring; *6* slide-valve spring; *7* graduating valve; *8* emergency-valve piston; *9* emergency-valve seat; *10* emergency valve; *11* rubber seat for emergency valve; *12* check valve spring; *13* check-valve case; *14* check-valve case gasket; *15* check-valve; *16* emergency-valve nut; *17* graduating-valve spring; *18* cylinder cap; *19* graduating-spring nut; *20* graduating sleeve; *21* graduating spring; *22* cylinder-cap gasket; *23* bolt and nut for cylinder cap; *24* bolt and nut for check-valve case; *25* by-pass piston; *26* by-pass piston ring; *27* by-pass valve; *28* by-pass-valve seat; *29* by-pass-valve spring; *30* by-pass-valve cap; *31* by-pass-piston cap; *32* strainer; *33* safety valve; *34* end cap.

The Type "L" triple valve is built in three sizes for use in connection with brake cylinders of different sizes as follows: Triple valve "L-1" for 8- and 10-inch cylinders; "L-2" for 12- and 14-inch cylinders; "L-3" for 16- and 18-inch cylinders.

The "L" triple valve has several recognized positions quite similar to those mentioned for other triple valves already described. In explanation of the operation of the valve, reference will be made for the sake of clearness to the diagrammatic views shown in Figs. 61 to 64. In these figures certain parts are referred to by the use of abbreviations as follows: B.P. (brake pipe); S.R. (supplementary reservoir); B.C. (brake cylinder); A.R. (auxiliary reservoir); S.V. (safety valve); EX. (exhaust).

Release and Charging Position. The valve is illustrated in release and charging position in Fig. 61.

Air from the brake pipe enters through the passages *a*, *e*, *g*, and *h*, to the face of the triple-valve piston, forcing it to release position, thence through feed groove *i* to chamber *R* and the auxiliary reservoir. Brake-pipe air in passage *a* also raises the check valve *15*, and entering chamber *Y* flows thence through the ports

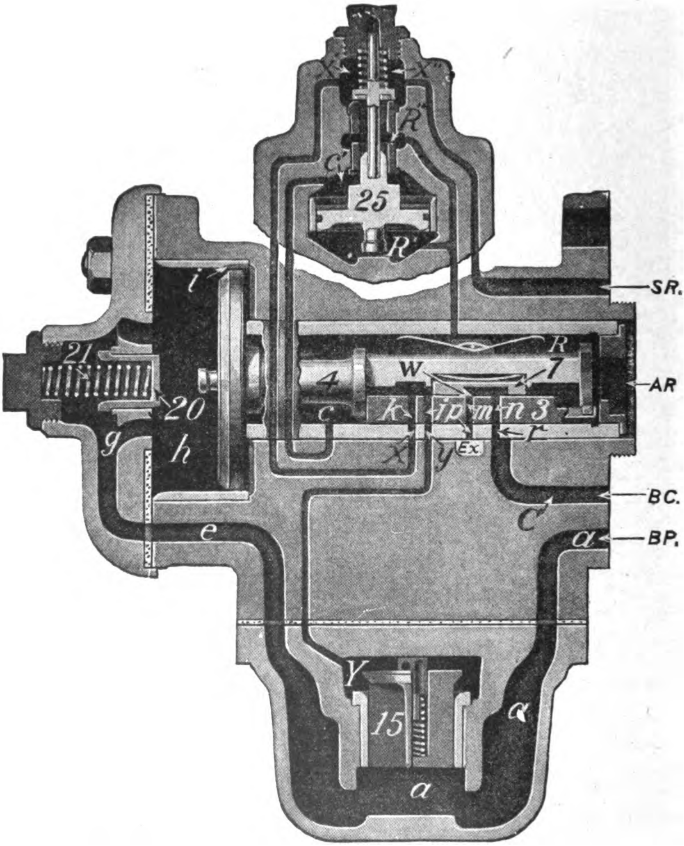


Fig. 61. Type "L" Triple Valve, Showing Release and Charging Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

y and *j* into chamber *R* and the auxiliary reservoir. This check valve then prevents any back flow of air from the auxiliary reservoir to the brake pipe. At the same time, port *k* registers with port *x*, and the air in chamber *R* also flows through these ports and *x'* and *x''* into the supplementary reservoir. Both the auxiliary and supplementary reservoirs are thus charged at the same time and to the same pressure from the brake pipe through the two different channels already mentioned.

With the parts in the above-mentioned position, air from the brake cylinder, entering the triple valve at *C*, flows through passage *r*, port *n*, large cavity *w* in the graduating valve, and ports *m* and *p* to the atmosphere, thus releasing the brake.

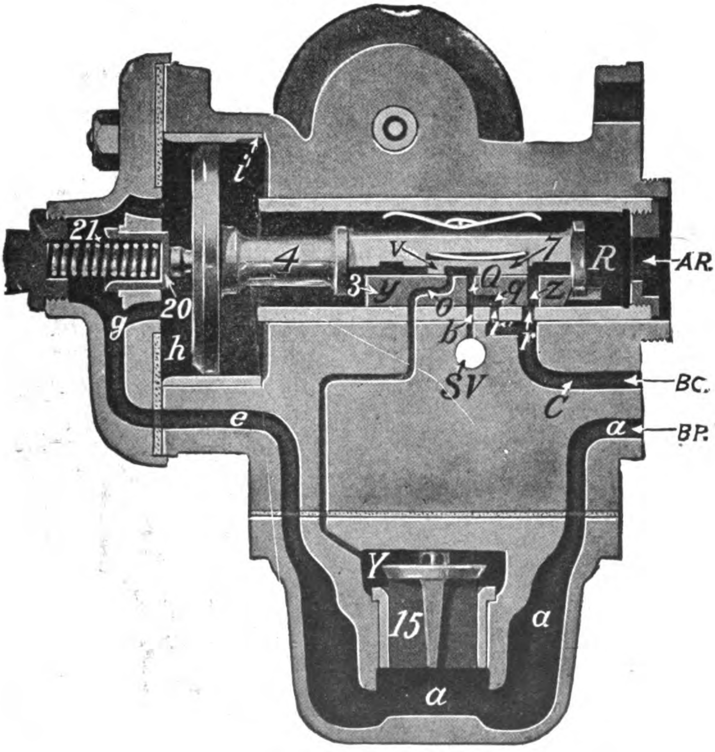


Fig. 62. Type "L" Triple Valve, Showing Quick-Service Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Service Application. A service reduction in brake-pipe pressure reduces the pressure in chamber *h* and on the face of the triple-valve piston below that in the auxiliary reservoir on the opposite side of the piston. The higher auxiliary reservoir pressure, therefore, forces the piston in the direction of the lower brake-pipe pressure, carrying with it the attached graduating valve. The first movement of the piston closes the ports *j*, *m*, and *k*, Fig. 61, thus shutting off communication between the brake pipe and the auxiliary and supplementary reservoirs and closing the exhaust passage from the brake cylinder to the atmosphere. The same movement opens port *z* and connects ports *Q* and *o* in the main slide valve through the small cavity in the graduating valve, Fig. 62. The spider, or lugs, on the end of the main slide valve, which is carried along with the piston and graduating valve as the reduc-

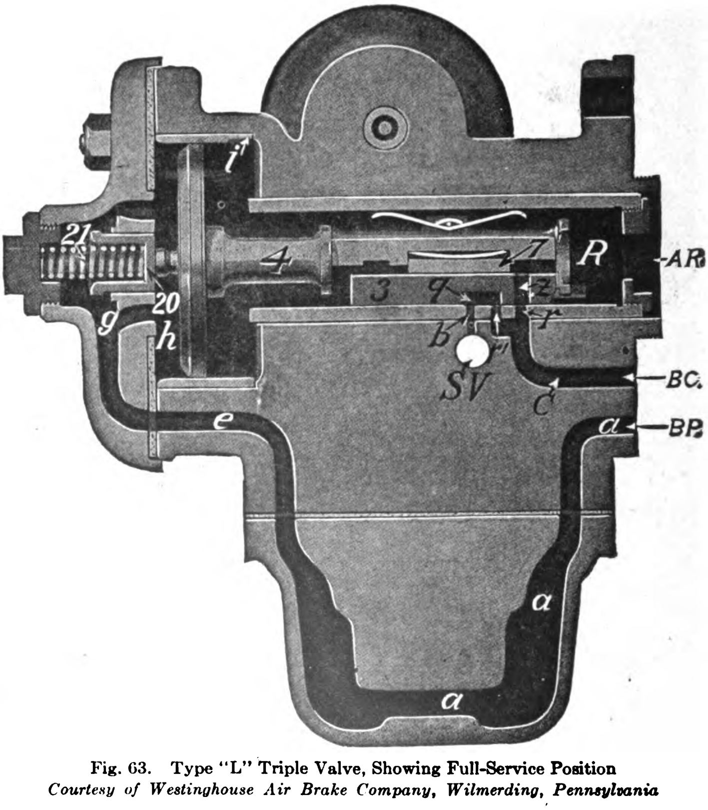


Fig. 63. Type "L" Triple Valve, Showing Full-Service Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

tion continues, finally brings the parts to *quick-service* position. Service port *z* in the slide valve registers with the brake-cylinder port *r* in the seat, permitting the air in the auxiliary reservoir to flow to the brake cylinder and apply the brakes. At the same time, the quick-service ports *o* and *Q*, cavity *q* in the slide valve, and the small cavity *v* in the graduating valve connect passage *y*, leading from the chamber *Y* in the check-valve case, with passage *r′* leading to the brake cylinder. This allows air from the brake pipe to lift the check valve and flow through the above-named ports to the brake cylinder. This constitutes the *quick-service* action of the triple valve, in that it causes a slight but definite reduction in break-pipe pressure locally at each valve. The amount of air vented from the brake pipe to the cylinder through the quick-service ports is not great in amount: first, because the ports and passages are small; and, second, because in the movement of slide valve *3* to full-service position the quick-service port *y* is restricted as it approaches this position and is completely closed just before the service port *z* is fully open. The amount by which the service port is opened depends in any given case upon the rate of reduction in break-pipe pressure as compared with that of the auxiliary reservoir. If the former is at first rapid as compared with the latter, which would be the case with short trains, the higher auxiliary-reservoir pressure moves the piston at once to *full-service* position, shown in Fig. 63, thus automatically cutting out the quick-service feature where it is not needed.

When in *full-service* position, the service port *z* is fully open and the quick-service port *o* is closed. This stops the flow of air from the brake pipe to the brake cylinder and the quick-service action ceases. The graduating spring is slightly compressed in the full-service position. In any case where the brake-pipe reduction is so rapid that the quick-service feature is of no advantage, the difference of pressure on the two sides of the triple-valve piston becomes at the same time sufficient to compress the graduating spring and automatically close the quick-service port. But if the brake-pipe reduction is less rapid or slow, as in the case of long trains or moderate-service reductions, a partial opening only of the service port is sufficient to preserve a balance between the pressure on the two sides of the triple-valve piston. The service port connecting the auxiliary reservoir to the brake cylinder is much larger than the quick-service port connecting the brake pipe to the brake cylinder. This serves to effectually prevent an emergency application being obtained when only a service application is desired.

During the time the slide valve *3* remains in quick- or full-service position the cavity *q* connects the brake-cylinder port *r′*

with port *b* leading to the safety valve, which is ordinarily set for 62 pounds. In event of the brake-cylinder pressure rising to 62 pounds, the safety valve acts and prevents further pressure increase in the brake cylinder.

Lap Position. After sufficient reduction of brake-pipe pressure has taken place to apply the brake to the desired amount, the flow of air from the auxiliary reservoir to the brake cylinder will reduce the pressure on the reservoir side of the triple-valve piston slightly below the brake-pipe pressure. The slightly excess pressure, together with the slightly compressed graduating spring, will move the piston and graduating valve to *lap* position. In this position all ports are blanked by the graduating valve, and the air flowing to the brake cylinder will be stopped. The slight difference in pressure which caused the piston to move is not sufficient to move the slide valve *3* when the piston-stem shoulder comes in contact with the slide valve. Therefore, there is no further movement of triple-valve parts until conditions are changed.

The *lap* position of the slide valve *3* is determined by the position previous to lap. The graduating valve is the only valve moved in obtaining *lap* position; so if the slide valve is in quick-service or full-service position, the lap position obtained will be quick-service lap or full-service lap.

Release and Recharge. When the brake-pipe pressure is increased to release the brake, the pressure on the brake-pipe side of the piston causes the piston to move, and with it the slide valve and graduating valve, to the extreme right, as shown in Fig. 61.

In this position the air in the brake cylinder is exhausted through ports *r* and *n*, the large cavity *w* in the graduating valve and port *m* to the exhaust passage *p* and atmosphere, as previously described. Meanwhile, the auxiliary reservoir is being recharged from the brake pipe through the ports *y* and *j* and feed groove *i*. At the same time, port *x*, leading from the supplementary reservoir, is open through port *k* to the auxiliary reservoir. The air, which was prevented from leaving the supplementary reservoir by movement of the slide valve to service position, now flows into the auxiliary reservoir and helps to recharge it.

During the time the slide valve is in release position, the pressures on the brake pipe and auxiliary reservoir sides of the triple-valve piston are always balanced. This is of importance, as it insures a quick response of the brakes to any reduction or increase in brake-pipe pressure irrespective of what operation may have occurred immediately preceding. The supplementary reservoir is at the same time being re-charged, as has been previously explained.

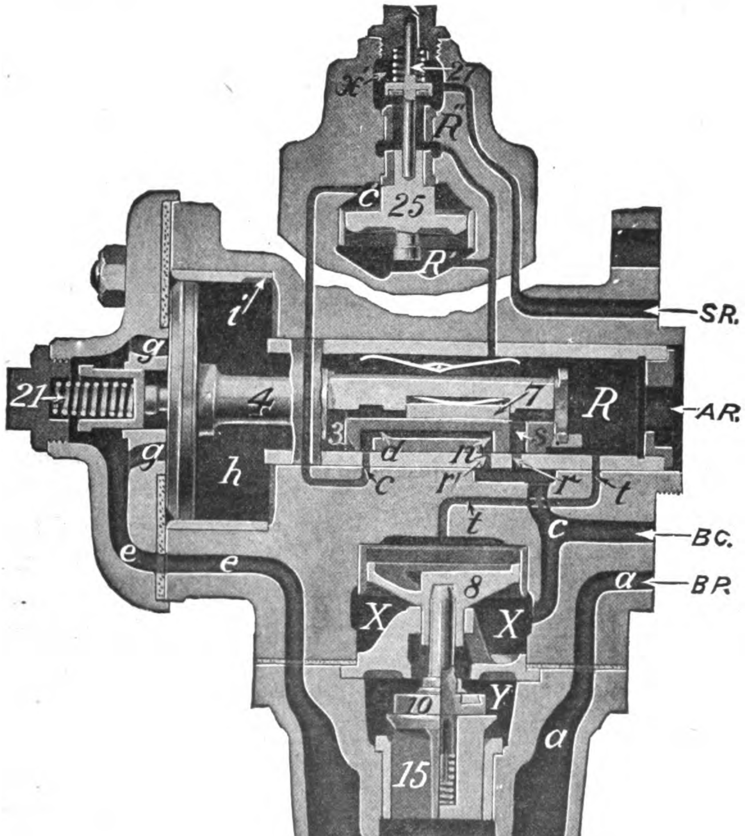


Fig. 64. Type "L" Triple Valve, Showing Emergency Position
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Graduated Release. Suppose that, after the brakes have been applied, only sufficient air is permitted to flow into the brake pipe to move piston *4* with the slide and graduating valve to release position, and the engineer's brake-valve handle is then returned to lap position. Then the flow of air from the supplementary reservoir through ports x and k to the auxiliary reservoir continuing after the rise in break-pipe pressure has ceased will raise the pressure on the auxiliary-reservoir side of the triple-valve piston slightly above that on the break-pipe side and cause the piston and its attached graduating valve to move to the left to graduated release-lap position.

In this position the graduating valve closes the exhaust port m, Fig. 61, thus preventing further flow of air from the brake cylinder to the atmosphere. It also closes port k—which prevents further recharging of the auxiliary reservoir from the supplementary reservoir—and port j and feed groove i, which cuts off the supply of air from the brake pipe to the auxiliary reservoir. Thus the brake is only partly released and a portion of the air pressure originally in the brake cylinder still remains there. In this way the brake may be released in a series of steps or graduations.

Emergency Position. When the brake-pipe pressure is reduced suddenly, or its reduction continues to be more rapid than that of the auxiliary-reservoir pressure, the piston is forced to the extreme left and compresses the graduating spring. The parts are then in emergency position, as shown in Fig. 64. In this position air from the auxiliary reservoir enters the brake-cylinder passage r through the port s in the main slide valve, instead of port z as in service application. Port t in the seat is also uncovered by the end of the main slide valve, thus admitting air from the auxiliary reservoir through port t to the top of the emergency piston. The air pressure thus admitted to the top of this piston pushes it down and forces the rubber-seated emergency valve from its seat. This allows the brake-pipe air in passage a to lift the emergency check valve and flow through chambers Y and X to the brake cylinder C in the ordinary way. At the same time, port d in the main slide valve registers with port c in the seat. This allows air from behind the by-pass piston to flow through ports c, d, and n to r' and the brake cylinder. As there is no pressure in the brake cylinder at this instant, the by-pass piston with its attached by-pass valve is forced upward, diagrammatically (or inward, actually) by the auxiliary-reservoir pressure acting on the lower (or outer) side of the piston. The air in the supplementary reservoir then flows past this valve into the passageway leading to the auxiliary reservoir. It thereby adds to the latter the volume of the supplementary reservoir. This gives, in effect, an auxiliary-reservoir volume approximately three and one-half times the size of the one which supplies air to the brake cylinder in service applications. Air from the supplementary reservoir continues to flow to the auxiliary reservoir until the pressure in the latter and that in the brake cylinder have risen nearly to that remaining in the supplementary reservoir. Communication

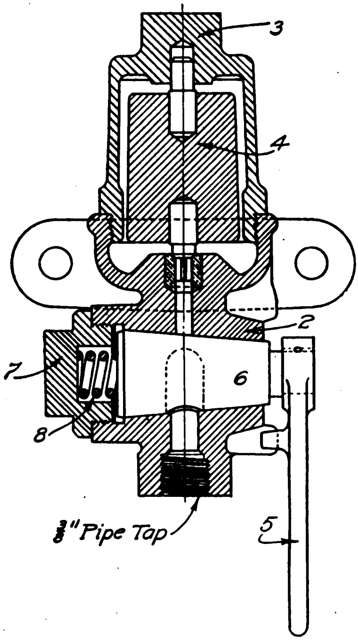


Fig. 65. Single-Pressure Retaining Valve, Open

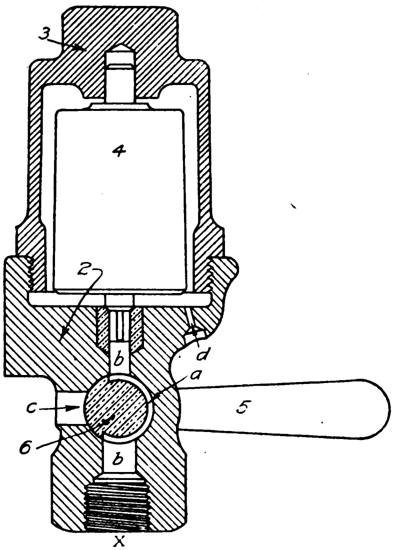


Fig. 66. Single-Pressure Retaining Valve, Closed

is then closed between the two reservoirs by means of the by-pass valve spring and valve.

In emergency position the communication with the safety valve is cut off and the pressure is held until the brake is released.

MISCELLANEOUS TYPES OF VALVES

Pressure Retaining Valve. The pressure retaining valve is a regular part of all freight car equipment and is furnished with passenger car equipments only on special order. It is usually fastened on the end of the car, by means of lag screws, in a convenient position, and is connected to the triple-valve exhaust port by the retaining-valve pipe. Pressure retaining valves are built in two types: namely, plain, or single-pressure; and combined high- and low-pressure.

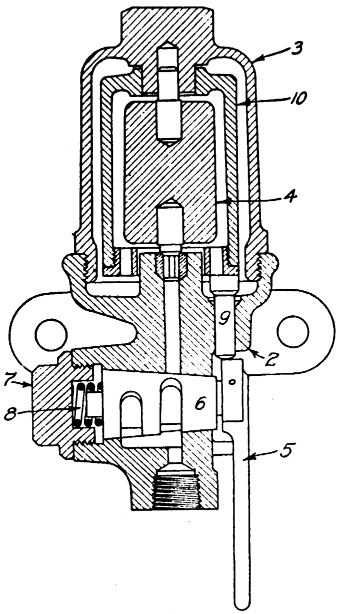


Fig. 67. High- and Low-Pressure Retaining Valve Section

The plain, or single-pressure, retaining valve, Figs. 65 and 66, consists of a plug cock *6* connected to the retaining valve pipe at *X* and having two outlets, one to the atmosphere and the other to the retaining valve proper. This latter consists of a weighted valve *4* normally resting on a seat *2* and holding port *b* closed. When the handle *5* of the retaining valve is turned down, the groove *a* in the cock key connects port *b* and the outlet *c* to the atmosphere. Consequently, when "turned down" the triple-valve exhaust is open through tne retaining-valve pipe, port *b*, groove *a*, and exhaust port *c* to the atmosphere. When the retaining-valve handle is "turned up" to the horizontal position, Fig. 66, groove *a* connects port *b* below the cock key with port *b* above it, so that when a release is made, the air exhausting from the brake cylinder flows to the retaining valve and through port *b*, cavity *a*, and upper port *b* to the weighted valve *4*, which it must lift in order to flow past valve *4* to the atmosphere through the small port *d*. The weight *4* is capable of retaining a pressure of 15 pounds in the brake cylinder. As long as the pressure of the air from the brake cylinder is greater than this, it holds the valve *4* from its seat and the air exhausts to the atmosphere through port *d*, which, being

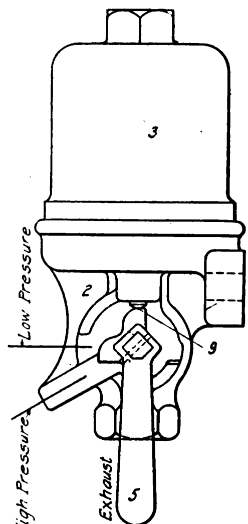


Fig. 68. High- and Low-Pressure Retaining Valve, Showing Three Positions

small, makes the release of the brake much slower than when the retaining valve is not used. When the pressure has been reduced to 15 pounds, it is no longer able to hold the weighted valve *4* off its seat and the valve then closes and the remaining 15 pounds is retained in the brake cylinder until the handle *5* is turned down. When used on vestibuled passenger cars, the valve is provided with an extension handle to permit of its being conveniently operated from the platform.

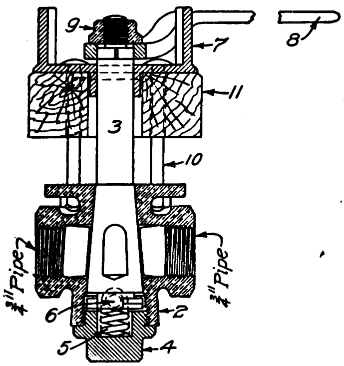


Fig. 69. Simple Conductor's Valve

High- and Low-Pressure Retaining Valve. Under extreme conditions of heavily loaded trains on grades, it is often necessary to provide for retaining more than 15 pounds in the brake cylinder. The high- and low-pressure retaining valve, Fig. 67, is used for this purpose. This is similar to the valve just described except that a cylindrical weight *10*, surrounding the usual weighted valve *4*, is added. When the handle *5* is "turned down", air from the brake cylinder passes freely to the atmosphere, as explained, and a lug on handle *5* raises the lifting pin *9* and the outer weight *10* so that the smaller weight *4* alone rests on the valve seat and the wear is reduced to a minimum. When the handle is "turned up" to a horizontal position, as in the case of the plain, or single-pressure, retaining valve, another lug on the handle raises lifting pin *9* and the outer weight *10* so that the smaller weight *4* alone acts to retain 15 pounds pressure in the brake cylinder in the manner already described.

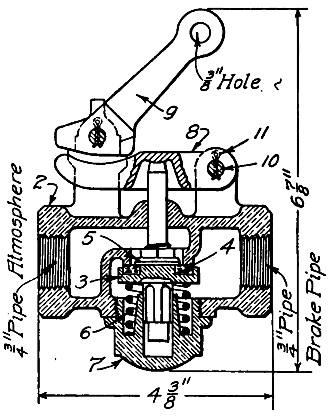


Fig. 70. "B-3-A" Conductor's Valve

When it is desired to retain a higher pressure in the brake cylinder, the handle is placed in the intermediate position marked "High Pressure", Fig. 68. This permits the lifting pin *9* to drop away from the outer weight *10*, Fig. 67, which then rests on the inner weight *4* and the air pressure must then lift both weights, the combined weight of which is capable of retaining 30 pounds in the brake cylinder before it can escape to the atmosphere. Conditions in some sections of the country require relatively lower pressures to be retained. To meet this demand, retaining valves are built to retain

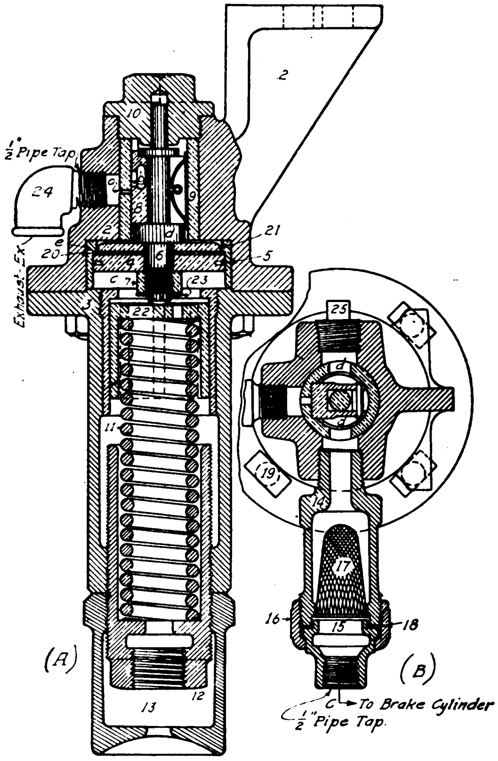


Fig. 71. Westinghouse High-Speed Reducing Valve

pressures from 10 to 25 pounds. Where it is desired to retain higher pressures, they are built as high as 50 pounds.

Conductor's Valve. The conductor's valve, Fig. 69, is a part of all passenger car equipments and is now in common use. Fig. 70 illustrates the type of valve now being furnished. It is connected to a branch pipe leading from the brake pipe and is conveniently located inside of the car, so that in case of an emergency or necessity it can be reached. Frequently a cord is attached to the handle which runs the entire length of the car and permits of the opening of the valve with the least possible delay. The valve most commonly used is of the non-self-closing plug-cock type. When the valve is opened, it permits air from the brake pipe to escape freely to the atmosphere, causing a quick-action application of all brakes in the train. After making a stop in this manner, the valve must be closed before the brake pipe and system can be re-charged and the brakes released.

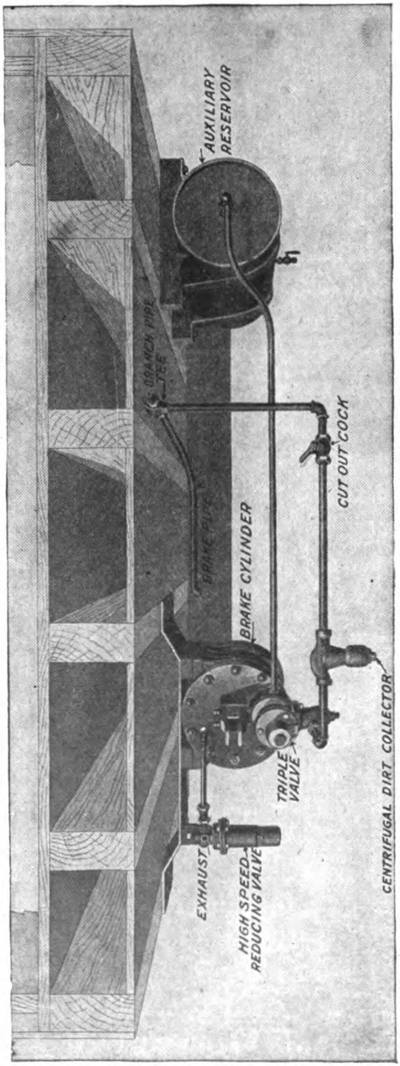


Fig. 72. Westinghouse High-Speed Reducing Valve Applied to Car

High-Speed Reducing Valve. It has been known for a good many years that as the speed of the train is increased, the maximum brake-shoe pressure may also be increased without danger of skidding the wheels. That is, a train going at a speed of 80 miles an hour would require a much greater brake-shoe pressure to skid the wheels than a train going 5 miles an hour. This fact has been taken advantage of in the design of the high-speed brake equipment. Instead of carrying a brake-pipe pressure of 70 pounds, a much higher pressure is used, the usual pressure being 110 pounds. When a full-service application is made, about 85 pounds pressure is obtained in the brake cylinder. If this pressure were allowed to continue in the brake cylinder until the train stopped, there would be danger of skidding the wheels. In order to prevent this, a valve known as the automatic high-speed reducing valve is used. The construction of this valve is shown in Fig. 71 and Fig. 72 illustrates the application of the valve to a car.

Method of Action. When air enters the brake cylinder from the auxiliary reservoir, it has free access to the reducing valve through a pipe at *C* in section *B*, Fig. 71, so that chamber *d* above piston *4* is always subject to brake-cylinder pressures. Regulating spring *11*, adjusted by nut *12*, provides a resistance to the downward movement of piston *4*, which is finally stopped by spring box *3*. Connected to piston *4* is its stem *6*, fitted with two collars which control the movements of slide valve *8*. Slide valve *8* is provided with a triangular port *b* in its face, which is always in communication with chamber *d*. Port *a* in the slide valve seat leads directly to the atmosphere through exhaust opening *Ex*.

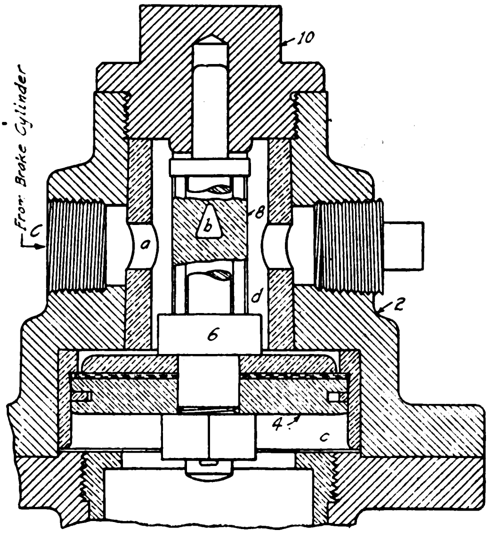


Fig. 73. Position of Ports for Release Position

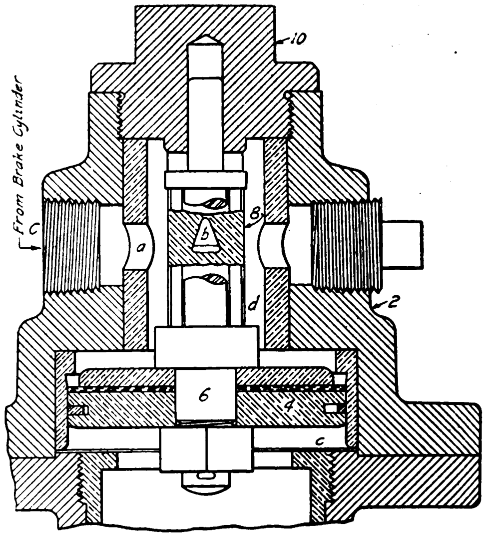


Fig. 74. Position of Ports, Service Stop, Pressure Exceeding 60 Pounds in Brake Cylinder

Normal Position. Fig. 71*A* shows slide valve *8* and its piston *4* in normal positions, which are held if brake-cylinder pressure does not exceed 60 pounds.

Release Position. In release position, Fig. 73, it will be noted that port *b* of slide valve *8* does not register with port *a* of its seat, so that when the brakes are applied they will remain so until released in the usual way, unless the brake-cylinder pressure becomes sufficiently great to overcome the tension of spring *11* and force piston *4* downward.

Heavy-Service Application. When the brake-cylinder pressure begins to exceed 60 pounds, in a heavy-service application, the pressure upon piston *4* moves it downward until port *b* in the slide valve registers with port *a* in its seat, as shown in Fig. 74, in which position any surplus brake-cylinder pressure is promptly discharged to the atmosphere. The spring then raises the piston and slide valve to their normal positions, closing the exhaust port and retaining 60 pounds pressure in the brake cylinder. In the operation just described, the greatest width of port *b* is exposed to port *a*, and these ports are so proportioned that, in this particular position, the surplus air is discharged from the cylinder fully as rapidly as it is admitted through the service-application port of the triple valve.

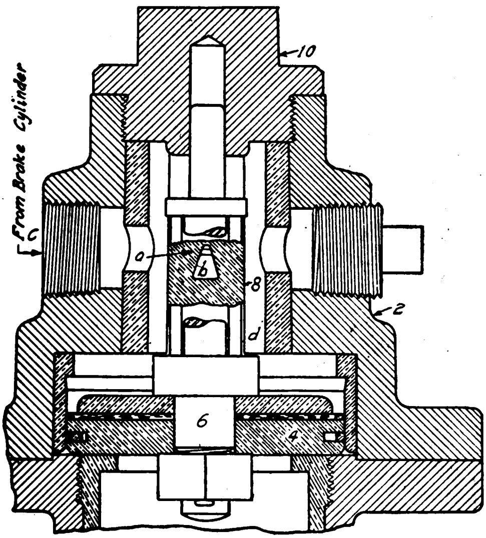


Fig. 75. Position of Ports, Emergency Stop for Westinghouse High-Speed Reducing Valve

Emergency Application. In an emergency application of the brakes, the rapid admission of a large volume of air to the brake cylinder raises the pressure more quickly than it can be discharged through the service port of the pressure-reducing valve. Under these conditions, piston *4* of the high-speed reducing valve, Fig. 75, is forced to the lower end of its stroke, in which position the apex of triangular port *b* in the slide valve is brought to register with port *a*, thus restricting the discharge of air from the brake cylinder in such a manner that the pressure in the brake cylinder does not become reduced to 60 pounds until the speed of the train has been very materially decreased; but the area of the opening of port *b* gradually increases as the reducing pressure above piston *4* permits the spring to raise the piston and slide valve slowly. The rate of the discharge thus increases as the speed of the train decreases, until finally, when the brake-cylinder pressure has become reduced to 60 pounds, port *a* is closed, and the remainder of the brake-cylinder pressure is retained until released in the usual way through the triple valve.

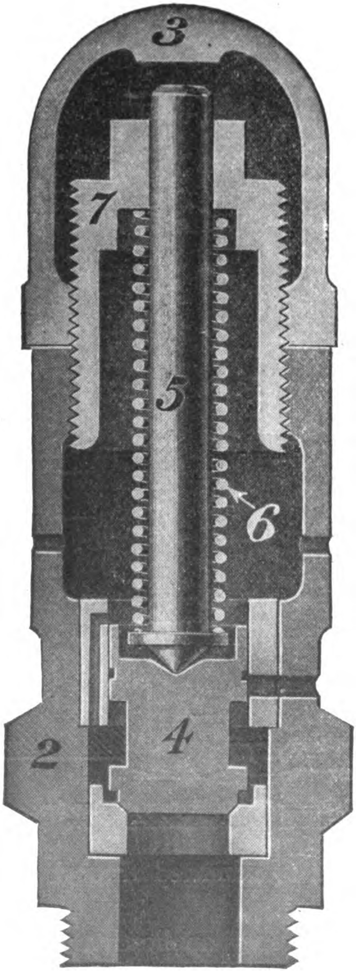


Fig. 76. "E-6" Safety Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

When an emergency application of the brakes occurs at high speeds, there is little danger of wheel sliding, and it will be observed that port *b* is so shaped that brake-cylinder pressure escapes slowly at such time, as already explained; while, at lower speeds, where a heavy-service application is more likely to occur and there is a greater tendency toward wheel sliding, the base of triangular port *b* is exposed, allowing brake-cylinder pressure to reduce quickly.

Cars not equipped with the reducing valve should not be attached to trains employing the high-speed brake equipment unless the brake cylinders are equipped with a safety valve provided for temporary use in such cases.

"E-6" Safety Valve. The "E-6" safety valve forms an important part of several different air-brake equipments. This is especially true of the "ET" locomotive brake equipment. Its form of construction and operation is clearly shown in Fig. 76, which is a vertical section of the valve. Its construction is such as to cause it to close quickly with a *pop* action, which insures a firm seating. Valve *4* is held to its seat by the compression of spring *6*. When the pressure

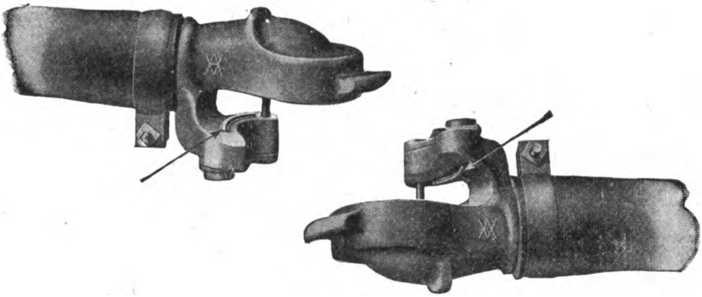


Fig. 77. Hose Protecting Coupling, Showing Flexible Head
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

below valve *4* overcomes the spring pressure above, it rises until valve stem *5* is stopped by cap nut *3*. The air in discharging passes around valve *4* and out at ports in the body *2*, one of which is shown. As the pressure drops, valve *4* moves downward slightly and partly closes the discharge ports in the body *2*. Air then flows to the spring chamber and assists the spring in closing the valve, thus assisting in the "pop" action referred to above.

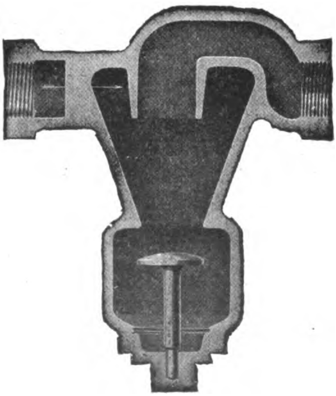


Fig. 78. Centrifugal Dirt Collector
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Two of the important brake-pipe fittings are shown in Figs. 77 and 78, Fig. 77 showing the scheme used in joining the flexible hose between cars. When uncoupled, the hose should always be attached to the dummy coupling to keep the hose from being injured by swinging and to prevent cinders and dirt from getting into the brake pipe. The hose should always be parted by hand and not pulled apart by the separation of the cars. Fig. 78 illustrates the type of centrifugal dirt collector. It is placed in the branch pipe leading to the triple valve. The centrifugal dirt collector replaces the older form of strainer which has been common for a number of years. It can be cleaned by removing the plug at the bottom.

BRAKES AND FOUNDATION BRAKE GEAR

General Requirements. The foundation brake gear includes all levers, rods, beams, pins, etc., which serve to transmit the braking force from the piston of the brake cylinder to the brake shoes. It is important that all longitudinal rods should be parallel with the center line of the car, when the brakes are fully applied. The brake beams should be hung in such a manner that they will always be the

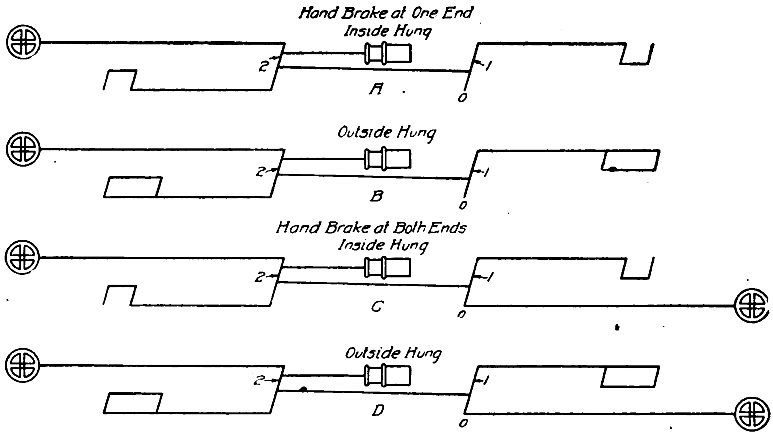


Fig. 79. Foundation Brake-Gear Systems Adopted by Master Car Builders' Association

same distance above the rail, the reason being that this practice reduces the chance for flat wheels, since the piston travel is not affected by the loading or unloading of the car. The rods and levers should be designed so that they will move in the same direction when the brakes are applied by hand as when by air. The levers should stand approximately at right angles to the rods, when the brakes are set.

A number of different systems of rods and levers have been used by different railroad companies, with varying degrees of success. The systems adopted by the Master Car Builders' Association are diagrammatically shown in Fig. 79. The four cases shown represent two general systems—those where the brake shoes are hung inside, between the truck wheels; and those where they are hung outside. Freight cars are generally fitted with the brake shoes hung inside, while the passenger cars usually have the brake shoes hung outside. In the first two cases (*A* and *B*), the brake can be applied by hand from only one end of the car; while in the other two cases (*C* and *D*), the brake can be operated by hand from either end. In applying the brake by hand in any case, the coil spring in the brake cylinder offers no resistance, since the push rod has no pin connection to the piston rod. The piston rod of the brake cylinder is hollow. When the brake is operated by hand, the push rod slides outward in the hollow rod without moving the piston. A detailed description of the operation of the four cases shown is not thought necessary. One or two points, however, might assist to a clearer understanding of them. The lower end of the lever *1* in *A* and *B* is fixed at *O*. The lower end of the lever *1* in *C* and *D* is held by a stop at *O* and cannot move to the left, but is free to move to the right when the brake is operated by hand from the right-hand end of the car. The lever *2* in all four cases has no fixed points. In all cases, the arrangement is such that no brake shoe will

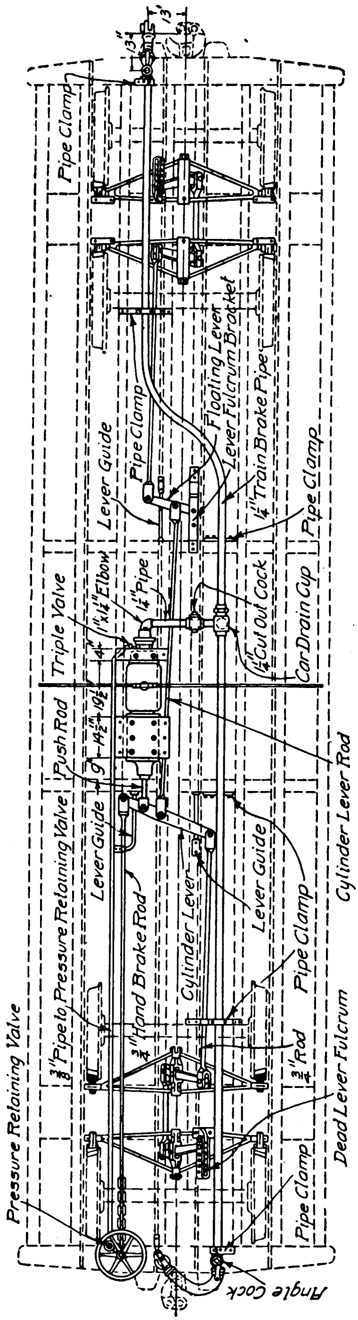
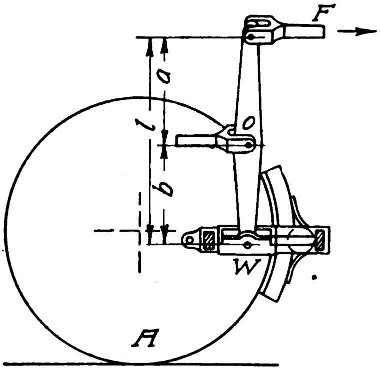


Fig. 80. Application, to a Freight Car, of Inside-Hung Brake-Gear System Shown at A in Fig. 79



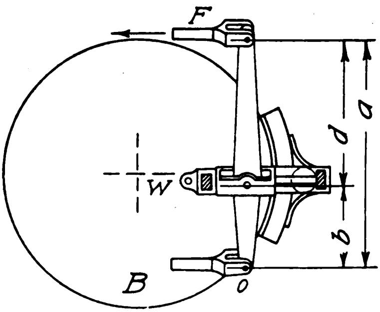
$$W = \frac{F \times a}{b};$$

$$F = \frac{W \times b}{a}; \quad l = a + b;$$

$$a = \frac{W \times b}{F}; \text{ or, } a = \frac{W \times l}{F + W};$$

$$b = \frac{F \times a}{W}; \text{ or, } b = \frac{F \times l}{F + W}.$$

FULCRUM BETWEEN APPLIED AND DELIVERED FORCES



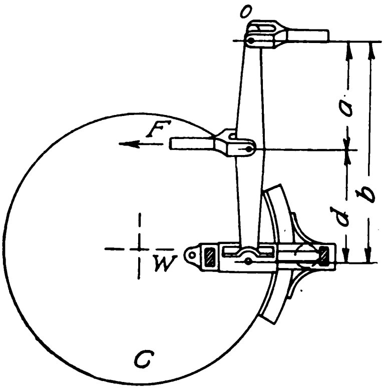
$$W = \frac{F \times a}{b};$$

$$F = \frac{W \times b}{a}; \quad a = b + d;$$

$$a = \frac{W \times b}{F}; \text{ or, } a = \frac{W \times d}{W - F};$$

$$b = \frac{F \times a}{W}; \text{ or, } b = \frac{F \times d}{W - F}.$$

DELIVERED FORCE BETWEEN FULCRUM AND APPLIED FORCE



$$W = \frac{F \times a}{b};$$

$$F = \frac{W \times b}{a}; \quad b = a + d;$$

$$a = \frac{W \times b}{F}; \text{ or, } a = \frac{W - d}{F - W};$$

$$b = \frac{F \times a}{W}; \text{ or, } b = \frac{F \times d}{F - W}.$$

APPLIED FORCE BETWEEN FULCRUM AND DELIVERED FORCE

Fig. 81. Illustrating Application of Principle of Moments to Levers in Brake Systems

press against its wheel with any great force until all brake shoes are held firmly against their respective wheels, and all shoes press against the wheels with an equal force. Fig. 80, with the various parts named, shows the application of case *A* of Fig. 79 to a freight car.

Leverage. It is a well-known principle in Mechanics, that the greater the weight on a car wheel, the greater the brake-shoe pressure necessary to cause it to slide or skid on the track. For this reason, in designing the brake levers, rods, etc., for a freight car, the light or unloaded weight of the car is the basis of all calculations. If the loaded weight of the car were used in the calculations, the proportions would be such that if the brakes were applied when the car was unloaded the wheels would slide. In order to prevent as far as possible chances arising of having flat spots worn on the wheels, due to wheels sliding on the track, the following percentages of light weights on the wheels are usually, but not always, employed in determining the brake-shoe pressure:

Passenger cars.........	90 per cent
Freight cars...........	70 per cent
Tenders...............	100 per cent
Locomotive drivers	75 per cent (of weight on drivers)
Locomotive truck......	75 per cent (of weight on truck)

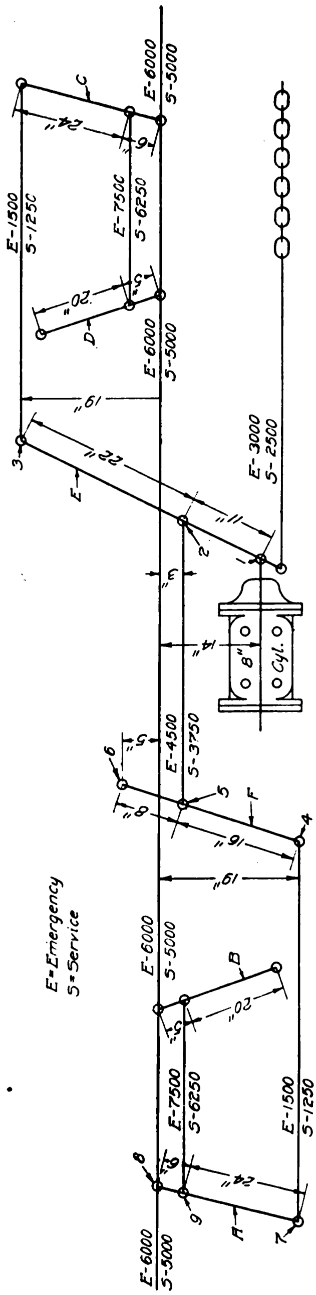


Fig. 82. Scheme of Levers and Rods Commonly Used on Freight Cars

It is frequently found necessary to change these percentages in order to meet special conditions which arise.

In calculating the brake-shoe pressure of any car the following three things must be known: *First*, the diameter of the brake cylinder and its maximum pressure; *second*, the sizes and positions of all levers in the system; and *third*, a working knowledge of the theorem of moments as used in Mechanics.

The principle or theorem of moments may briefly be stated as follows: *The product of the force applied at one pin and its perpendicular distance from the fulcrum pin is equal to the product of the force delivered at the other pin and its perpendicular distance from the fulcrum pin.* This principle has been applied to the three different classes of levers, and the forces and distances worked out, Fig. 81. The chief difficulty the amateur experiences is in locating the fulcrum pin. In *A*, *B*, and *C*, Fig. 81, the fulcrum pin is located at *O*, the force applied is *F*, and the force delivered is *W*. In any case, if the pull *F* on the lever is known, the brake-shoe pressure *W* can be determined.

Fig. 82 represents diagrammatically the scheme of levers and rods commonly used on freight cars. All distances of rods from the center line of the car are taken when the levers are at right angles to it. The brake cylinder on a certain freight car, taken as an illustration, is 8 inches in diameter, and has an area of about 50 square inches. If the maximum brake-cylinder pressure in emergency applications is 60 pounds, the total pressure delivered to the push rod would be 50×60, or 3000 pounds. This 3000 pounds is transmitted to the lever *E* at the pin *1*. The lever *E* is of the class shown in *B*, Fig. 81, and its fulcrum is at the pin *3*. Applying the formula gives 4500 pounds delivered at the pin *2*. This 4500 pounds is transmitted to the lever *F*, which is of the class shown in *C*, Fig. 81, and its fulcrum is at the pin *6*. Applying the formula gives 1500 pounds delivered at the pin *4*. This 1500 pounds is transmitted to the lever *A*, which is of the class shown in *A*, Fig. 81, and its fulcrum is at the pin *9*. Applying the formula gives 6000 pounds delivered to the brake beam at the pin *8*. In a similar manner the other brake-beam pressures can be determined. In the figure, the calculation has been carried through for both service and emergency applications.

It is seen that 6000 pounds is transmitted to the middle of each of the four brake beams. Each brake shoe will then receive a pressure of 3000 pounds. Since there are eight wheels, the total braking pressure will be 8×3000, or 24,000 pounds. This total braking pressure must not exceed 70 per cent of the unloaded weight of the car.

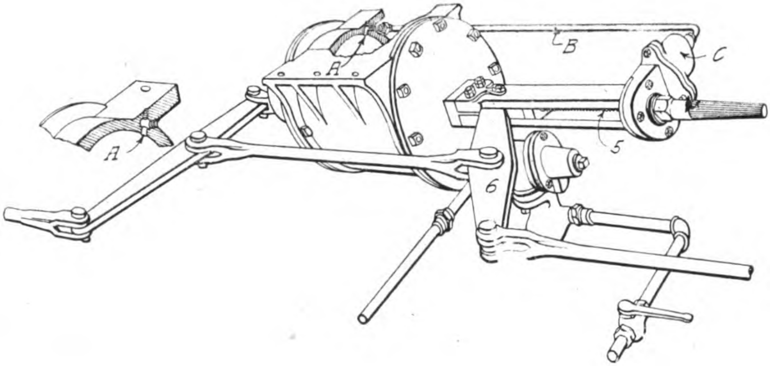


Fig. 83. Automatic Slack-Adjuster.

Automatic Slack-Adjuster. Full braking pressure will be secured as long as the maximum allowable brake-cylinder pressure can be maintained. Since the brake-cylinder pressure depends upon the length of stroke of the piston, it follows that the stroke of

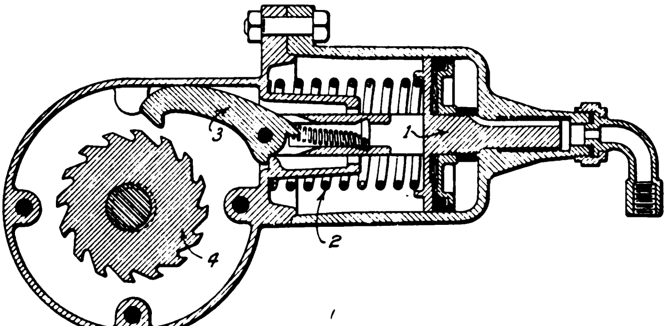


Fig. 84. Part Sectional View of Automatic Slack-Adjuster

the piston should be kept as nearly constant as possible. The greater the stroke, the less the pressure. The stroke of the piston should be kept at about 8 inches. As the brake shoes and various connections wear, the stroke of the piston is increased, and the pres-

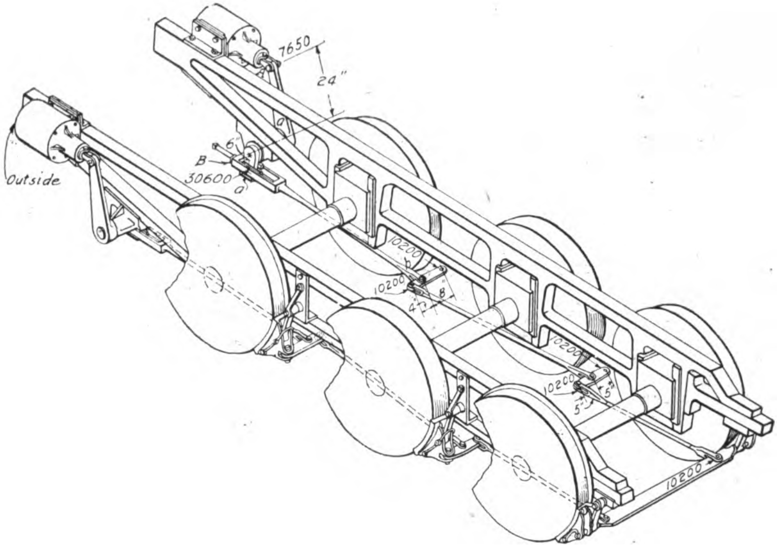


Fig. 85. Outside Equalized Driver-Brake for Locomotives

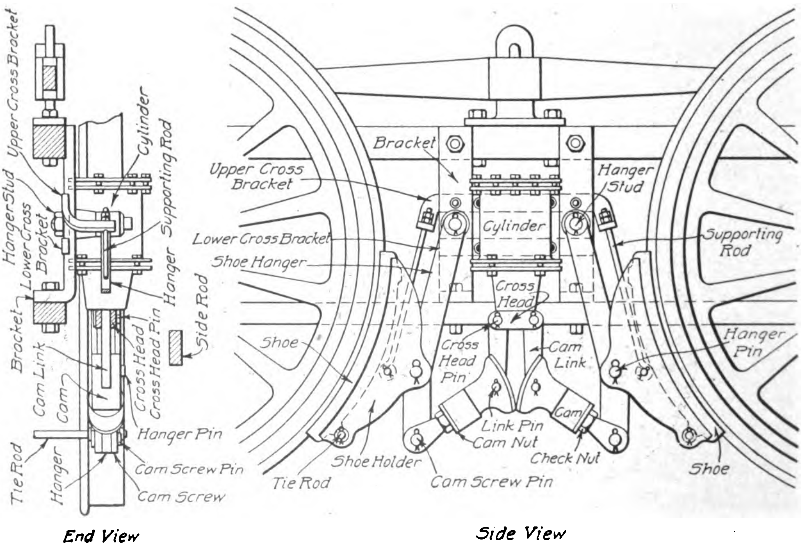


Fig. 86. Cam Driver-Brake for Locomotives

sure with which the shoes are forced against the wheels is decreased. In order to compensate for this wear, some means must be provided for taking up the slack. This is done in one of two ways—by changing the fulcrum pin of the dead lever (see Fig. 80) or by using the automatic slack-adjuster. The first method of adjustment is the one most commonly used and is necessarily very coarsely graded. The automatic slack-adjuster, when used at all, is usually fitted to the passenger car equipment.

The automatic slack-adjuster, Figs. 83 and 84, is manufactured by the Westinghouse Air Brake Company. The purpose of the

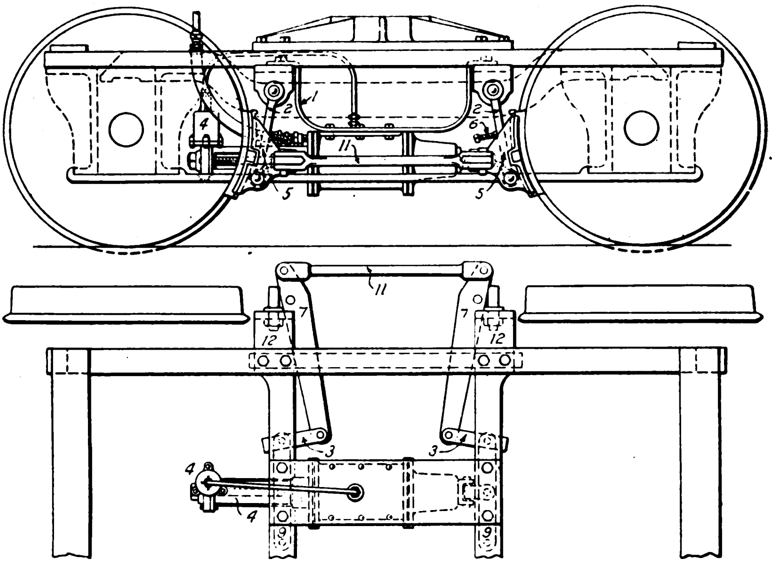


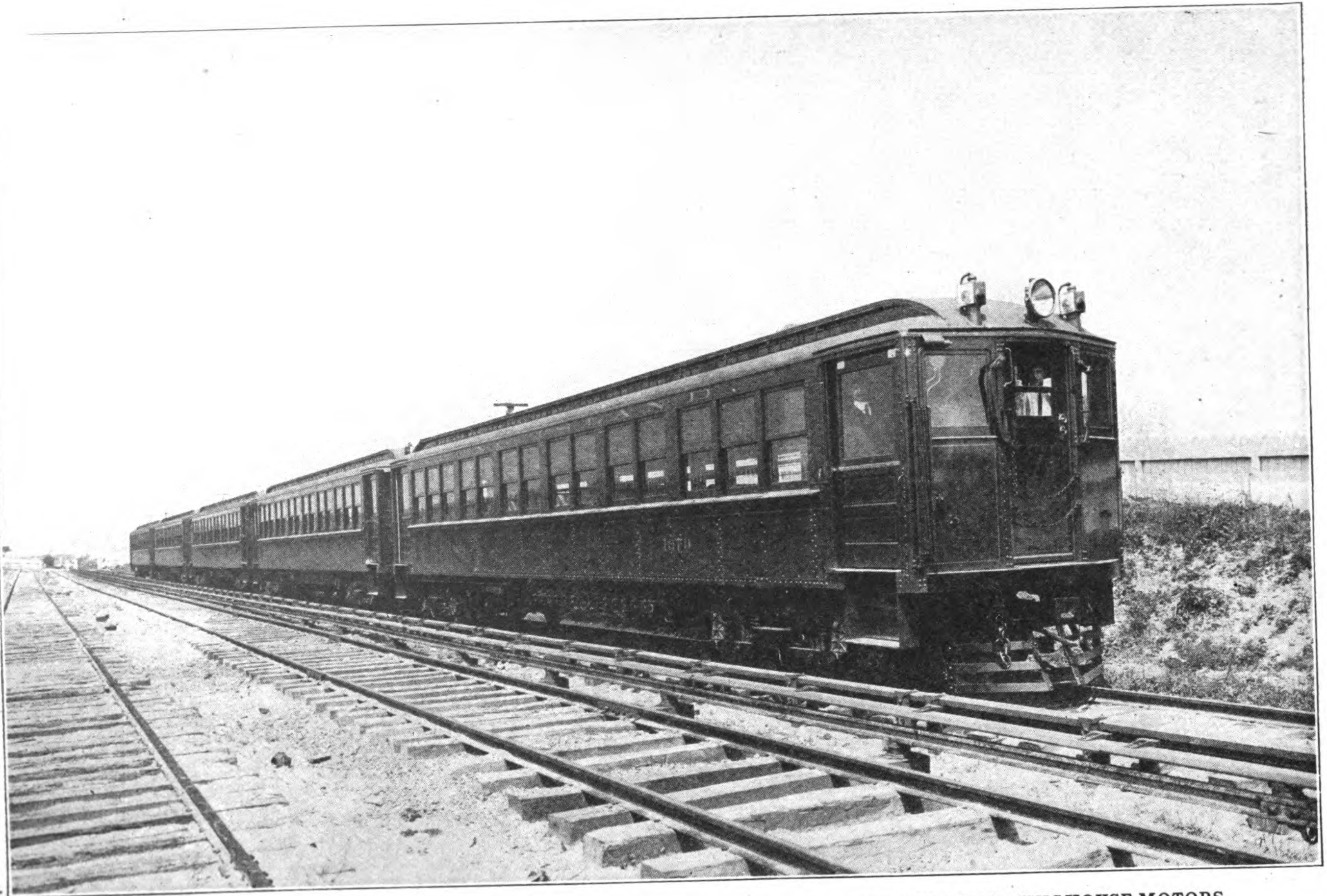
Fig. 87. Locomotive Truck Brake

apparatus is to maintain a constant, predetermined piston travel. The brake-cylinder piston acts as a valve to control the admission and release of air to pipe *B* through port *A*. Whenever the stroke of the brake-cylinder piston is so great that port *A* is passed by the piston, air from the cylinder enters port *A* into pipe *B* and enters cylinder *C*, which is shown in section in Fig. 84. The air entering the small cylinder acts on piston *1*, forcing it to the left, compressing spring *2*, and causing the small pawl *3* to engage the ratchet wheel *4*. When the brake is released, the brake-cylinder piston returns, and air in the small cylinder *C* escapes to the atmosphere through pipe *B* and port *A*, thus permitting spring *2* to force piston *1* to its normal position. In so doing, pawl *3* turns the ratchet wheel *4* on screw *5*, and thereby draws the fulcrum end of lever *6* slightly nearer the slack-adjuster cylinder *C*. Each operation of piston *1*, as just described, reduces the brake-cylinder piston travel about $\frac{1}{32}$ of an inch. When piston *1* is in its normal position, the outer end of pawl *3* is lifted, permitting screw *5* to be turned by hand.

Locomotive Driver Brakes. The brakes are applied to the drivers of a locomotive in two general ways—by the outside equalized system, Fig. 85, and by cams, Fig. 86. The former scheme has practically replaced the latter, because of its simple design and adjustment. In the system, Fig. 85, the levers are proportioned so that each wheel receives the same braking pressure. If the brake cylinders are each 14 inches in diameter and the cylinder pressure is 50 pounds, the pressure delivered at pin *A* is about 7650 pounds, while that on each wheel is 10,200 pounds. These values vary for different locomotives. The stroke of the piston is regulated by the adjustment mechanism at *B*.

The action of the cam-driver brake is shown in Fig. 86. When air is admitted to the brake cylinder, the piston is forced downward. This action pushes down the crosshead cams, which force the brake shoes against the drivers. The piston travel is controlled by adjusting the cam nut on each cam.

Locomotive Truck Brakes. In certain types of locomotives, a considerable proportion of the weight of the locomotive is carried on the truck. It follows, that in order to develop the full braking power of the locomotive, a well-designed truck brake should be provided. The type of brake shown in Fig. 87 is now quite common. It is fitted with an automatic slack-adjuster, but this feature is not so important here as on the car equipment.



MULTIPLE-UNIT CONTROL ELECTRIC TRAIN ON LONG ISLAND RAILROAD, EQUIPPED WITH WESTINGHOUSE MOTORS AND CONTROL APPARATUS

Courtesy of Westinghouse Electric and Manufacturing Company

AIR BRAKES

PART II

MODERN BRAKE EQUIPMENT

FUNDAMENTAL TYPES

High-Speed Brake Equipment. The high-speed brake equipment, Fig. 88, is a modification of the quick-action brake and can be used in passenger service. The parts not found on the ordinary equipment are as follows: Type "E" safety valve, high-speed reducing valve, reversing cock, feed-valve bracket, and an additional feed valve.

Action of Reversing Cock. The locomotive equipment may be changed from the quick-action to the high-speed brake by simply turning the reversing-cock handle. When this handle is in the position opposite to that shown in Fig. 88, the 70-pound feed valve is in service, so that the locomotive is ready to operate the ordinary quick-action brake; when the brake-valve handle is in running position, 70 pounds pressure is carried in the brake pipe, and the compressor will slow down when main-reservoir pressure reaches 90 pounds. If, however, the brake-valve handle is in lap, service, or emergency-application position, main-reservoir pressure is cut off from the excess-pressure head, and the compressor will continue to operate until the main-reservoir pressure reaches the limit set by the maximum pressure head, to insure available pressure promptly to release and re-charge the brakes on long and heavy trains.

If the reversing-cock handle be turned to the position shown, the 110-pound feed valve will become operative, giving 110 pounds brake-pipe pressure, which results in a corresponding increase in main-reservoir pressure depending upon the adjustment of the maximum pressure head of the governor.

Principles Involved. The principles involved in the high-speed brake are (a) the friction between the brake shoe and the wheel,

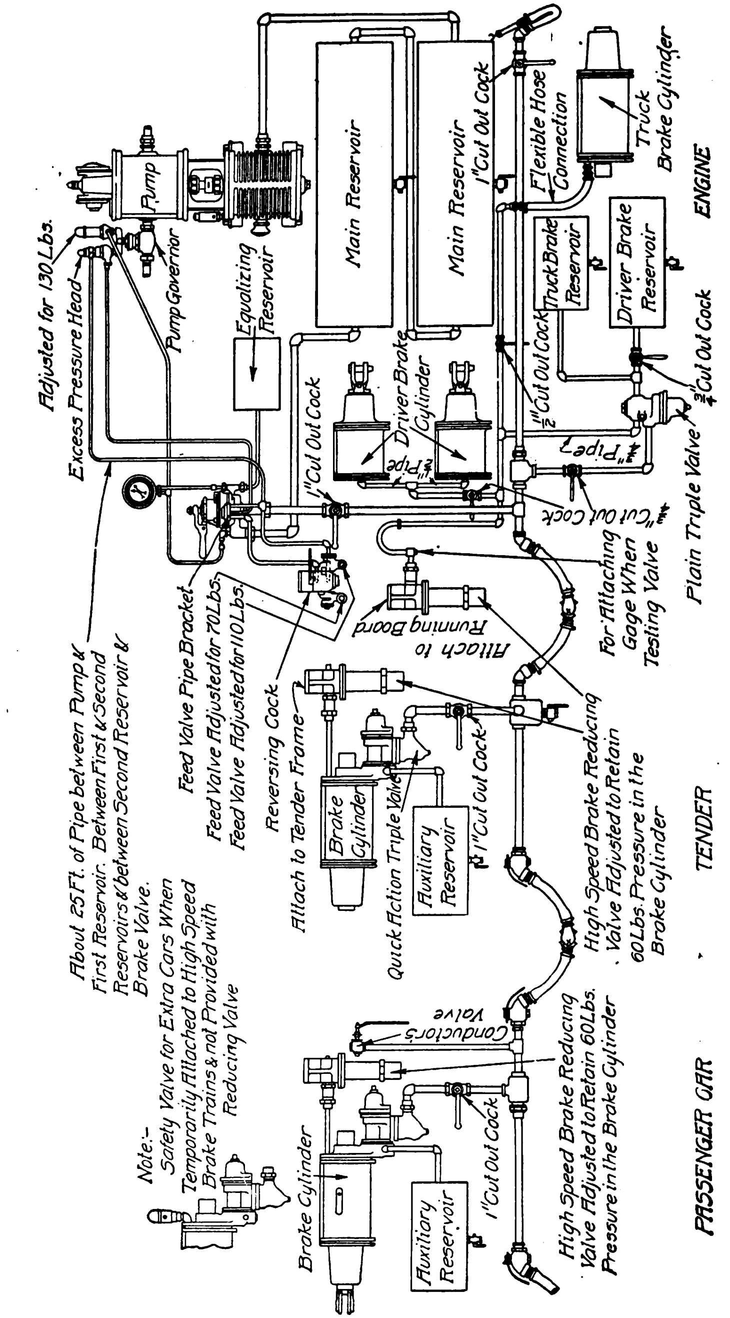


Fig. 88. Diagrammatic Illustration of Westinghouse High-Speed Brake Equipment

that tends to stop the rotation, becomes less as the rapidity of rotation of the wheel increases, and (b) the adhesion between the wheel and rail remains practically constant regardless of the speed. It will thus be seen that, at high speeds, a greater brake-cylinder pressure, with corresponding increase of the brake-shoe pressure, can be used without danger of sliding wheels; but, in such a case, it is necessary to provide means for reducing this high-cylinder pressure as the speed of the train is decreased. This is accomplished by the automatic reducing valve, which has previously been explained.

Cars not fitted with reducing valves should not be attached to trains using the high-speed brake unless the brake cylinders are

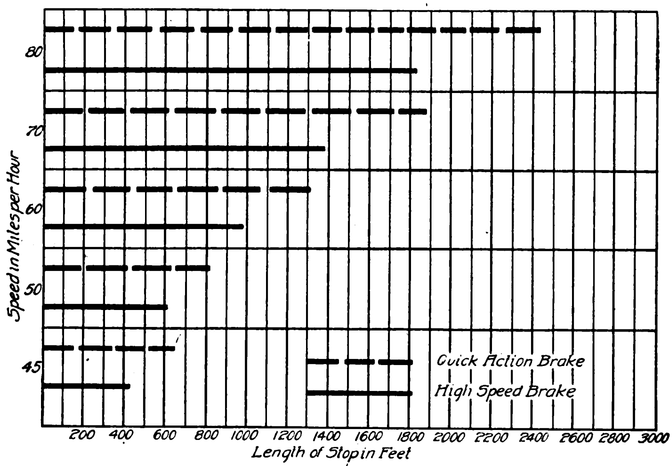


Fig. 89. Diagram Showing Minimum Length of Stop for Train of Engine and Six Coaches with Quick-Action and High-Speed Brakes

fitted with the Type "E" safety valve provided for temporary use. Fig. 89 illustrates graphically the saving in distance in stopping a train fitted with the high-speed brake equipment.

Double-Pressure Control or Schedule "U". The differences between Schedule "U" and high-speed equipments are that no additional parts are used on cars with Schedule "U". The Type "E" safety valve takes the place of the high-speed reducing valve in the locomotive and tender equipment, and plain triple valves are used on both the locomotive and tender. The equipment is shown in Fig. 90. The few simple appliances afford the means whereby the engineer can change the brake-pipe and main-reservoir pressure from one predetermined standard to another at will.

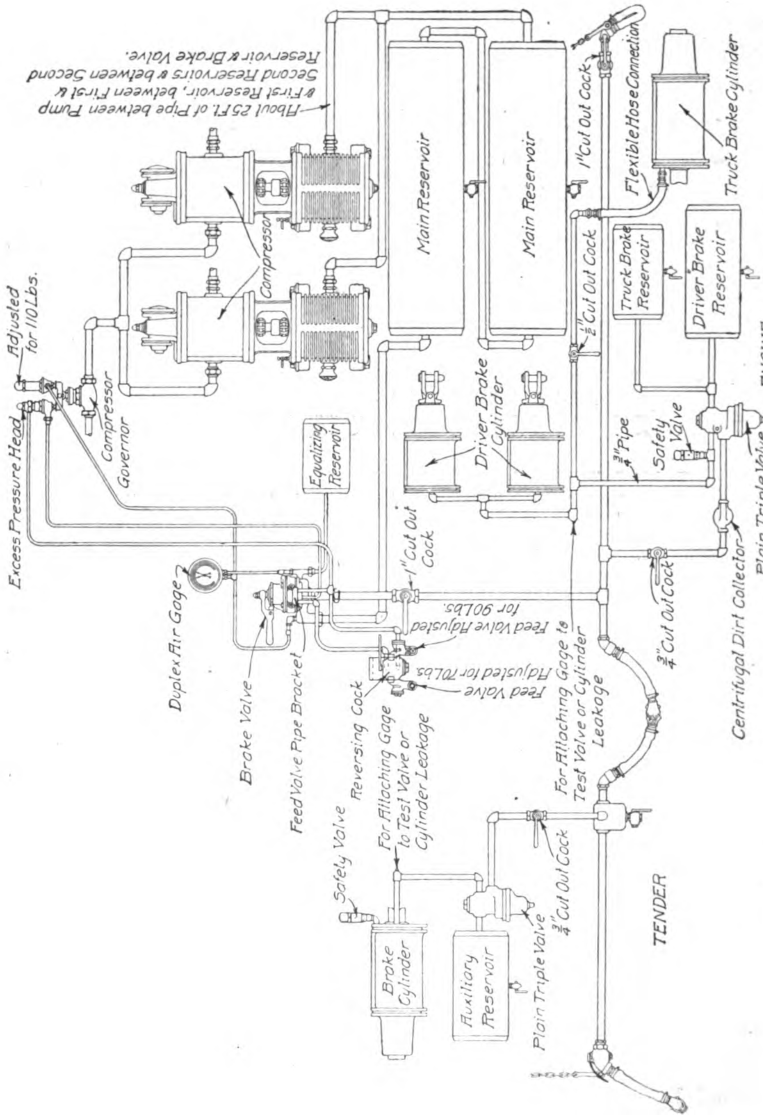


Fig. 90. Diagrammatic Illustration of Double-Pressure Control Apparatus, or Schedule U

The equipment is particularly adapted for use upon heavy grades where "empties" are hauled up the grade and "loads" down.

The 70-pound brake-pipe pressure provides for a proper control of the empty cars and requires less work from the compressor, while the 90-pound pressure makes it possible to obtain higher brake-cylinder pressures to compensate for the increased weight to be controlled when the cars are loaded. The loaded weight of the car is still, however, sufficiently in excess of the maximum braking power obtainable to insure an ample margin against wheel sliding.

"LN" Passenger-Car Brake Equipment. The demand for a more efficient brake equipment for passenger service, to meet the new conditions of heavier trains, faster speeds, and more frequent service, resulted in the development of the "LN" equipment. A diagram illustrating the arrangement of piping and the location

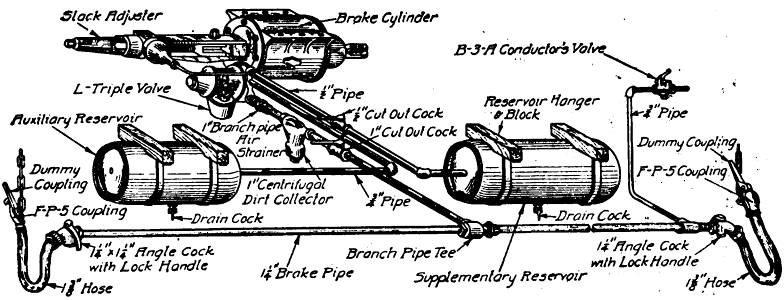


Fig. 91. Westinghouse Piping Diagram for "LN" Passenger Brake Equipment

and names of all parts is shown in Fig. 91. The principles underlying the action of the parts have already been presented under the discussion of the Type "L" triple valve.

Specifications. The equipment is made up of the following parts:

(1) A *Type "L" triple valve,* which has connections through the brake-cylinder head to the brake-pipe branch pipe, the auxiliary reservoir, and the supplementary reservoir. It operates automatically in response to an increase or decrease in brake-pipe pressure, as previously described.

(2) The *Type "E" safety valve* is attached directly to the Type "L" triple valve and thus becomes an important feature of the "LN" equipment, since in service applications it prevents any excess brake-cylinder pressure and in emergency applications it is cut out entirely.

(3) A *brake cylinder,* with a piston and rod which operates in the usual way.

(4) *Reservoirs,* of which there is one auxiliary and usually one supplementary, for the purpose of storing air for use in applying the brakes. When desirable or more convenient, however, two supplementary reservoirs of the proper size may be used.

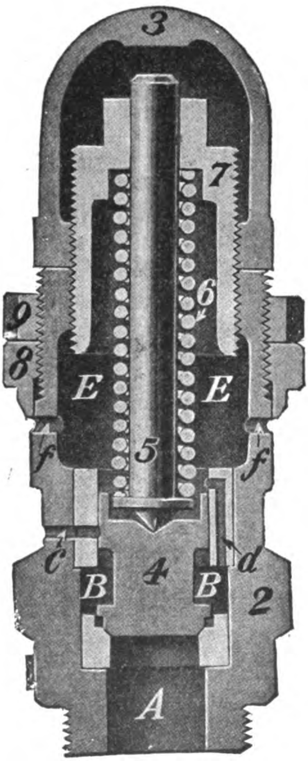


Fig. 91a. Westinghouse "E-7" Safety Valve

(5) A *centrifugal dirt collector* is connected in the branch pipe between the brake pipe and triple valve as near the triple valve as circumstances will permit.

(6) A *branch-pipe air strainer* is inserted in the branch pipe close to the triple-valve connection on the brake-cylinder head for further protection to the triple valve.

(7) A *conductor's valve* placed inside each car by means of which the brakes may be applied by the conductor in case of accident or emergency.

(8) A *branch-pipe tee,* various *cut-out cocks, angle cocks, hose couplings, dummy couplings,* etc., the location and uses of which will be readily understood by reference to Fig. 91.

(9) An *automatic slack-adjuster,* which is not a fundamental part of the equipment but is recommended for use.

"E-7" Safety Valve. The "E-7" safety valve, Fig. 91a, is different from the type of safety valve represented by the "E-6", illustrated in Fig. 76, in that within certain limits the closing pressure can be regulated as well as the pressure at which the valve will open. The "E-7" safety valve, like the "E-6", opens and closes with a *pop* action, but the action is more pronounced. Practically the only difference between the "E-6" and "E-7" safety valves is the addition to the latter of the adjusting nut *8* and the jam nut *9*. Chamber *E* is open to the atmosphere at all times, but the ports *f* in the body are small and restrict the exhaust to such an extent that the pressure accumulates very rapidly and assists spring *6* in forcing valve *4* quickly to its seat.

In order to adjust the safety valve for the maximum, or opening, pressure which, in the case of the "LN" equipment, is 62 pounds, remove the cap nut *3* and screw down or back off regulating nut *7* as required, after which replace cap nut *3*. The minimum, or closing, pressure used in the "LN" equipment is 58 pounds and can be adjusted by changing the size of the atmospheric exhaust ports *f*, using regulating nut *8*. After making this adjustment, the jam nut *9* should be screwed down snug.

The high-emergency cylinder pressure with the graduated release feature, as explained under the discussion of the "L" triple valve, makes it possible to use the equipment as a high-speed brake and obtain better results when carrying 90 pounds brake-pipe pressure than when using 110 pounds pressure with the old standard equipment in steam-road service. Increasing the brake-pipe pressure, therefore, gives a more powerful brake if desired.

No. 6 "ET" LOCOMOTIVE BRAKE EQUIPMENT

It has been shown that a single modern locomotive possessed a possible braking power of one-tenth of a 50-car freight train, one-eighth of a 12-car Pullman train, one-fourth of a 10-car passenger train, and one-third of a 6-car passenger train. These figures would indicate that the locomotive brake equipment should be developed to the highest degree. The first step taken in this direction was the development of the combined automatic and straight-air equipment for locomotives. This system was greatly simplified and improved by the more recent development of the so-called "ET" locomotive brake equipment.

Functions and Advantages. The No. 6 "ET" (engine and tender) equipment possesses all the functions which are now required in locomotive brake service; it can be applied to any locomotive without change or modification of any of its parts. The locomotive so equipped may be used in any kind of service, such as high-speed passenger, double-pressure control, ordinary passenger or freight, or switching service, without change or adjustment of the brake apparatus. Its important advantages are as follows:

The locomotive brakes may be used with or independently of the train brakes and this without regard to the position of the locomotive in the train.

They may be applied with any desired pressure between the minimum and the maximum, and this pressure will be automatically maintained in the locomotive brake cylinders regardless of leakage from them and of variation in piston travel, undesirable though these defects are, until released by the brake valve.

They can be graduated on or off with either the automatic or the independent brake valves; hence, in all kinds of service the train may be handled without shock or danger of parting, and in passenger service smooth, accurate stops can be made with greater ease than was heretofore possible.

Arrangement of Piping, Etc. The general arrangement of piping, etc., is shown diagrammatically in Fig. 92. The names of the various parts composing the equipment are:

(a) The *air compressor* to compress the air. The *main reservoirs* in which to store and cool the air and collect water and dirt.
(b) A *duplex compressor governor* to control the compressor when the pressures for which it is regulated are obtained.
(c) A *distributing valve,* and small double-chamber reservoir to which it is attached, placed on the locomotive to perform the functions of triple valves, auxiliary reservoirs, double check valves, high-speed reducing valves, etc.
(d) Two *brake valves*—the *automatic* to operate the locomotive and train brakes, and the *independent* to operate the locomotive brakes only.
(e) A *feed valve* to regulate the brake-pipe pressure.
(f) A *reducing valve* to reduce the pressure for the independent brake valve and for the air-signal system when used.
(g) Two *duplex air gages*—one, to indicate equalizing-reservoir and main-reservoir pressures; the other, to indicate brake-pipe and locomotive brake-cylinder pressures.
(h) *Driver, tender,* and *truck brake cylinders, cut-out cocks, air strainers, hose couplings, fittings,* etc., incidental to the piping, for purposes readily understood.

Names of Pipes. In order to simplify the description of the different parts of the equipment, the following names of pipes are given which are shown in Fig. 92:

Discharge Pipe: Connects the air compressor to the first main reservoir.
Connecting Pipe: Connects the two main reservoirs.
Main Reservoir Pipe: Connects the second main reservoir to the automatic brake valve, distributing valve, feed valve, reducing valve, and compressor governor.
Feed Valve Pipe: Connects the feed valve to the automatic brake valve.
Excess-Pressure Pipe: Connects the feed-valve pipe to the upper connection of the excess-pressure head of the compressor governor.

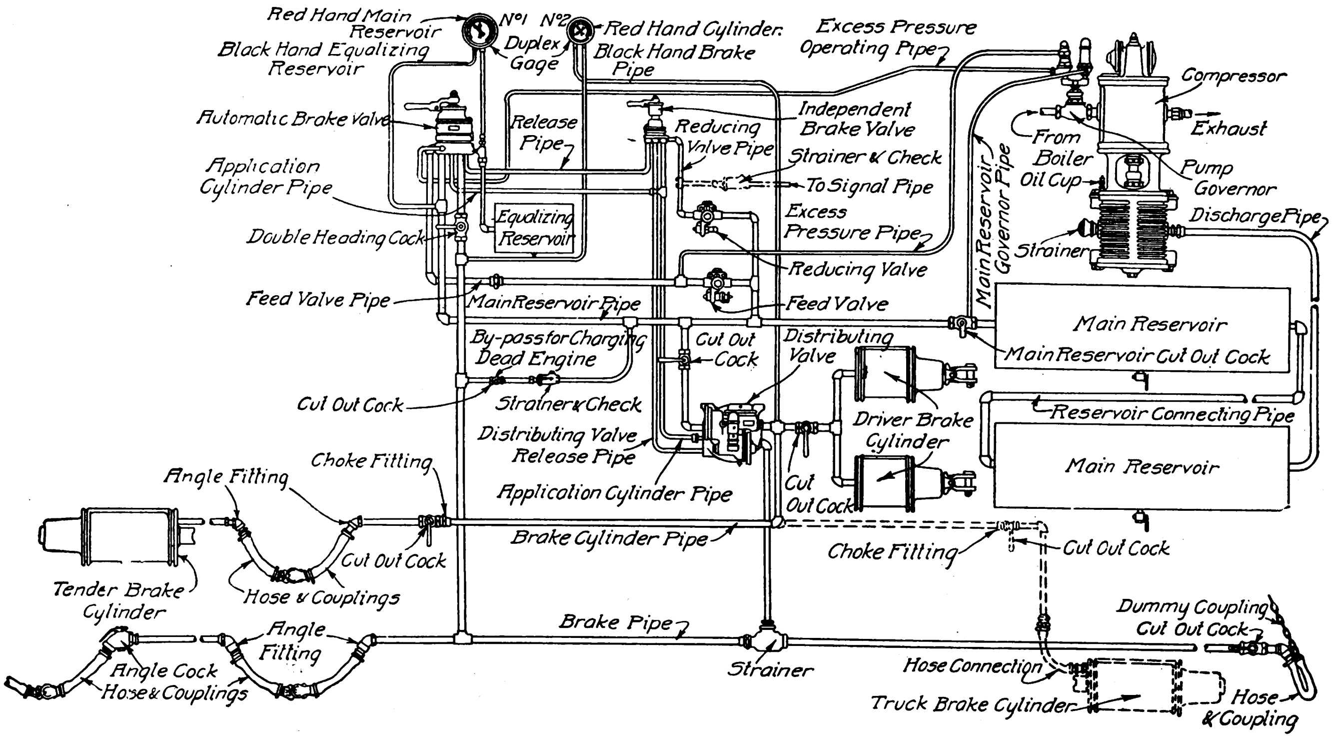


Fig 92. Diagram of Westinghouse "ET-6" Equipment

Excess-Pressure Operating Pipe: Connects the automatic brake valve to the lower connection of the excess-pressure head of the compressor governor.

Reducing Valve Pipe: Connects the reducing valve to the independent brake valve, and to the signal system, when used.

Brake Pipe: Connects the automatic brake valve with the distributing valve and all triple valves on the cars in the train.

Brake-Cylinder Pipe: Connects the distributing valve with the driver, tender, and truck-brake cylinders.

Application Cylinder Pipe: Connects the application cylinder of the distributing valve to the independent and automatic brake valves.

Distributing Valve Release Pipe: Connects the application-cylinder exhaust port of the distributing valve to the automatic brake valve through the independent brake valve.

In some installations the automatic brake valve is provided with a pipe bracket to which the feed valve is directly attached, thus eliminating the feed-valve pipe and the excess-pressure pipe.

Manipulation of Equipment. *Positions of Automatic and Independent Brake Valves.* The automatic brake valve has six fixed positions for its handle—*release, running, holding, lap, service,* and *emergency;* while the independent brake valve has but five—*release, running, lap, slow-application,* and *quick-application.*

General Directions. The following directions for the manipulation of the equipment are abbreviated from that furnished by the manufacturers and applies to modern equipment. They are not intended to apply rigidly to all individual cases or conditions:

When not in use, carry the handles of both brake valves in *running* position.

To apply the brakes in service, move the handle of the automatic brake valve to the *service* position, making the required brake-pipe reduction, then back to *lap* position, which is the one for holding all the brakes applied.

To make a smooth and accurate two-application passenger stop, make the first application sufficiently heavy to bring the speed of the train down to about 15 miles per hour at a convenient distance from the stopping point, then release as explained in the following paragraph and re-apply as required to make the desired stop, the final release being made as explained below.

Passenger Service. In making the first release of a two-application stop, the brake-valve handle should be moved to *release* position and then quickly back to *running* position, where it should be allowed to remain for an instant—*first,* to permit the pressures in the equalizing reservoir and brake pipe to equalize; and *second,* to release part of the driver brake-cylinder pressure—then moved to *lap* position and from there to *service* position, as required. In passenger service, the time the handle is in *release* position should be only momentary; but the time in *running* position should be governed by the conditions existing for each particular case, such as the length of train, kind of reduction made, time available, and so on.

In making the final release of a two-application stop, with short trains, release shortly before coming to a standstill by moving the handle to *release* position and immediately back to *running* position, and leave it there. With long trains, the brakes should, as a rule, be held applied until the train stops.

The release after a one-application stop should be made in the same manner as the final release of a two-application stop.

Freight Service. Under present conditions it is, as a rule, safest to come to a stop before releasing the brakes on a freight train, especially a long one, rather than attempt to release at low speed. However, if conditions—for example, a short train, or a train equipped with Type "K" triple valves—permit of the release while in motion, the brake-valve handle should be moved to *release* position and held there long enough to move as many of the triple valves to release position as possible without unduly overcharging the head end of the train—the time in *release* position should be governed by the length of train, amount of reduction made, etc.—then returned to *running* position to release the locomotive brakes and complete the recharging of the auxiliary reservoirs. A few seconds after such a release, particularly on long trains, it is necessary to again move the handle to *release* position and quickly back to *running* position to "kick off" any brakes at the head end of the train that may have re-applied due to their auxiliary reservoirs having been slightly overcharged.

Holding Locomotive Brakes Applied. If, when releasing, it is desired to hold the locomotive brakes applied after the other brakes release, move the handle from *release* back to *holding* instead of *running* position, then release the locomotive brakes fully by moving the handle to *running* position and leaving it there, or graduate them off, as circumstances require, by short, successive movements between *holding* and *running* positions.

Emergency Application. To apply the brakes in emergency, move the handle of the automatic brake valve quickly to *emergency* position and leave it there until the train stops and the danger is past.

When using the independent brake only, the handle of the automatic brake valve should be carried in *running* position. The independent application may be released by moving the independent brake-valve handle to *running* position. Release position is for use only when the automatic brake-valve handle is not in *running* position.

While handling long trains of cars, in road or switching service, the independent brake should be operated with care to prevent damage to cars and lading, caused by running the slack in or out too hard. In cases of emergency arising while the independent brake is applied, apply the automatic brake instantly. The safety valve will restrict the brake-cylinder pressure to the proper maximum.

Heavy Grade Service. The brakes on the locomotive and on the train may be alternated in heavy grade service where conditions—such as short, steep grades or where grade is heavy and straight for short distance—require, to prevent overheating of driving-wheel tires and to assist the pressure-retaining valves in holding the train while the auxiliary reservoirs are being re-charged. This is done by keeping the locomotive brakes released by use of the independent brake valve when the train brakes are applied, and applying the locomotive brakes just before the train brakes are released, and then releasing the locomotive brakes after the train brakes are re-applied. Care and judgment should be exercised in the use of driver brakes on grades to prevent overheating of tires.

Release Position of Independent Brake Valve. When all brakes are applied automatically, to graduate off or entirely release the locomotive brakes only, use *release* position of the independent brake valve.

The red hand of gage No. 2, Fig. 92, will show at all times the pressure in the locomotive brake cylinders, and this hand should be watched in brake manipulation.

Release position of the independent brake valve will release the locomotive brakes under any and all conditions.

Use of Automatic Brake Valve for Holding and Grade Work. The automatic brakes should never be used to hold a locomotive or a train while standing even where the locomotive is not detached, for longer than ten minutes, and not for such time if the grade is very steep or the condition of the brakes is not good. The safest method is to hold with hand brakes only and keep the auxiliary reservoirs fully charged so as to guard against a start from brakes leaking off and to be ready to obtain any part of full braking power immediately on starting.

The independent brake is a very important safety feature in this connection, as it will hold a locomotive with a leaky throttle or quite a heavy train on a fairly steep grade if, as the automatic brakes are released, the slack is prevented from running in or out—depending on the tendency of the grade—and giving the locomotive a start. To illustrate: The best method to make a stop on a descending grade is to apply the independent brake heavily as the stop is being completed, thus bunching the train solidly; then, when stopped, place and leave the handle of the independent brake valve in *application* position; then release the automatic brakes and keep them charged. Should the independent brake be unable to prevent the train from starting, the automatic brakes will become sufficiently recharged to make an immediate stop; in such an event enough hand brakes should at once be applied as are necessary to hold the train. Many runaways and some serious wrecks have resulted through failure to comply with the foregoing instructions.

When leaving the engine, while doing work about it, or when it is standing at a coal chute or water plug, always leave the independent brake-valve handle in *application* position.

After Emergency Application not Controlled by Engineer. After an emergency application of the brakes, while running over the road, due to any cause other than intended by the operating engineer himself:

(1) In passenger service, move the brake-valve handle to *emergency* position at once and leave it there until the train stops.

(2) In freight service, move the brake-valve handle to lap position and let it remain there until the train stops.

This is to prevent loss of main-reservoir pressure and insure the brakes remaining applied until released by the engineer in charge of the train. After the train stops, the cause of the application should be located and remedied before proceeding.

More than One Locomotive on Train. Where there are two or more locomotives in a train, the instructions already given remain unchanged so far as the leading locomotive, or the locomotive from which the brakes are being operated, is concerned. On all other locomotives in the train, however, the double-heading cock under the automatic brake valve must be closed and the automatic and independent brake-valve handles carried in *running* position.

Air Strainer and Check Valve. The location of the air strainer and check valve in the piping system of the No. 6 "ET" equipment is shown at the left center in Fig. 92. This part of the apparatus is known as the *dead engine* feature. A section of this fixture is shown in Fig. 92a, which illustrates its scheme of operation. Its function is to permit the operation of the locomotive brakes when the compressor on a locomotive in a train is for any reason inoperative.

The cut-out cock, located near the air strainer and check valve, should be kept closed except in the case of a dead engine, as these parts are not required at any other time. With the cut-out cock open, air from the brake pipe enters at the opening *BP*, passes through the curled hair strainer *5*, lifts check valve *4*,

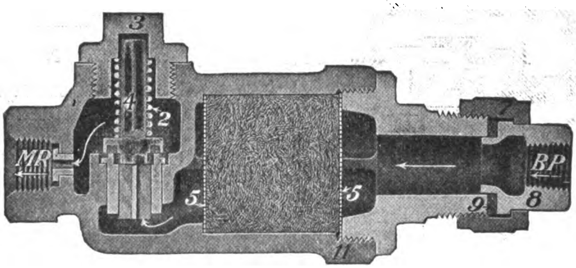


Fig. 92a. Combined Air Strainer and Check Valve
Courtesy Westinghouse Air Brake Company, Wilmerding, Pennsylvania

which is held to its seat by a strong spring *2;* it then passes through the choke bushing and out at *MR* to the main reservoir, thus providing air pressure for operating the brakes on the dead locomotive. The double-heading cock should be closed and the handle of each brake valve should be carried in running position.

The strainer protects the check valve and choke bushing from collections of dirt. The spring *2* insures the proper seating of the check valve and, while assuring ample pressure to operate the locomotive brakes, keeps the pressure in the main reservoir somewhat lower than the brake-pipe pressure, thereby reducing any leakage therefrom. The choke bushing prevents a sudden drop in brake-pipe pressure and the application of the train brakes, which would otherwise occur with an uncharged main reservoir cut-in to a charged brake pipe.

Many of the parts composing the No. 6 "ET" equipment are the same as used in connection with other equipments and have already been explained. These parts include the following: the "H-6" automatic brake valve, the "S-6" independent brake valve, the "B-6" feed valve, the "C-6" reducing valve, the "E-6" safety valve, the Type "SF" compressor governor, the air compressor, etc. The new features are the different pipes and connections, and the distributing valve and double-chamber reservoir.

DISTRIBUTING VALVE AND DOUBLE-CHAMBER RESERVOIR

General Method of Operation. Fig. 93 illustrates diagrammatically the essential features of the distributing valve and the double-chamber reservoir. Instead of a triple valve and auxiliary reservoir for each of the engine and tender equipments, the distributing valve is made to supply all brake cylinders. The distributing valve is made up of two portions called the "equalizing portion" and the "application portion". The valve is connected to a double-chamber reservoir, the two chambers being called, respectively, the "pressure chamber" and the "application chamber". For various reasons the distributing valve and double-chamber reservoir are combined in one device, Figs. 94 and 95.

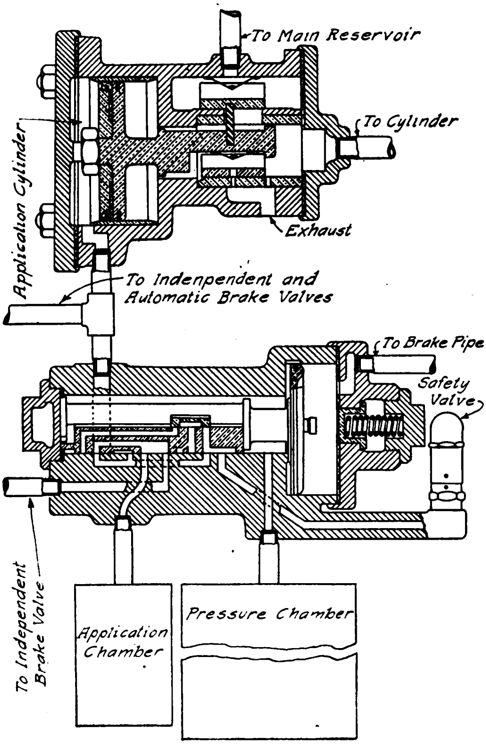


Fig. 93. Diagrammatic View of Essential Parts of Westinghouse Distributing Valve and Double-Chamber Reservoir

The distributing valve is the most important feature of the "ET" equipment. As shown by Figs. 94, 95, and 96, it has five

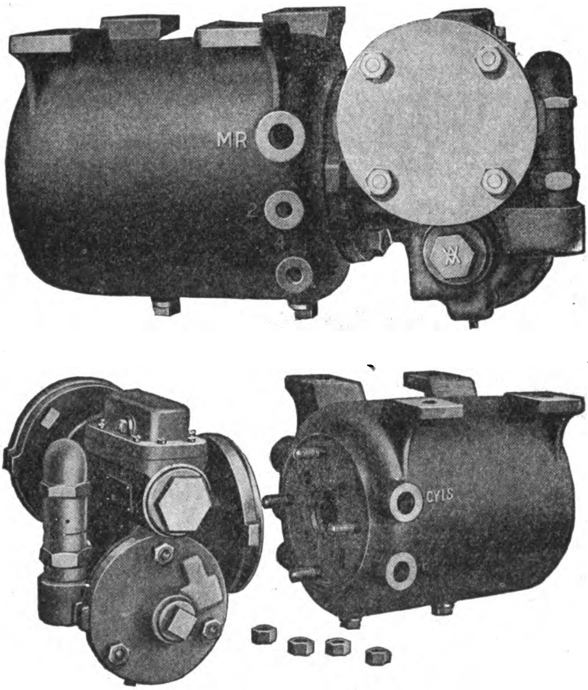


Fig. 94. No. 6 Distributing Valve and Double-Chamber Reservoir. *MR*, Main-Reservoir Pipe; *4*, Distributor Valve Release Pipe; *2*, Application-Cylinder Pipe; *CYLS*, Brake-Cylinder Pipe; *BP*, Brake Pipe

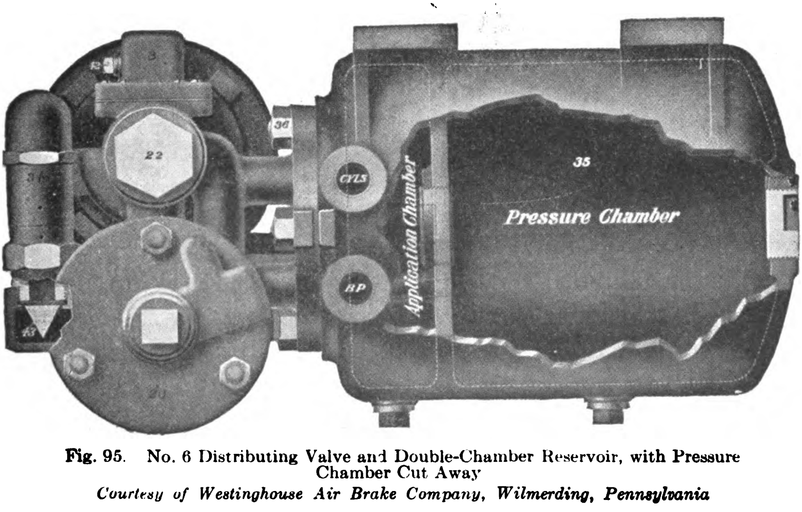


Fig. 95. No. 6 Distributing Valve and Double-Chamber Reservoir, with Pressure Chamber Cut Away

Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania pipe connections. Fig. 96 is a vertical section of the actual valve. For the sake of clearness, the distributing valve together with the double-pressure chamber may be considered as a miniature brake set, consisting of the equalizing portion representing the triple valve; the pressure chamber, the auxiliary reservoir; and the application portion always having practically the same pressure in its

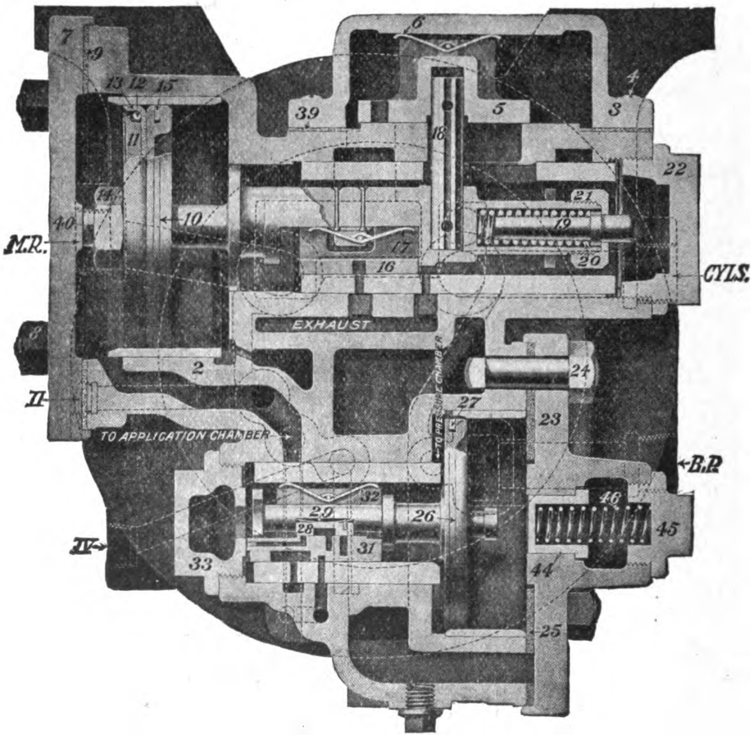


Fig. 96. Section of No. 6 Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

cylinder as that in the brake cylinders. The equalizing portion and pressure chamber are used in automatic applications only; reductions of brake-pipe pressure cause the equalizing valve to connect the pressure chamber to the application chamber and cylinder, allowing air to flow from the former to the latter. The upper slide valve, connected to the piston rod of the application portion, admits air to the brake cylinders and is called the "application valve", while the lower one releases the air from the brake cylinders and is called the "exhaust valve". As the air admitted to the brake cylinders comes directly from the main reservoirs, the supply is practically unlimited. Any pressure in the application cylinder will force the application piston to close the exhaust valve, open the application valve, and admit air from the main reservoirs to the

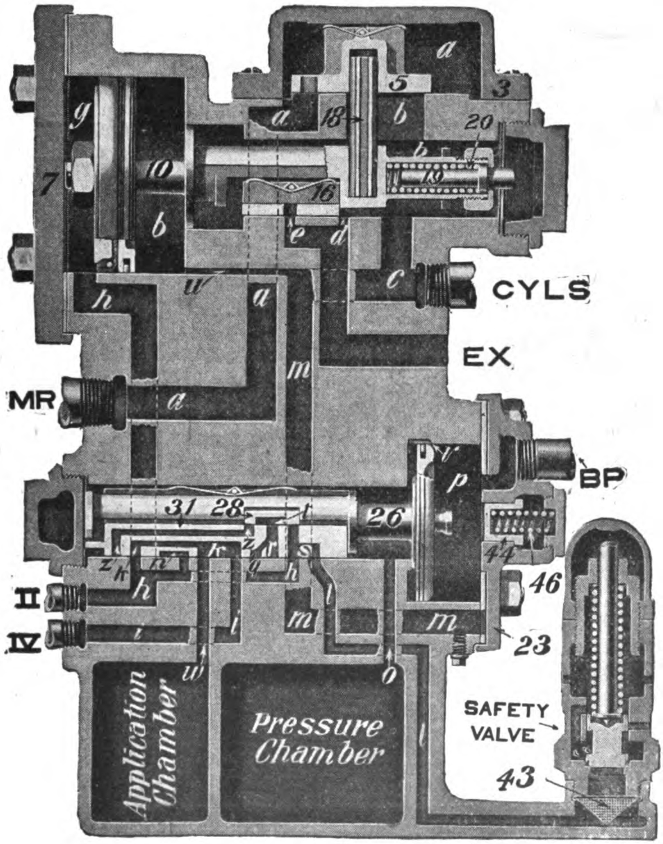


Fig. 97. Release Position, Automatic or Independent Connections for Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

locomotive brake cylinders until their pressure equals or slightly exceeds that in the application cylinder; whereupon the application piston and valve will be returned to lap position, closing the application valve. Also any variation of application-cylinder pressure will be exactly duplicated in the locomotive brake cylinders, and the resulting pressure maintained regardless of any brake-cylinder leakage. The operation of this locomotive brake, therefore, depends upon the admitting of air to and the releasing of air from the application cylinder—in independent applications, directly by means of the independent brake valve; in automatic applications, by means of the equalizing portion and the air pressure stored in the pressure chamber.

The well-known principle embodied in the quick-action triple valve, by which it gives a high braking power in emergency applications and a sufficiently lower one in full-service applications to provide a desired protection against wheel sliding, is embodied in the "No. 6" distributing valve. In describing the operation of the valve, reference will be made to the nine diagrammatic views shown in Figs. 97 to 106. For convenience, the chambers of the reservoir are indicated at the bottom as being a part of the valve.

Automatic Brake Operation

Charging. Referring to Fig. 97, which shows the parts in the release position, it will be seen that as chamber *p* is connected to the brake pipe, brake-pipe air flows through the feed groove *v* over the top of piston *26* into the chamber above equalizing valve *31*, and through port *o* to the pressure chamber, until the pressures on both sides of the piston are equal.

Service. When the engineer wishes to make a service application by the use of the automatic brake valve, the brake-pipe pressure in chamber *p* is reduced, the amount of this reduction depending on the degree with which it is desired to set the brakes. This action causes a difference in pressure on the two sides of piston *26*, which causes the piston to move toward the right until it occupies the position shown in Fig. 98. The first movement of piston *26* closes the feed groove *v*, and at the same time moves the graduating valve *28* until it uncovers the upper end of the port *z* in the equalizing valve *31*. As piston *26* continues its movement toward the right, the shoulder on the end of its stem comes in contact with the left end of equalizing valve *31*, which is then also moved to the right until the projecting piece on the right of the piston strikes the equalizing piston graduating sleeve *44*. The initial tension of the graduating spring *46* prevents further movement of the piston and attached parts, unless an emergency application has been made, as explained later, instead of a service application. With the parts in this position, port *z* in the equalizing valve registers with port *h* in its seat, and cavity *n* in the equalizing valve connects ports *h* and *w* in the seat. As the equalizing valve chamber is always in communication with the pressure chamber, and with the parts in the position illustrated in

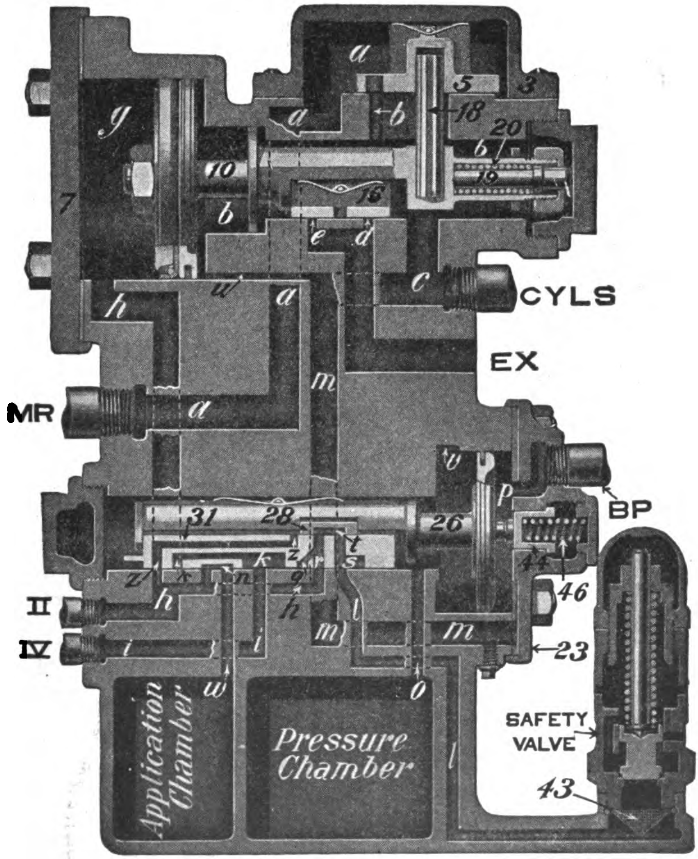


Fig. 98. Automatic Service Position of Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Fig. 98, air can flow from the pressure chamber to both the application cylinder and the application chamber. This air pressure from the pressure chamber acting on piston *10* moves it to the right, as shown, causing exhaust valve *16* to close exhaust ports *e* and *d*, and acts with sufficient force to compress application piston graduating spring *20*. As piston *10* is moved to the right, it carries with it application valve 5, by means of its connection with the piston stem through the pin *18*. With the application valve in the position shown, its only port is fully opened and air is permitted to flow from the main reservoirs into chambers *bb* and through passage *c* to the brake cylinders. Air from the main reservoirs will continue

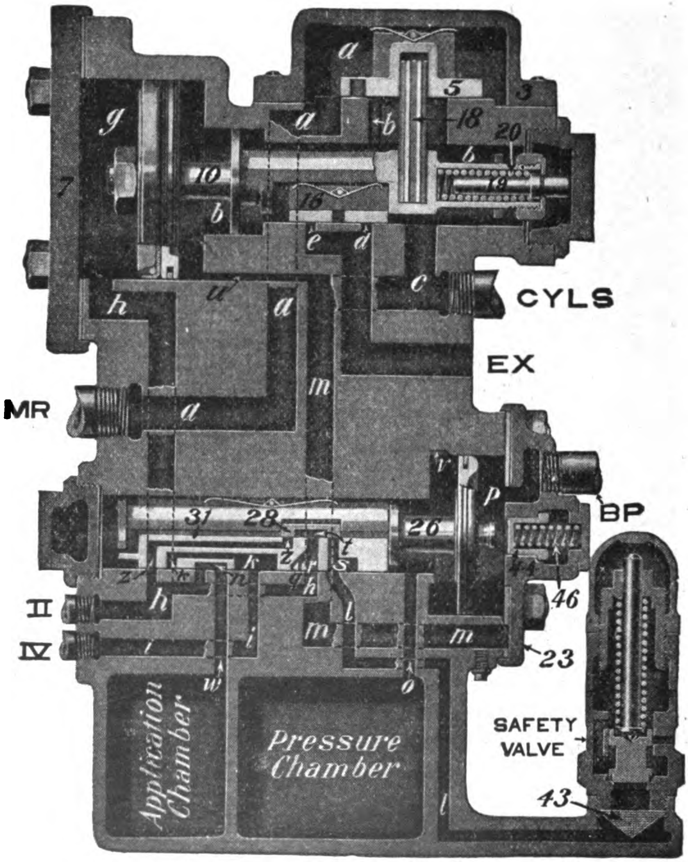


Fig. 99. Service-Lap Position for Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

to flow, through the path indicated above, into the brake cylinders until full equalization occurs.

During the movement just described, cavity *t* in the graduating valve *28* connects ports *r* and *s* in the equalizing valve, and by the same movement ports *r* and *s* are brought to register with ports *h* and *l* in the seat. This establishes communication between the application cylinder and the safety valve, which, being set at 68 pounds (three pounds above the maximum obtained in an emergency application from 70 pounds brake-pipe pressure), limits the brake-cylinder pressure to this amount.

The amount of pressure resulting in the application cylinder for a certain brake-pipe service reduction depends on the comparative volumes of the pressure chamber, application cylinder, and its chamber. These volumes are such that with 70 pounds in the pressure chamber they will equalize at about 50 pounds.

Service Lap. When the brake-pipe reduction is not sufficient to cause a full-service application, the conditions described above continue until the pressure in the pressure chamber is reduced enough below that in the brake pipe to cause piston *26* to force graduating valve *28* to the left until stopped by the shoulder on the piston stem striking the right-hand end of equalizing valve *31*, the position indicated in Fig. 99 and known as service lap. In this position, graduating valve *28* has closed port *z* so that no more air can flow from the pressure chamber to the application cylinder and chamber. It also has closed port *s*, cutting off communication to the safety valve, so that any possible leak in the latter cannot reduce the application-cylinder pressure, and thus similarly affect the pressure in the brake cylinders. The flow of air past application valve *5* to the brake cylinders continues until their pressure slightly exceeds that in the application cylinder, when the higher pressure and application-piston graduating spring together force piston *10* to the left, Fig. 99, thereby closing port *b*. Further movement is prevented by the resistance of exhaust valve *16* and the application-piston graduating spring having expanded to normal position.

From the above description it will be seen that application piston *10* has application-cylinder pressure on one side *g* and brake-cylinder pressure on the other. When either pressure varies, the piston will move toward the lower. Consequently, if pressure in chamber *b* is reduced by brake-cylinder leakage, the pressure maintained in the application cylinder *g* will force piston *10* to the right, opening application valve *5* and again admitting air from the main reservoirs to the brake cylinders until the pressure in chamber *b* is again slightly above that in the application cylinder *g*, when the piston again moves back to lap position.

Automatic Release. When the automatic brake-valve handle is placed in release position, and the brake-pipe pressure in chamber *p* is thereby increased above that in the pressure chamber, equalizing piston *26* moves to the left, carrying with it equalizing valve *31* and graduating valve *28* to the position shown in Fig. 97. The feed groove *v* now being open permits the pressure in the pressure chamber to feed up until it is equal to that in the brake pipe, as before described. This action does not release the locomotive brakes because it does not discharge application-cylinder pressure. The release pipe is closed by the rotary valve of the automatic brake valve, and the application-cylinder pipe is closed by the rotary valves of both brake valves. To release the locomotive brakes, the automatic brake valve must be moved to running position. The release pipe is then connected by the rotary valve to the atmosphere and, as exhaust cavity *k* in the equalizing valve *31* connects ports *i*, *w*, and *h* in the valve seat, the air in the application cylinder and chamber will escape. As this pressure reduces, the brake-cylinder pressure will force application piston *10* to the left until exhaust valve *16* uncovers exhaust ports *d* and *e*, allowing brake-cylinder pressure to escape, Fig. 97, or in case of graduated release, to reduce in like amount to the reduction in the application-cylinder pressure.

Emergency. When a sudden and heavy brake-pipe reduction is made, as in an emergency application, the air pressure in the pressure chamber forces equalization piston *26*, Fig. 100, to the right with sufficient force to compress equalizing-piston graduating spring *46*, and to seat against the leather gasket beneath cap *23*. This movement causes equalizing valve *31* to uncover port *h* in the seat without opening port *w*, making a direct opening from the pressure chamber to the application cylinder only, so that they quickly become equalized. This cylinder volume, being small and connected with that of the pressure chamber at 70 pounds pressure, equalizes at about 65 pounds. Also, in this position of the automatic brake valve, a small port in the rotary valve allows air from the main reservoirs to feed into the application-cylinder pipe, and thus to the application cylinder. The application cylinder is now connected to the safety valve through port *h* in the seat, cavity *q* and port *r* in the equalizing valve, and port *l* in the seat. Cavity *q* and port *r* in the equalizing valve are connected by a small port, the size of which permits the air in the application cylinder to escape through the safety valve at the same rate that the air from the main reservoirs, feeding through the rotary valve of the automatic brake valve, can supply it, preventing the pressure from rising above the adjustment of the safety valve.

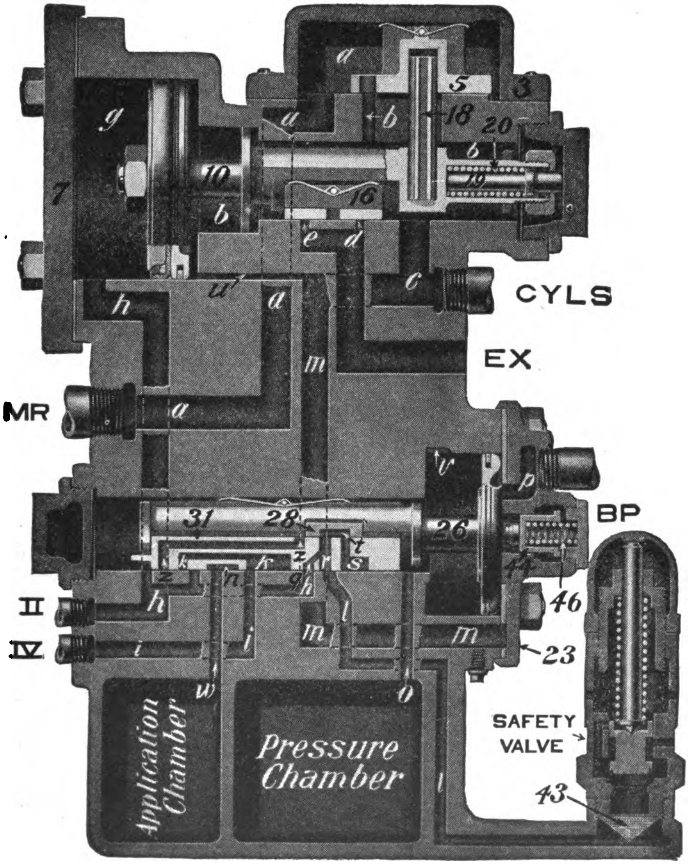


Fig. 100. Emergency Position for Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

In high-speed brake service, the feed valve is regulated for 110 pounds brake-pipe pressure instead of 70, and main-reservoir pressure is 130 or 140 pounds. Under these conditions an emergency application raises the application-cylinder pressure to about 93 pounds; but the passage between cavity *q* and port *r* is so small that the flow of application-cylinder pressure to the safety valve is just enough greater than the supply through the brake valve to decrease that pressure in practically the same time and manner as is done by the high-speed reducing valve, until it is approximately 75 pounds. The reason why the pressure in the application cylinder, pressure

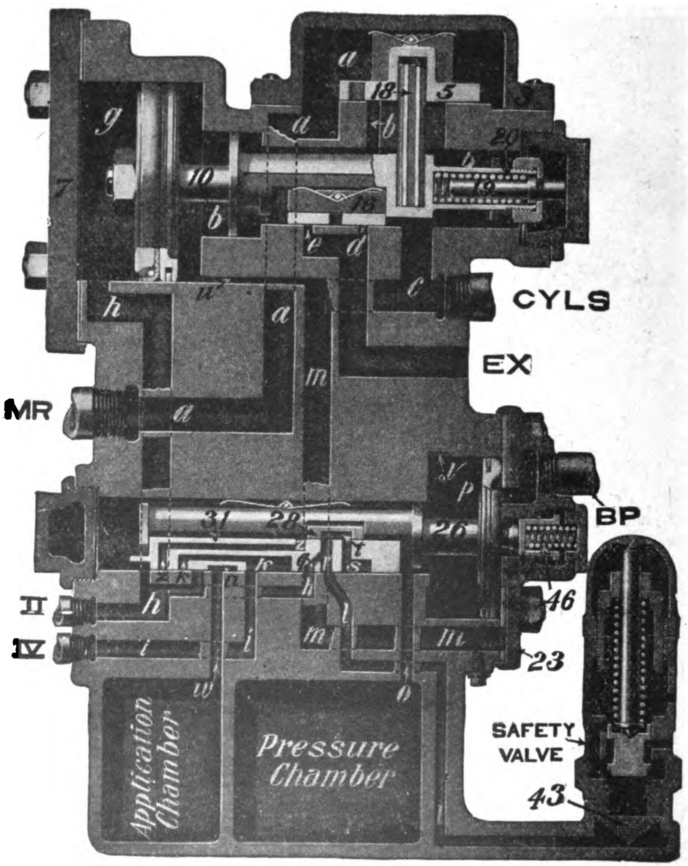


Fig. 101. Emergency Lap Position for Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

chamber, and brake cylinders does not fall to 68 pounds, to which pressure the safety-valve is adjusted, is because the inflow of air through the brake valve with the high main-reservoir pressure used in high-speed service is equal, at 75 pounds, to the outflow through the small opening to the safety valve. This is done to get a shorter stop in emergency. The application portion of the distributing valve operates similarly, but more quickly than in service application.

Emergency Lap. The movable parts of the valve remain in the position shown in Fig. 100 until the brake-cylinder pressure slightly exceeds the application-cylinder pressure, when the application piston and application valve move back to the position known as "emergency lap" as shown in Fig. 101.

The release after an emergency is brought about by the same manipulation of the automatic brake valve as that following service application, but the effect on the distributing valve is somewhat different. When the equalizing piston, equalizing valve, and graduating valve are forced to the release position by the increased brake-pipe pressure in chamber *p*, the application chamber—pressure in which is zero—is connected to the application cylinder, having emergency pressure therein through port *w*, cavity *k*, and port *h*. The pressure in the application cylinder at once expands into the application chamber until these pressures are equal, which results in the release of brake-cylinder pressure until it is slightly less than that in the application cylinder and chamber. Consequently, in releasing after an emergency (using the release position of the automatic brake valve), the brake-cylinder pressure will automatically reduce to about 15 pounds, where it will remain until the automatic brake-valve handle is moved to running position.

If the brakes are applied by a conductor's valve, a burst hose, or parting of train, the movement of equalizing valve *31* breaks the connection between ports *h* and *i* through cavity *k*, so that the brakes will apply and remain applied until the brake-pipe pressure is restored. The handle of the automatic brake valve should be immediately moved to emergency position to prevent a loss of main-reservoir pressure.

Independent Brake Operation

Independent Application. When the handle of the independent brake valve is moved to either slow- or quick-application position, air from the main reservoir, limited by the reducing valve to a maximum of 45 pounds, is allowed to flow to the application cylinder, forcing application piston *10* to the right as shown in Fig. 102. This movement causes application valve *5* to open its port and allow air from the main reservoirs to flow into chambers *bb* and through passage *c* to the brake cylinders, as in an automatic application, until the pressure slightly exceeds that in the application cylinder. The application-piston graduating spring *20* and higher pressure then force application piston *10* to the left until application valve *5* closes its port. Further movement is prevented by the resistance of exhaust valve *16* and the application-piston graduating

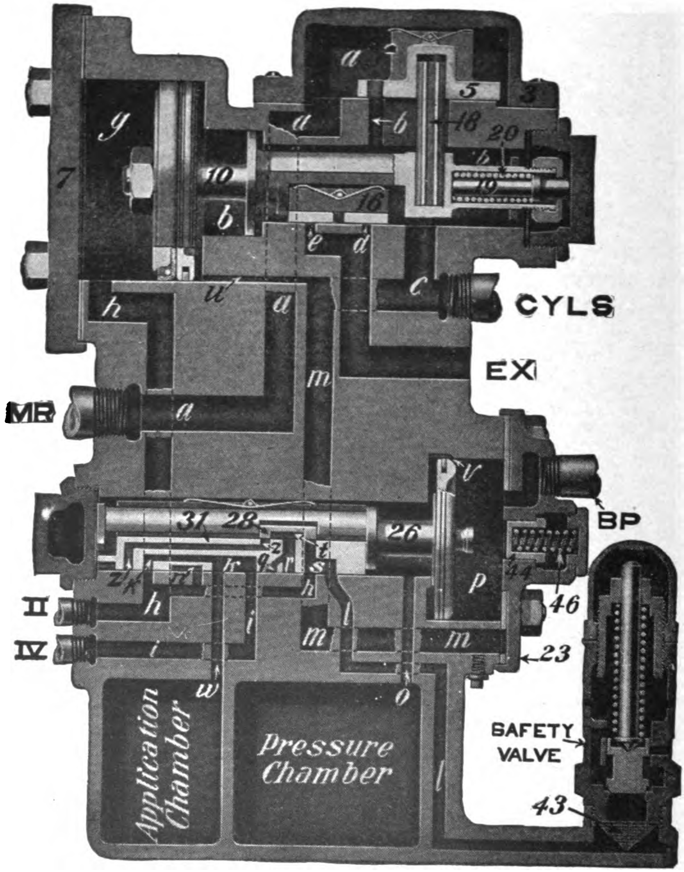


Fig. 102. Independent Application Position for Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

spring having expanded to its normal position. This position, shown in Fig. 103, is known as "independent lap".

Independent Release. When the handle of the independent brake valve is moved to release position, a direct opening is made from the application cylinder to the atmosphere. As the application-cylinder pressure escapes, brake-cylinder pressure in chamber *b* moves application piston *10* to the left, causing exhaust valve *16* to open exhaust ports *e* and *d* as shown in Fig. 97, thereby allowing brake-cylinder pressure to discharge to the atmosphere.

If the independent brake valve is returned to lap before all the application-cylinder pressure has escaped, the application piston *10*

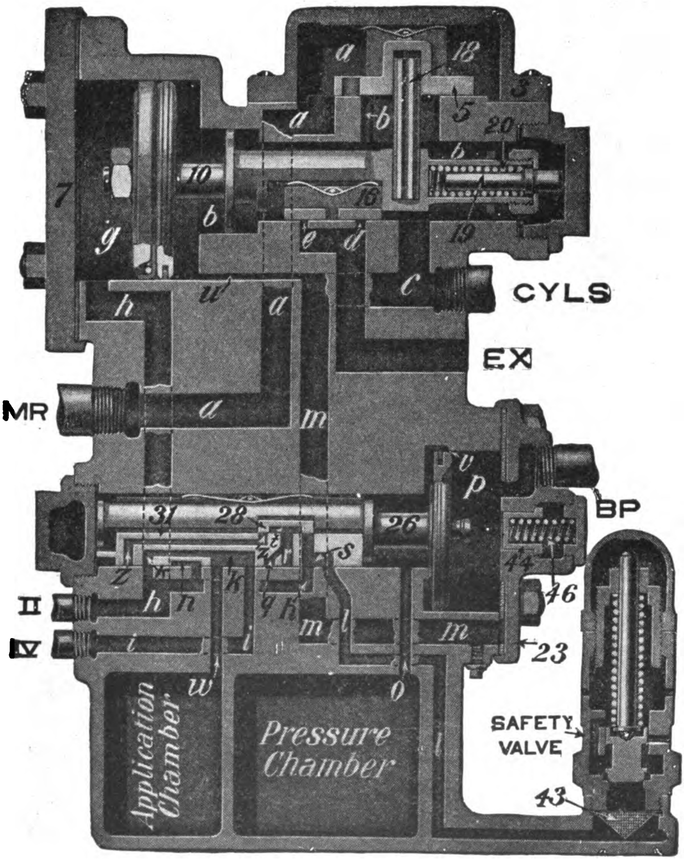


Fig. 103. Independent Lap Position for Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

will return to independent lap position, Fig. 103, as soon as the brake-cylinder pressure is reduced a little below that remaining in the application cylinder, thus closing exhaust ports *e* and *d* and holding the remaining pressure in the brake cylinders. In this way the independent release may be graduated as desired.

Fig. 104 shows the position the distributing valve parts will assume if the locomotive brakes are released by the independent brake valve after an automatic application has been made. This results in the application portion going to release position without changing the conditions in either the pressure chamber or brake

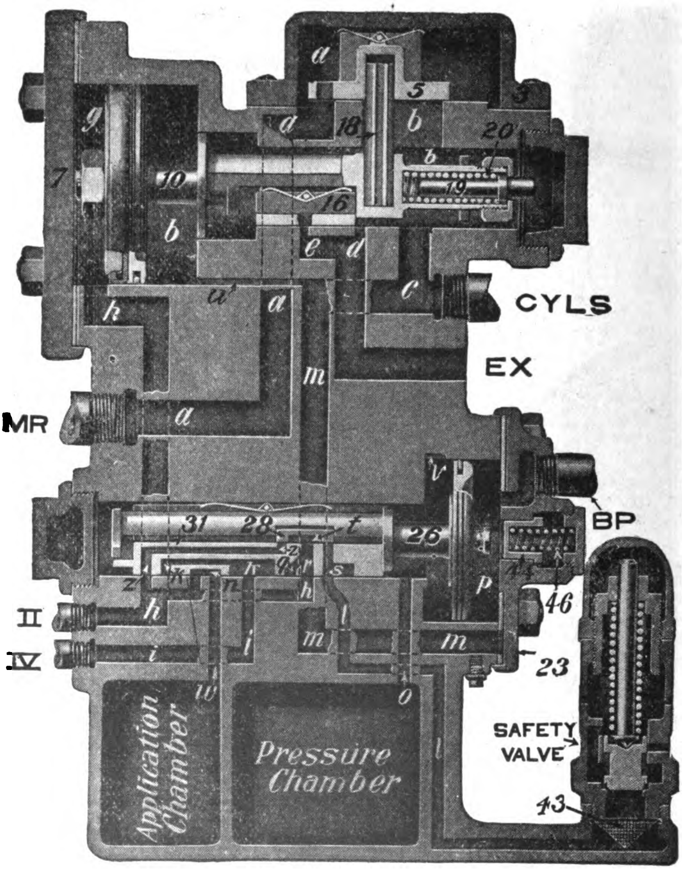


Fig. 104. Release Position for Distributing Valve
Courtesy of Westinghouse Air-Brake Company, Wilmerding, Pennsylvania

pipe; consequently, the equalizing portion does not move until release is made by the automatic brake valve.

An independent release of locomotive brakes may also be made in the same manner, after an emergency application by the automatic brake valve. However, owing to the fact that, in this position, the automatic brake valve will be supplying the application cylinder through the maintaining port in the rotary valve, the handle of the independent brake valve must be held in release position to prevent the locomotive brakes from re-applying so long as the handle of the automatic brake valve remains in emergency position. The equalizing portion of the distributing valve will remain in the position shown in Figs. 100 and 101.

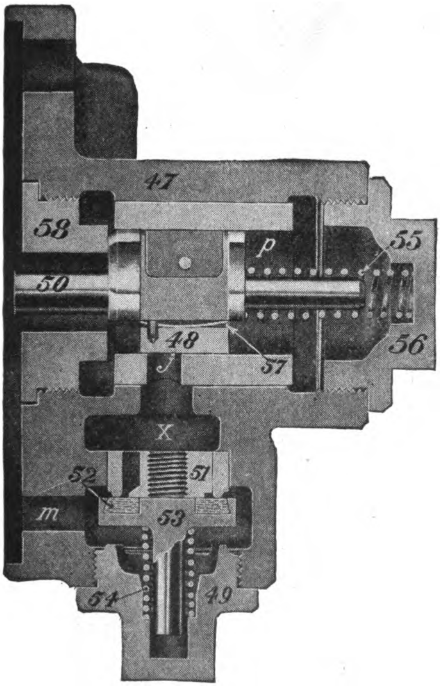


Fig. 105. Section Showing Quick-Action Cylinder Cap for No. 6 Distributing Valve
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Double-Heading. When there are two or more locomotives in a train, the instructions already given remain unchanged so far as the leading locomotive, or the locomotive from which the brakes are being operated, is concerned. On all other locomotives in the train, however, the double-heading cock under the automatic brake valve must be closed and the automatic and independent brake-valve handles carried in running position. The release pipe is then open to the atmosphere at the automatic brake valve, and the operation of the distributing valve is the same as that described during automatic brake applications. In double heading, therefore, the application and the release of the distributing valve on each helper locomotive is similar to that of the triple valves on the train. Port *u* drains the application cylinder of any moisture precipitated from the air in chamber *b*, such moisture passing to the lower part of the distributing valve through port *m*, where it may be drawn off by removing the pipe plug.

Quick-Action Cylinder Cap. The equalizing portion of the distributing valve corresponds to the plain triple valve of the old standard locomotive brake equipments. There are, however, conditions under which it is advisable to have it correspond to a quick-action triple valve; that is, vent brake-pipe air into the brake cylinders in an emergency application. To obtain this, the cylinder cap *23*, Fig. 96, is replaced by the quick-action cylinder cap, Fig. 105.

In an emergency application, as equalizing piston *26* moves to the right and seals against the gasket, Fig. 106, the knob on the

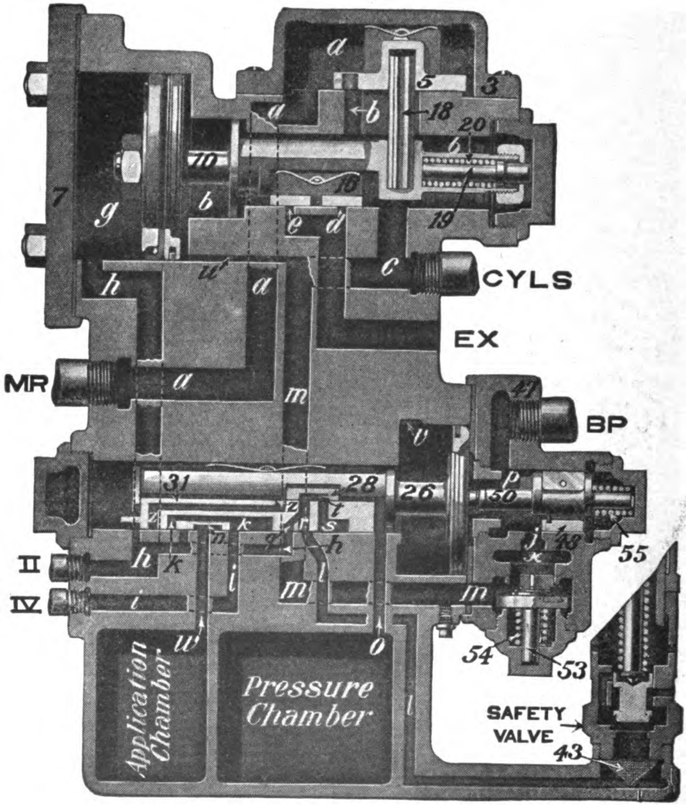


Fig. 106. Emergency Position of No. 6 Distributing Valve with Quick-Action Cap
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

piston strikes the graduating stem *50*, causing it to compress equalizing-piston graduating spring *55*, and move emergency valve *48* to the right, opening port *j*. Brake-pipe pressure in chamber *p* flows to chamber *X*, pushes down check valve *53*, and passes to the brake cylinders through port *m* in the cap and distributing valve body. When the brake cylinders and brake pipe equalize, check valve *53* is forced to its seat by spring *54*, thus preventing air in the brake cylinders from flowing back into the brake pipe. When a release of the brakes occurs and piston *26* is moved back to its normal position, Fig. 97, spring *55* forces graduating stem *50* and emergency valve *48* back to the position shown in Fig. 105.

"PC" PASSENGER BRAKE EQUIPMENT

Characteristics. The "PC" passenger brake equipment was designed for fast passenger service and for cars weighing as high as 150,000 pounds. Briefly stated, the requirements recognized as essential in a satisfactory brake for this modern service are as follows:

(a) Automatic in action.
(b) Efficiency not materially affected by unequal piston travel or brake-cylinder leakage.
(c) Certainty and uniformity of service action.
(d) Graduated release.
(e) Quick re-charge and consequent ready response of brakes to any brake-pipe reduction made at any time.
(f) Maximum possible rate of re-charging the brake pipe alone.
(g) Predetermined and fixed flexibility of service operation.
(h) Maximum sensitiveness to release, consistent with stability, combined with minimum sensitiveness to the inevitable fluctuations in brake-pipe pressure tending to cause undesired light-service applications, brakes creeping on, etc., and yet guard against the attainment of too high a difference of pressure between the brake pipe and the pressure chamber (auxiliary reservoir).
(i) Full emergency pressure obtainable at any time after a service application.
(j) Full emergency pressure applied automatically after any predetermined brake-pipe reduction has been made after equalization.
(k) Emergency braking power approximately 100 per cent greater than the maximum obtainable in service applications.
(l) Maximum brake-cylinder pressure obtained in the least possible time.
(m) Maximum brake-cylinder pressure maintained throughout the stop.
(n) Brake rigging designed for maximum efficiency.
(o) Adaptability to all classes and conditions of service.

Special Features of "PC" Equipment. The construction and principle of operation of the "PC" brake equipment is such as to permit of the fulfillment of all of the above requirements. The features which may be mentioned as being peculiar to the equipment are as follows:

(1) Graduated release and quick re-charge obtained as with previous improved types of triple valves.
(2) Certainty and uniformity of service action.
(3) Quick rise in brake-cylinder pressure.

(4) Uniformity and maintenance of service brake-cylinder pressure during the stop.
(5) Predetermined limiting of service braking power.
(6) Automatic emergency application on depletion of brake-pipe pressure.
(7) Full emergency braking power at any time.
(8) The service and emergency features being separated permits the necessary flexibility for service applications to be obtained without impairing in the slightest the emergency features of the equipment.
(9) A low total leverage ratio, with corresponding over-all efficiency.
(10) Less sensitiveness to the inevitable fluctuations in brake-pipe pressure, which tend to cause undesired light applications of the brake.
(11) Maximum rate of rise of brake-pipe pressure possible with given length of brake pipe, with consequently greater certainty of brakes releasing when a release is made.
(12) Greatly increased sensitiveness to release in long trains, when it becomes necessary to have the maximum sensitiveness to an increase in brake-pipe pressure to insure all valves in the train responding as intended.
(13) The elimination of the graduated release feature is specially provided for in the construction of the valve. This is provided for to permit the use of cars not equipped with a graduated release brake.

All of the functions mentioned above have been combined in such a way that they will interchange with existing equipments in an entirely satisfactory manner.

Names of Various Parts and Their Identification. Fig. 107 shows all of the parts making up the equipment, together with their names. It also illustrates the two methods of installation. The following is a list of the names of the various parts, a number of which have previously been described in connection with other brake equipments:

(1) The "No. 3-E" control valve, corresponding in a general way to the triple valve of the old-style passenger equipment, and more closely to the distributing valve of the "ET" equipment.
(2) Two brake cylinders—one for service and both for emergency applications.
(3) Two supply reservoirs, called the service and emergency reservoirs, respectively.
(4) A centrifugal dirt collector.
(5) A branch-pipe air strainer.
(6) A conductor's valve.
(7) A branch-pipe tee, cut-out cocks, angle cocks, hose couplings, dummy couplings, etc., similar to those found on other equipments.
(8) An automatic slack-adjuster, which is not an essential part of the equipment, but which is strongly recommended.

Of all the parts making up the equipment, the control valve illustrated in Figs. 108, 109, and 110, is the most important. As can be seen, the valve portions are supported upon the compartment reser-

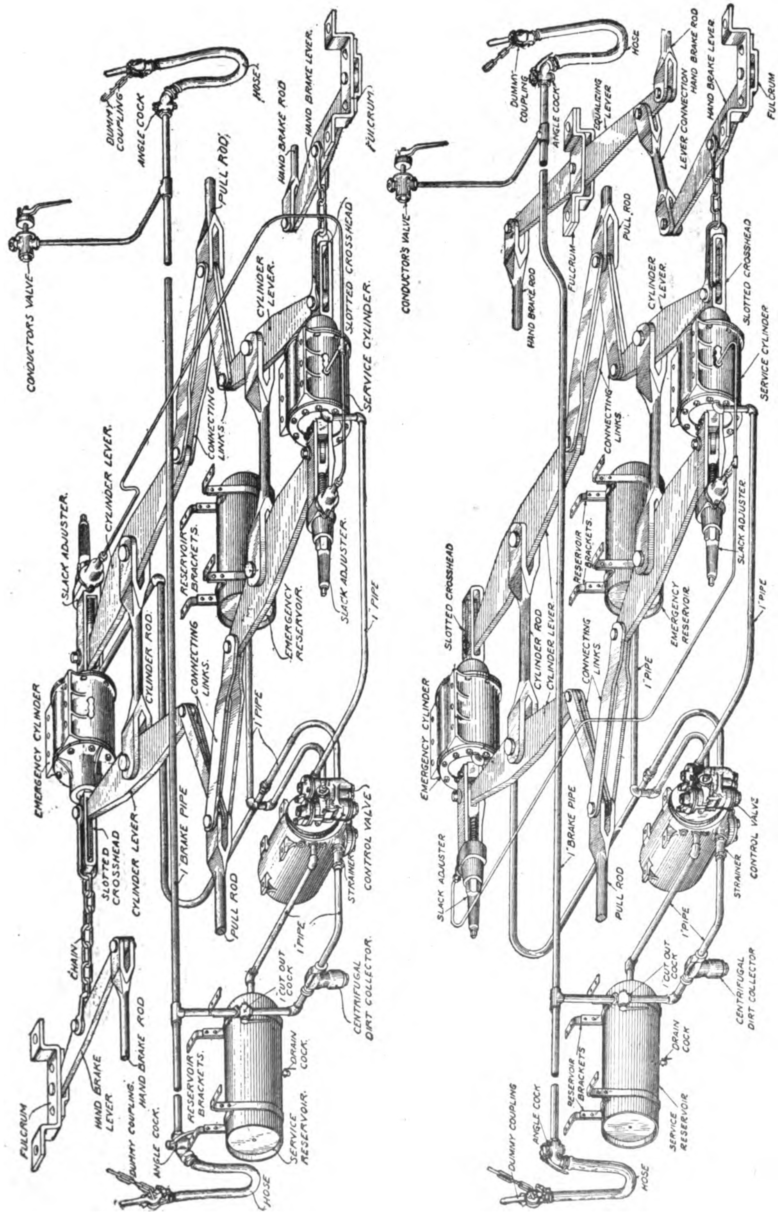


Fig. 107. Westinghouse "PC" Brake Equipment. Upper, Cylinders Pointing in Opposite Directions; Lower, Cylinders Pointing in Same Direction

voir, which is bolted to the underframing of the car. The compartment reservoir is made up of the pressure chamber, application chamber, and the reduction-limiting chamber. The equalizing and

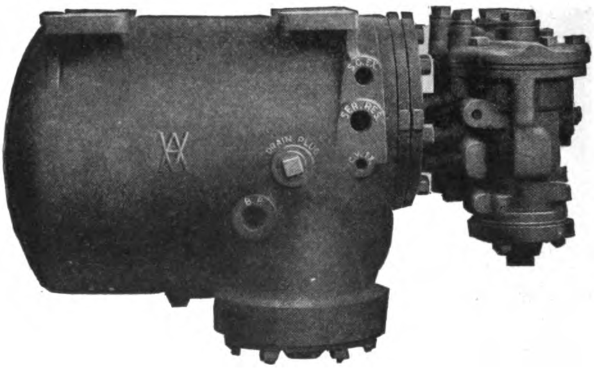


Fig. 108. Westinghouse "3-E" Control Valve, Showing Side View

application portions of the compartment reservoir correspond to those of the "ET" equipment. The location and size of the pipe connections are more clearly shown in the outline drawings, Figs. 111 and 112. Actual sections of the control valve and compartment reservoir are shown in Figs. 113, 114, and 115, having all of the parts numbered. The following five paragraphs are arranged to assist in identifying the various parts:

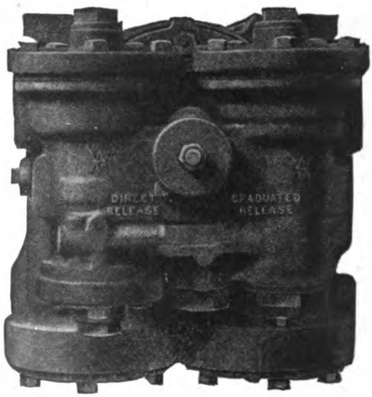


Fig. 109. Westinghouse "3-E" Control Valve, Showing Front View

Equalizing Portion: *2* Equalizing body; *3* Release piston; *4* Release slide valve; *5* Release slide-valve spring; *6* Release graduating valve; *7* Release graduating-valve spring; *8* Release piston-cap nut; *9* Release piston ring; *10* Release cylinder cap; *11* Release cylinder-cap gasket; *12* Square-head cap screw; *13* Release piston graduating sleeve; *14* Release piston graduating spring; *15* Release piston graduating nut; *16* Check valve; *17* Check-valve cap nut; *18* Direct and graduated release cap; *19* Stud and nut for direct and graduated release cap; *20* Equalizing piston; *21* Equalizing piston ring (large); *22* Equalizing slide valve; *23* Equalizing slide-valve spring; *24* Equalizing graduating valve; *25* Equalizing graduating-valve spring; *26* Large equalizing cylinder cap; *27* Large equalizing cylinder-cap gasket; *28* Square-head cap screw; *29* Equalizing piston-stop sleeve; *30* Equalizing piston-stop spring; *31* Equalizing graduating nut; *32* Equalizing piston ring (small); *33* Small equalizing cylinder cap; *34* Gasket for small equalizing cylinder cap; *35* Square-head cap screw; *36* Cap nut for small equalizing cylinder cap; *37* Small equalizing pis-

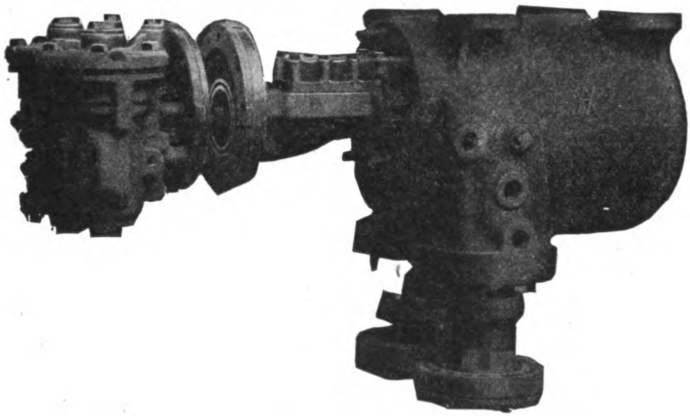


Fig. 110. Westinghouse "3-E" Control Valve, Showing Different Portions of Valve

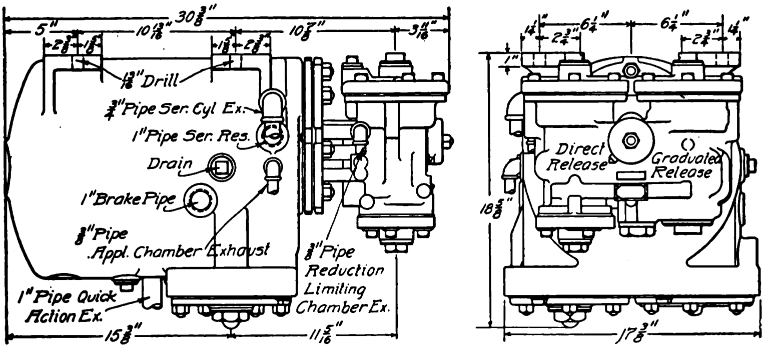


Fig. 111. Outline of Westinghouse "3-E" Control Valve

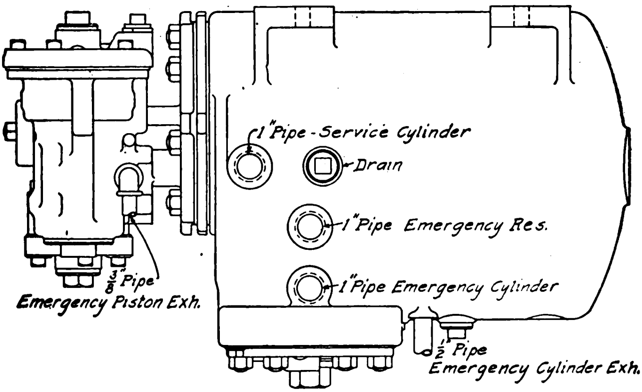


Fig. 112. Outline of Westinghouse "3-E" Control Valve, Showing Side Opposite to That of Fig. 111

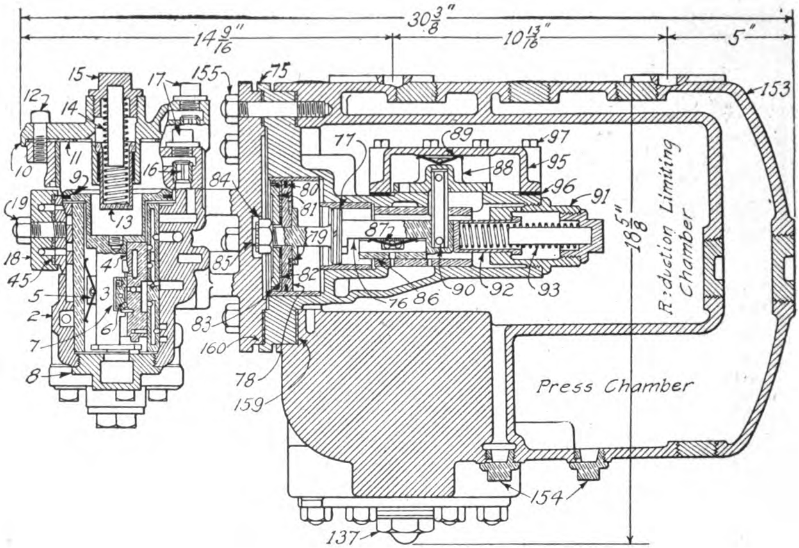


Fig. 113. Actual Longitudinal Section of Westinghouse "3-E" Control Valve

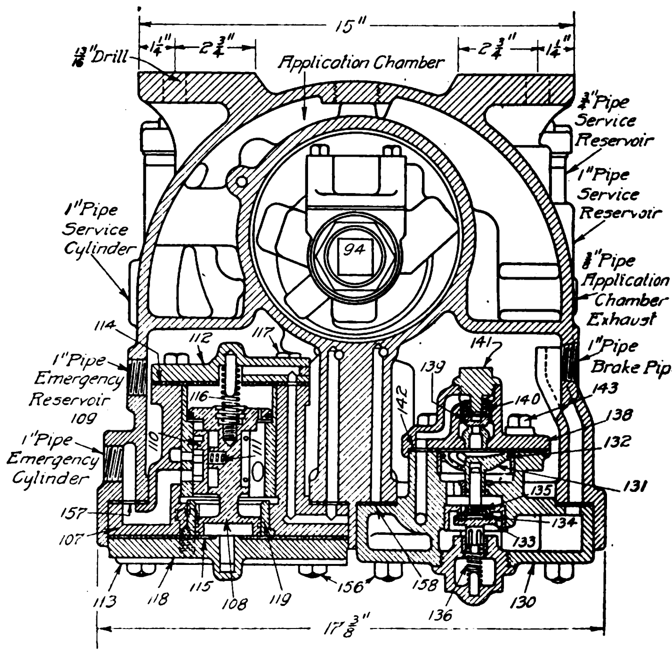


Fig. 114. Actual Cross Section of Westinghouse "3-E" Control Valve

ton bush; *38* Service-reservoir charging valve; *39* Charging-valve piston ring; *40* Charging-valve piston ring; *41* Charging-valve seat; *42* Charging-valve washer; *43* Internal charging-valve nut; *44* External charging-valve nut; *45* Gasket for direct and graduated release cap.

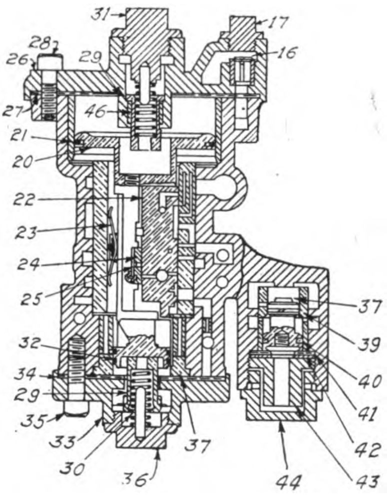


Fig. 115. Section through Equalizing Portion of Westinghouse "3-E" Control Valve

Application Portion: *75* Body; *76* Piston stem; *77* Piston ring (small); *78* Piston head; *79* Piston seal; *80* Piston ring (large); *81* Piston follower; *82* Piston-packing leather; *83* Piston-packing leather expander; *84* Piston nut; *85* Piston cotter; *86* Exhaust valve; *87* Exhaust-valve spring; *88* Application valve; *89* Application-valve spring; *90* Application-piston bolt; *91* Spring box; *92* Piston-spring sleeve; *93* Piston spring; *94* Graduating nut; *95* Application-valve cover; *96* Application-valve cover gasket; *97* Square-head screw for application-valve cover.

Emergency Portion: *107* Body; *108* Piston complete; *109* Piston ring; *110* Slide valve; *111* Slide-valve spring; *112* Small cylinder cap; *113* Large cylinder cap; *114* Small cylinder-cap gasket; *115* Large cylinder cap gasket; *116* Piston spring; *117* Square-head cap screw for small cylinder cap; *118* Oval fillister head cap screw; *119* Emergency-piston bush.

Quick-Action Portion: *130* Body; *131* Piston complete; *132* Piston ring; *133* Quick-action valve; *134* Quick-action valve seat; *135* Quick-action valve nut; *136* Quick-action valve spring; *137* Quick-action valve cap nut; *138* Quick-action valve cover; *139* Quick-action closing valve; *140* Quick-action closing valve spring; *141* Cover cap nut; *142* Cover gasket; *143* Square-head cap screw for cover.

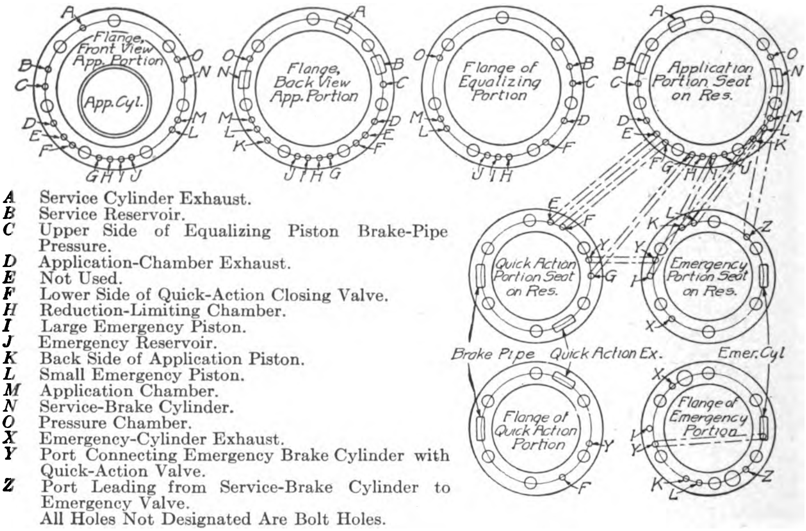
Reservoir: *153* Triple-compartment reservoir; *154* Cap nut; *155* Stud with hex. nut; *156* Stud with hex. nut; *157* Emergency-cylinder gasket; *158* Quick-action cylinder gasket; *159* Large reservoir gasket; *160* Equalizing-cylinder gasket.

CONTROL VALVE

Fig. 116 is presented to assist in gaining a clearer idea of the location of the parts in the different portions of the control valve. On account of the complicated construction of the "No. 3-E" control valve, reference will be made to the diagrammatic views shown in Figs. 117 to 131, in explaining its action.

Fig. 117 shows all of the ports and operative parts of the control valve in *normal* position. This is the position which the various parts of the valve would occupy with all parts properly assembled, but before any air has been admitted to the brake pipe.

It will be noted that the direct- and graduated-release cap is shown in its *graduated-release* position. Just below it is shown the position which the cap occupies when adjusted for direct instead of graduated release. In all the succeeding views, except Fig. 129, the cap is considered to be adjusted for graduated release. Fig.



A Service Cylinder Exhaust.
B Service Reservoir.
C Upper Side of Equalizing Piston Brake-Pipe Pressure.
D Application-Chamber Exhaust.
E Not Used.
F Lower Side of Quick-Action Closing Valve.
H Reduction-Limiting Chamber.
I Large Emergency Piston.
J Emergency Reservoir.
K Back Side of Application Piston.
L Small Emergency Piston.
M Application Chamber.
N Service-Brake Cylinder.
O Pressure Chamber.
X Emergency-Cylinder Exhaust.
Y Port Connecting Emergency Brake Cylinder with Quick-Action Valve.
Z Port Leading from Service-Brake Cylinder to Emergency Valve.
All Holes Not Designated Are Bolt Holes.

Fig. 116. Diagrams of Flanges and Seats for Westinghouse "3-E" Control-Valve Portions

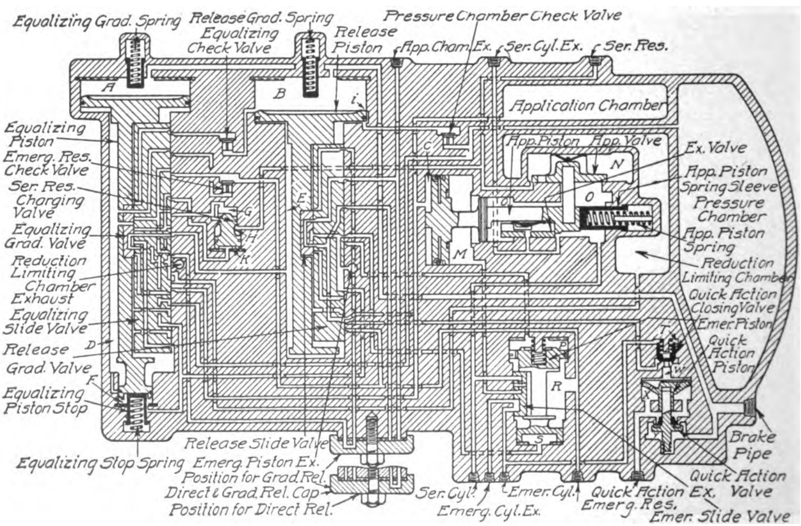


Fig. 117. Normal Position of Westinghouse "3-E" Control Valve

129 with the accompanying explanation refers to the operation of the valve with the cap adjusted for direct release.

Release and Charging Position

Fig. 118 shows only those parts and ports which are operative while the brake is being released and the pressure chamber and emergency and service reservoirs are being charged.

Charging Empty Equipment. In charging the empty equipment, air from the brake pipe entering the control valve at the point indicated passes to chambers *B* and *A* and forces the equalizing and release pistons of the equalizing portion, with their attached valves, to *release* position. Brake-pipe air then passes from chamber *B*, lifting the equalizing check valve, and by way of the equalizing slide

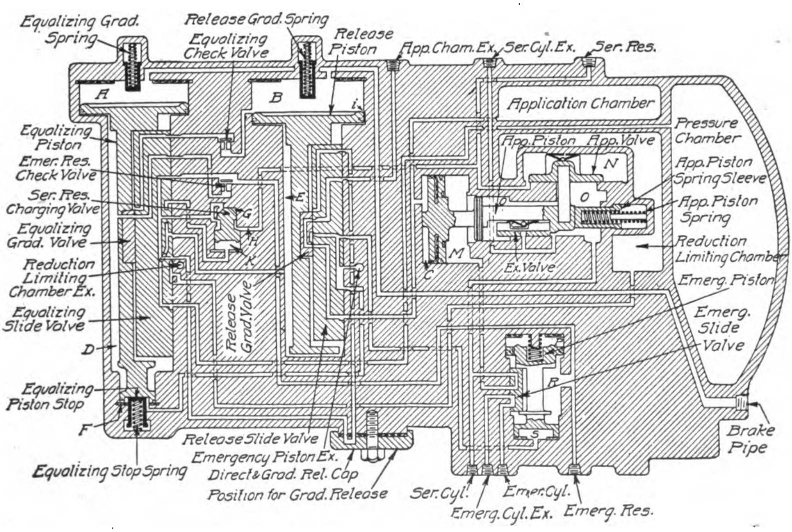


Fig. 118. Release Position, Charging-Pressure Chamber, Emergency and Service Reservoirs for Westinghouse "3-E" Control Valve

valve into chamber *D*. Air from chamber *D* then flows through the equalizing graduating and slide valve—so shown in the diagrammatic drawing for the sake of clearness. In this and a number of instances following, this port in actual valves opens past the end of instead of through the graduating valve, past the emergency-reservoir check valve, and thence in two directions: (1) to chamber *R* and to the emergency reservoir, and (2) through the equalizing slide valve to two different ports, one connecting to the service-reservoir charging valve and thence to the service reservoir; the other by way of the direct- and graduated-release cap and through the release slide valve and past the end of the release graduating valve to chamber *E*.

Air from the brake pipe and chamber *B* also flows through feed groove *i* and charges chamber *E*. From chamber *E*, the air flows by way of the equalizing slide valve in two directions: (1) to the pressure chamber direct (which is thus charged to brake-pipe pressure), and (2) to chamber *K*. With substantially the same pressures (brake-pipe pressure as explained) in chambers *G* and *K*, and a lower pressure (service-reservoir pressure) in chamber *H*, the service-reservoir charging valve remains in the position shown in Fig. 117, being held in this position until the re-charging is completed, since chamber *K* is relatively small and the ports leading to it of ample capacity to charge it more quickly than the pressure can be built up in chambers *G* and *H*.

Release Connections. Referring to Fig. 117, it will be noted that the pressure-chamber check valve prevents the air in chamber *E* from flowing directly to the pressure chamber, but allows a free passage of air in the opposite direction.

Chamber *F* at the small end of the equalizing piston is connected through the release slide valve to the emergency-piston exhaust and atmosphere, thus holding the equalizing piston and its valves positively in release position. Chamber *S* at the small end of the emergency piston is connected through the release slide valve to the emergency-piston exhaust and the atmosphere in release position, thus holding the emergency piston and its valve positively in the proper position.

The reduction-limiting chamber is connected through the equalizing slide valve to the reduction-limiting chamber exhaust and atmosphere. The application chamber and chamber *C* are connected through the release slide valve and graduating valve to the application-chamber exhaust port leading to the atmosphere.

The service brake cylinder is connected through the exhaust slide valve of the application portion to the service brake-cylinder exhaust port leading to the atmosphere. The emergency brake cylinder is connected through the emergency slide valve to the emergency-cylinder exhaust port leading to the atmosphere.

It will be noted that Fig. 117 and some that follow show a small cavity in the release graduating valve. This cavity is connected to the emergency-piston exhaust in all positions of the valve, but has no other connection. The purpose of this cavity is merely to insure that, under all conditions, there will be sufficient differential pressure acting on the graduating valve to hold it to its seat.

Service Application

(a) **Preliminary Service Position.** With the equipment fully charged as explained above, the result of a service reduction in brake-pipe pressure will be to lower the pressure in chambers *A* and *B* below that in chambers *D* and *E*, thus creating a differential pres-

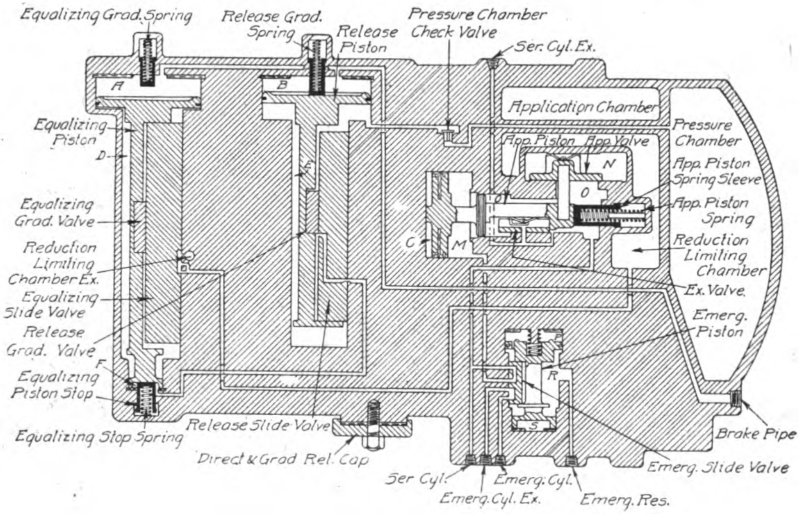


Fig. 119. Preliminary Service Position of Westinghouse "3-E" Control Valve

sure on the equalizing and release pistons. Since chamber *F* is open to the atmosphere, Fig. 118, the release piston will move on a much less differential than the equalizing piston. There is a small amount of lost motion between release piston and release graduating valve, and somewhat more between release piston and release slide valve so that during the first movement of the release piston, the release slide valve still remains in its release position, thus keeping chamber *F* open through the emergency-piston exhaust port to the atmosphere. The release piston, therefore, is the first to move when a brake-pipe reduction is made and it carries with it the release graduating valve and finally moves the release slide valve to the position shown in Fig. 119, called *preliminary service* position. In this position the piston has closed the feed groove *i* (which is therefore not shown in Fig. 119) and just touches the release graduating-piston sleeve.

The function of the valve in this position is to close the port leading from the application chamber to the atmosphere (which is therefore not shown in Fig. 119), to close the port connecting chamber *F* to the emergency-piston exhaust, and to open this latter port, connecting chamber *E* past the end of the release graduating valve and through the release slide valve to chamber *F*. Pressure-chamber air is, therefore, free to flow past the pressure-chamber check

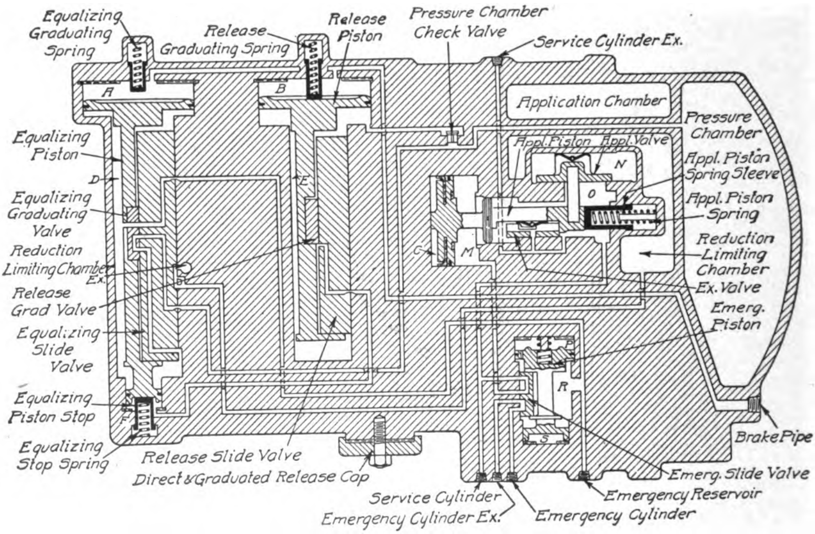


Fig. 120. Secondary Service Position of Westinghouse "3-E" Control Valve

valve to chamber *F*, thus balancing the pressures in chambers *F* and *D* on the opposite sides of the small end of the equalizing piston.

This position, it should be understood, is assumed only momentarily and should be regarded as the first stage only of the complete movement of the parts from *release* and *charging* to the *service* position of the parts.

(b) **Secondary Service Position.** The balancing of the pressures in chambers *F* and *D*, as explained, permits the equalizing piston to move in accordance with the difference of pressure already existing between chambers *D* and *A*. When the shoulder on the end of the piston stem comes in contact with the equalizing slide valve, as shown in Fig. 120, a connection is momentarily made from the emergency reservoir through the equalizing slide valve and past the end of (although shown as through in the view) the graduating valve to chamber *D*. The purpose of this connection is to prevent a drop in pressure in chamber *D* which would otherwise take place on account of the movement (displacement) of the equalizing piston. The displacement of the equalizing piston is sufficiently great, compared with the volume of chamber *D*, to require the provision just explained.

At the same time, the pressure chamber is connected through the equalizing slide valve and graduating valve to chamber *D*, thus

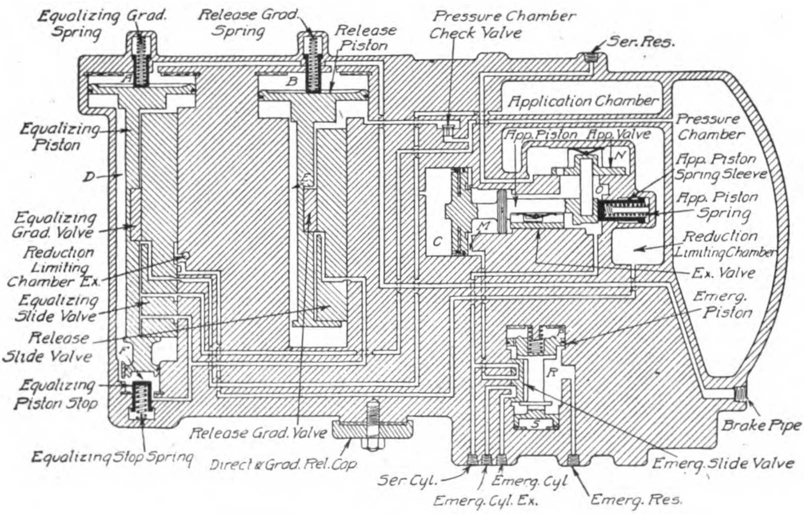


Fig. 121. Service Position of Westinghouse "3-E" Control Valve

keeping the pressures in these two chambers equal. The other connections remain as explained under the heading "Preliminary Service Position".

(c) **Service Position.** The differential between the brake-pipe pressure in chamber *A* and the pressure in chamber *D* (pressure-chamber pressure as explained) is sufficient to move the equalizing piston and its valves past the intermediate secondary service position into service position, Fig. 121, in which the equalizing piston just touches the equalizing graduating-spring sleeve.

Chambers *F* and *D* are in communication by way of a feed port around the small end of the equalizing piston. The pressure chamber is connected to chamber D through two channels, *first*, by way of the pressure-chamber check valve to chamber E and thence past the end of the release graduating valve through the release slide valve to chamber D by way of a port past the end of (shown as through in diagram) the equalizing slide valve, as well as through chamber F; and *second*, the pressure chamber is also connected directly to the seat of the equalizing slide valve and past the end of (shown as through in diagram) the slide valve direct to chamber D.

From chamber D, air from the pressure chamber can flow past the end of the equalizing graduating valve and through the equalizing

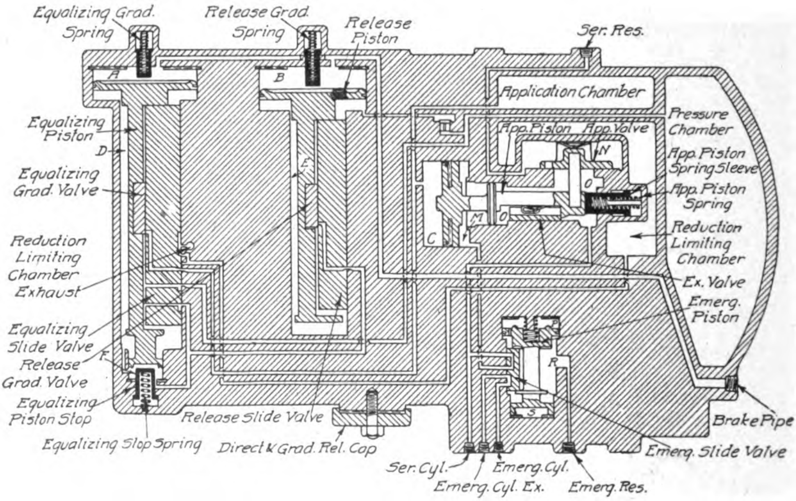


Fig. 122. Service Lap Position for Westinghouse "3-E" Control Valve

slide valve to the application chamber and chamber C on the face of the application piston. The pressure of the compressed air thus admitted to chamber C causes the application piston to move to its application position, compressing the application-piston spring in so doing.

In this position the brake-cylinder exhaust slide valve closes the brake-cylinder exhaust ports (which, therefore, are not shown in Fig. 121), and the application slide valve opens the application port, permitting air from the service reservoir (chamber N) to flow to chamber O and the service brake cylinder, thus applying the brakes. The air flowing thus to the service brake cylinder also flows by way of the emergency slide valve to chamber M, in which the pressure is increased equally with that of the service brake cylinder. The flow of air from the service reservoir to the service cylinder continues, therefore, until the pressure in the service brake cylinder and in chamber M becomes substantially equal to that in the application chamber on the opposite side of the application piston. The application-piston spring then returns the piston and the application slide valve back to *lap* position, Fig. 122, thus holding the brakes applied with a service brake-cylinder pressure substantially equal to that put into the application chamber, as before mentioned.

It will be noted that in *service* position, the reduction limiting chamber and emergency brake cylinder still remain connected to the atmosphere, as explained under the heading "Release Position".

(d) Service Lap Position. In case that less than a full-service reduction is made, that is to say that the brake-pipe pressure is not

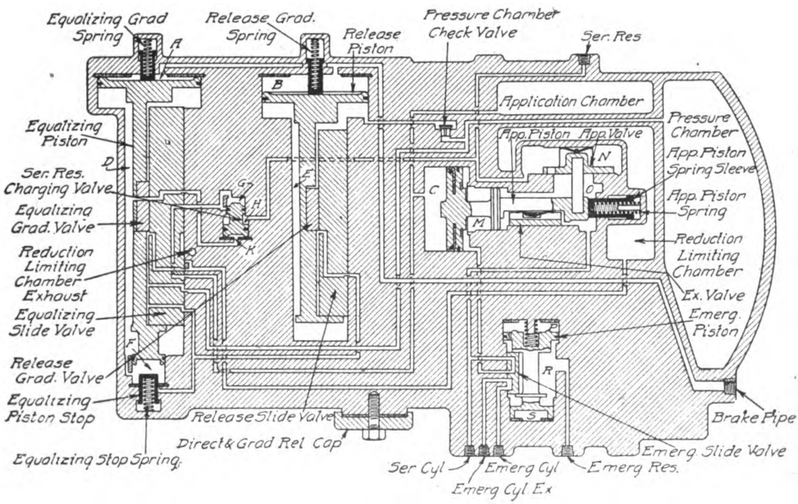


Fig. 123. Over-Reduction Position for Westinghouse "3-E" Control Valve

reduced below the point at which the pressure-chamber and application-chamber pressures equalize, the flow of air from the pressure chamber to the application chamber as explained under the heading "Service Position" will finally reduce the pressure in chamber D to slightly below that to which the brake-pipe pressure is reduced. The slightly higher brake-pipe pressure in chamber A then causes the equalizing piston and graduating valve to return to their *service lap* positions, Fig. 122, and close communication from the pressure to the application chamber, holding whatever pressure was built up in chamber *C* and the application chamber.

It will be plain that any decrease in brake-cylinder pressure, due to leakage, will now reduce the pressure in chamber *M* below that which is bottled up in the application chamber (chamber *C*). The differential pressure thus established on the application piston will cause it to move again toward its *service* position and open the application valve port, as shown in Fig. 123, just enough to supply a sufficient amount of air from the service reservoir to the service brake cylinder to restore the depleted brake-cylinder pressure to its original amount, following which the application valve will be again lapped as already explained. In this way, the brake-cylinder pressure will be maintained constant, regardless of leakage, up to the capacity of the service reservoir.

The release piston and graduating valve may or may not return to their lap positions at the same time as, and in a manner similar to the movement of, the application piston and valves, but they perform no function in either case. Otherwise the parts remain the same as in service position.

(e) **Over-Reduction Position.** If the brake-pipe reduction is carried below the point at which the pressure and application chambers equalize—86 pounds when using 110 pounds brake-pipe pressure and 54 pounds with 70 pounds brake-pipe pressure—such an over-reduction results in lowering the pressure in chamber *A* below that in chamber *D* (pressure-chamber pressure). The equalizing piston consequently moves beyond its *service* position, Fig. 121, carrying with it the equalizing slide valve and graduating valve to what is called the *over-reduction* position.

The relative resistances of the release and equalizing graduating springs is such that the release piston and its valves still remain as in *service*, although for the moment the same differential between pressure-chamber and brake-pipe pressure is acting upon the release piston as was sufficient to move the equalizing piston and its valves to the *over-reduction* position.

The result is that air from the pressure chamber—which is still connected to chamber *D* in substantially the same manner as explained under "Service Position"—now flows past the end of the equalizing graduating valve and through the equalizing slide valve to the reduction-limiting chamber instead of to the application chamber as in *service* position.

The reduction-limiting chamber being at atmospheric pressure permits the pressure in the pressure chamber (and chambers *E* and *D*) to drop, in accordance with the continued over-reduction of brake-pipe pressure, to the point of equalization of the reduced pressure-chamber pressure and the reduction-limiting chamber pressure. Otherwise the condition of the pressures in the reservoirs and brake cylinders controlled by the control valve is unchanged, except that in the movement of the equalizing slide valve to *over-reduction* position, Fig. 123, a connection is made from the application chamber and chamber *C* by way of the equalizing slide valve to the top (chamber *G*) of the service-reservoir charging valve, and from chamber *D* (pressure-chamber pressure) past the end of the equalizing graduating valve and through the equalizing slide valve to chamber *K*. Since the pressure in the pressure chamber is being reduced, while that in the application chamber and service reservoir is equalized, or practically so, at about 86 pounds pressure, the service-reservoir charging valve is not lifted, but is held down to its seat.

With the parts in this position, it will be noted that the service reservoir and the application chamber are separated only by the ring in the small end of the service-reservoir charging valve. If there is any slight leakage which tends to cause a drop in application-chamber pressure—which is relatively small compared with the service-reservoir volume—the air in the service reservoir will gradually find its way around the ring in the small end of the service-reservoir charging valve and prevent any material drop in application-chamber pressure, thus practically eliminating the possibility of the brakes gradually leaking off, due to application-chamber leakage. The application valve port is shown partly open, supplying brake-cylinder leakage, as already explained.

(f) **Over-Reduction Lap Position.** Provided the brake-pipe reduction is not carried below the equalizing point of the pressure chamber and reduction-limiting chamber, a slight reduction of the pressure in the pressure chamber (and chambers *D* and *E*) below that held in the brake pipe, resulting from the continued flow of air from the pressure chamber to the reduction-limiting chamber, will cause the equalizing piston and graduating valve to be returned to *over-reduction lap* position, Fig. 124. This closes the port from the pressure chamber to the reduction-limiting chamber and prevents further flow of air in this direction, but otherwise all parts and pressures are as explained under "Over-Reduction Position", except that the port connecting chamber *D* past the end of the equalizing graduating valve and through slide valve to chamber *K* is blanked by the movement of the equalizing graduating valve.

Should the brakes be held applied in *over-reduction lap* position for a sufficient length of time, with an application-chamber leakage

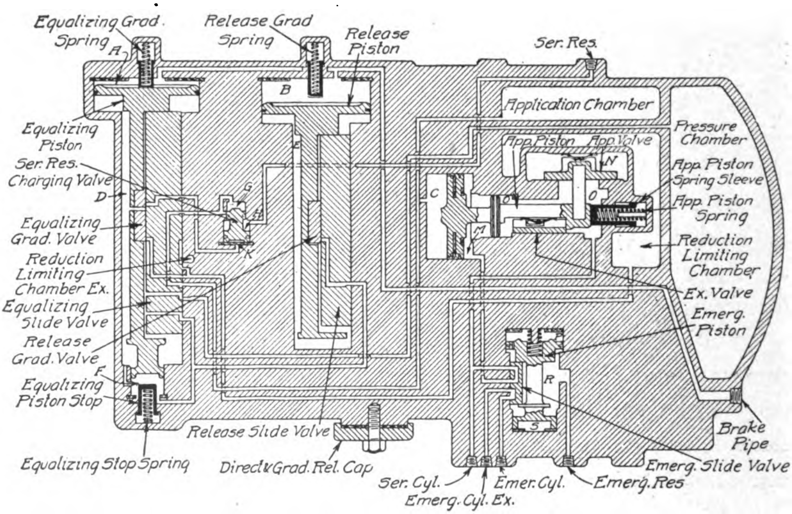


Fig. 124. Over-Reduction Lap Position for Westinghouse "3-E" Control Valve

so great that the air from the service reservoir could not get past the ring in the small end of the service-reservoir charging valve fast enough to supply such leakage (in the manner explained in connection with Fig. 123), the service-reservoir charging valve will finally be lifted, making wide open connection from the service reservoir to the application chamber.

From what has been said, it will be plain that if the brake-pipe reduction is continued below the point at which the pressure and the reduction-limiting chambers equalize, the pressure in the pressure chamber can no longer continue to reduce in accordance with the still falling brake-pipe pressure. This results in a differential being established between the pressure in the pressure chamber (and chambers *D* and *E*) and the brake-pipe pressure which, when the brake-pipe pressure is reduced below 60 pounds when carrying 110 pounds brake-pipe pressure or below 35 pounds with 70 pounds brake-pipe pressure, is sufficient to cause the release piston to travel to its extreme (emergency) position and produce quick action and an emergency application of the brakes as will be explained under "Emergency Position".

Releasing Action

(a) **Preliminary Release Position.** Whether the parts are in service lap or over-reduction lap position, after an application has been made, an increase in brake-pipe pressure above that in the

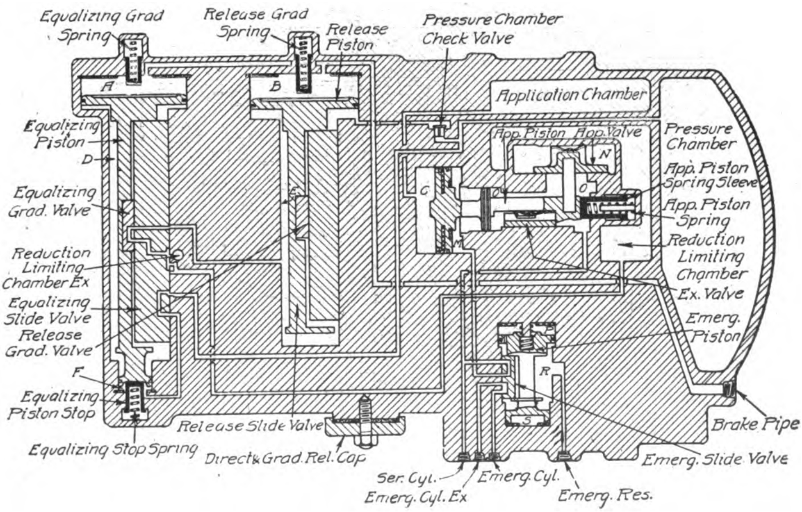


Fig. 125 Preliminary Release Position for Westinghouse "3-E" Control Valve

pressure chamber (chambers *D* and *E*) will cause the equalizing piston and its valves to return to the release positions described below.

The equalizing piston moves before the release piston, the parts being designed to require a somewhat higher differential to move the release piston and its attached valves than is sufficient to move the equalizing piston.

In preliminary release position, Fig. 125, it will be noted that chamber *E* behind the release piston is connected by way of the equalizing slide valve and graduating valve to the reduction-limiting chamber exhaust. This connection is made but momentarily, in what may be considered the first stage of the movement of the parts to release position. It plays a very important part, however, in the release operation of the valve, since, by thus insuring a momentary but material drop in the pressure in chamber *E* below that in the brake pipe and in chamber *B*, the release piston is forced to return positively to its release position shown in Fig. 126—*secondary release* position.

In *preliminary release* position, the pressure chamber is connected by way of the equalizing slide valve to chamber *F*. The

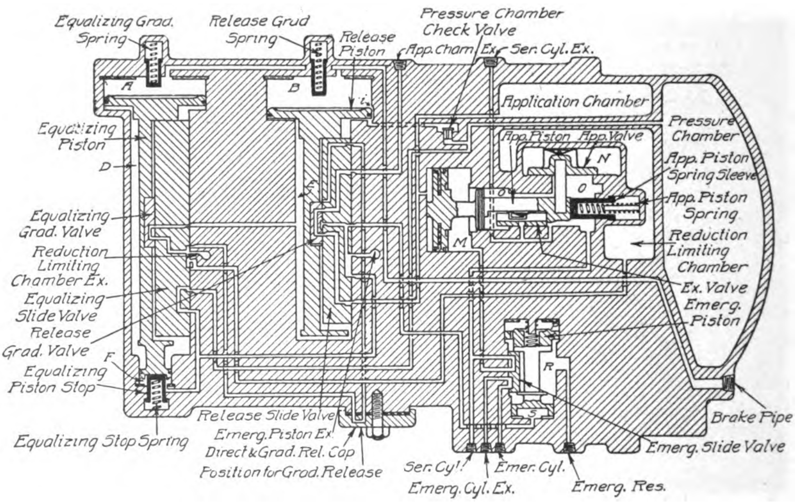


Fig. 126. Secondary Release Position for Westinghouse "3-E" Control Valve

pressure thus acting in chamber *F*, in addition to the force of the equalizing stop spring, serves to insure that the equalizing piston and its valves hesitate in preliminary release position for a sufficient length of time to reduce the pressure in chamber *E*, as already explained.

It will be observed that the application piston is still in its lap position, holding the pressure in the service brake cylinder. This continues until the release of air from the application chamber and chamber *C*, which does not take place until the parts move to the next stage in the release movement—*secondary release* position, Fig. 126.

In the movement of the equalizing slide valve to preliminary release position, the reduction chamber is connected to the reduction-chamber exhaust port and the atmosphere, and so remains until the parts again move to over-reduction position or beyond.

Although there are other connections made in the preliminary release position as shown in Fig. 125, they perform no particular function other than has already been described, and consequently do not need to be again referred to.

(b) **Secondary Release Position.** In the movement of the parts to release position, the next stage, following the preliminary release position is called the *secondary release* position, Fig. 126. It will be seen from the illustration that the venting of the air from chamber *E* through the equalizing slide valve and graduating valve to the reduction-limiting chamber exhaust has resulted in the relatively higher brake-pipe pressure moving the release piston and its valves to their release positions, although for an instant the equalizing piston and its valves still remain as shown in Fig. 125—*preliminary release* position.

With the release piston and its valves in the position shown in Fig. 126, a connection is made from chamber *F* through the release slide valve to the emergency-piston exhaust. At the same time the pressure chamber is connected by way of the equalizing slide valve to the same port which connects chamber *F* to the atmosphere. This tends to maintain the pressure in chamber *F* temporarily so as to insure the connection from chamber *E* to the atmosphere being held open, as explained above, until the release piston and its valves are entirely back in their release positions. In so moving, however, the release slide valve is gradually increasing the size of the opening from chamber *F* to the atmosphere, until a point is reached where the pressure in chamber *F* is lowered sufficiently to permit the differential pressure already acting on the equalizing piston to start this piston toward its release position. The resulting movement of the equalizing slide valve restricts and finally stops entirely the flow of air from the pressure chamber to chamber *F*, the pressure in which is, therefore, rapidly exhausted to the atmosphere through the ports already mentioned and the equalizing piston and its valves are then held positively in their release position as shown in Fig. 127.

Comparing Fig. 125 and Fig. 126, it will be noted that the movement of the release piston, slide valve, and graduating valve from the position shown in Fig. 125 to that shown in Fig. 126, opens communication from chamber *E* past the end of the release graduating valve, through the release slide valve and direct- and graduated-release cap and through the equalizing slide valve to the reduction-limiting chamber exhaust and atmosphere. This outlet from chamber *E* to the atmosphere is simply additional, it will be noted, to

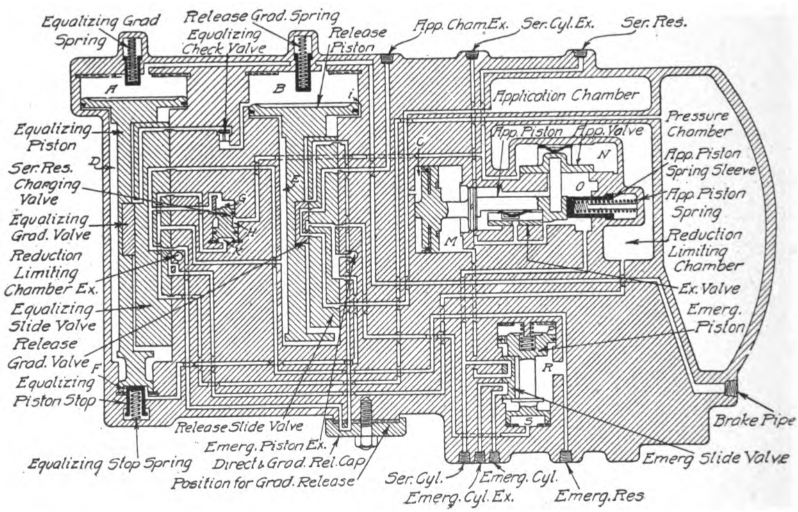


Fig. 127. Graduated Release and Release, Charging-Pressure Chamber Only, for Westinghouse "3-E" Control Valve

that already existing as explained in connection with Fig. 125, and, like it, is but momentary. In the succeeding position, Fig. 127, both these connections from chamber *E* to the atmosphere are cut off.

The movement of the release graduating and slide valves to their release positions opens the application chamber and chamber *C* by way of the valves mentioned to the application-chamber exhaust and atmosphere. The resulting reduction of pressure in chamber *C* below that exerted by the application-piston spring and the air pressure in chamber *M* causes the application piston, with its attached valves, to move back to release position, Fig. 126, opening the service brake cylinder through the exhaust valve to the service-cylinder exhaust and atmosphere. The release of the brake is, therefore, commenced as soon as the release piston and its valves are returned to their release positions.

While there are other connections shown in Fig. 126 besides those just explained, they perform no particular function, so far as the momentary position of the parts in secondary release position, Fig. 126, is concerned, and will, therefore, not be referred to until all can be explained together under "Graduated Release Position", Fig. 127.

(c) **Graduated Release Position.** As already stated, the movement of the release slide valve to its release position connects chamber F to the emergency-piston exhaust and atmosphere, causing the equalizing piston and its valves to be moved to and held positively in their release positions, Fig. 127.

It should be clearly understood that a very slight increase in brake-pipe pressure (about $1\frac{1}{2}$ to 2 pounds) above that remaining in the pressure chamber is sufficient to move the parts through the successive momentary positions of preliminary and secondary release as just explained, until they reach their final positions shown in Fig. 127—*graduated release* position.

In this position (graduated release being assumed to be cut in), the application chamber and chamber C are open through the release slide valve and graduating valve to the application-chamber exhaust and atmosphere. So far as this connection is concerned, the release would be complete provided the parts did not move, but it will be noted that in this position also the emergency reservoir is connected by way of the equalizing slide valve, and the direct- and graduated-release cap (which is adjusted to give graduated release) through the release slide valve and past the end of the release graduating valve to chamber E. The pressure in the emergency reservoir is substantially that to which it was originally charged, namely, normal brake-pipe pressure. The pressure in chamber E, it will be remembered, was reduced equally with the pressure-chamber pressure when the brake application was made. Air from the emergency reservoir, at the higher pressure, will therefore flow into chamber E and, from chamber E by way of the equalizing slide valve, to the pressure chamber, at the lower pressure, and tend to increase the pressure in chamber E and the pressure chamber at the same time that the brake-pipe pressure in chamber B is being increased. If the pressure in chamber E rises faster than that in chamber B, the higher pressure which will soon be built up in chamber E will tend to move the release piston and graduating valve over toward graduated-release lap position, Fig. 128, and either partially restrict or wholly stop the flow of air from the application chamber to the atmosphere, and from the emergency reservoir to chamber E. If the brake-pipe pressure is increased very slowly, the relatively rapid increase of pressure in chamber E may cause the release piston and graduating valve to graduate the release as explained in connection with

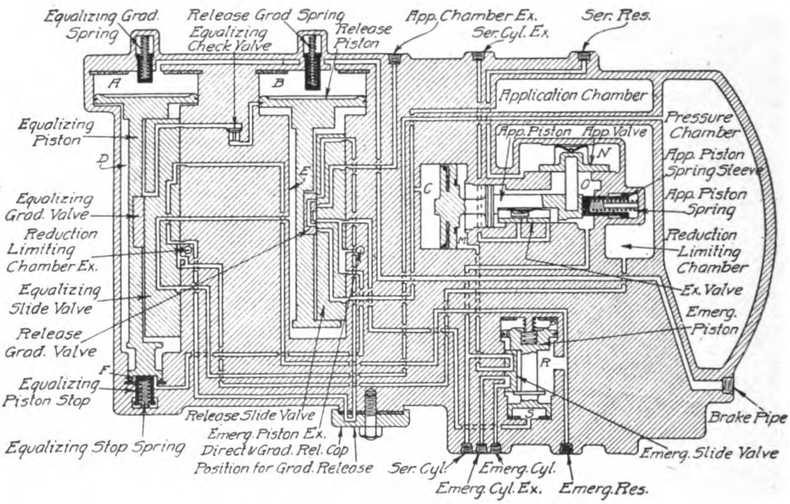


Fig. 128. Graduated-Release Lap Position for Westinghouse "3-E" Control Valve

Fig. 128. If the rate of rise of brake-pipe pressure is not slow enough to permit this action, the parts will move toward the position shown in Fig. 128 sufficiently to so restrict the flow of air from the emergency reservoir to chamber E as to adjust the rate of rise of pressure in chamber E to correspond to that of the brake pipe and chamber B, in which case the release of air from the application chamber will be correspondingly prolonged.

The escape of air from the application chamber and chamber C to the atmosphere, as already explained in connection with Fig. 126, results in the application-piston spring and brake-cylinder pressure acting in chamber M moving the application piston with its valve back from their lap position, as shown in Fig. 125, to their release position, as shown in Figs. 125 and 127, in which position air from the brake cylinder is exhausted to the atmosphere by way of the exhaust valve and service-cylinder exhaust port. Whether the brake-cylinder pressure is entirely or only partially released depends upon whether the exhaust air from the application chamber and chamber *C* is partial or complete. This has already been referred to and will be further mentioned in connection with Fig. 128. It will be noted that in Figs. 125, 126, and 127, the reduction-limiting chamber is connected to the reduction-limiting chamber exhaust and atmosphere through the equalizing slide valve, and that in Figs. 126 and 127 chamber *S* is connected through the release slide valve to the emergency-piston exhaust and atmosphere, so that the air in these chambers is completely exhausted to the atmosphere when either a graduated or direct release is made.

Referring to Fig. 127, it will be noted that chamber *E* is connected to chamber *K* and that air from the emergency reservoir has access to chamber *G*. These connections being opened by the movement of the equalizing slide valve to its release position, whether or not the service-reservoir charging valve will be opened and permit the re-charging of the service reservoir to begin at once will depend on the relative pressures in the pressure chamber and emergency and service reservoirs.. With the ordinary manipulation of the brake, the service-reservoir charging valve will remain closed, Fig. 127, preventing the air from the emergency reservoir reaching the service reservoir, and the pressure chamber only will be re-charged until its pressure has been increased to within about 5 pounds of that in the emergency reservoir.

As already indicated, if the brake pipe is fully re-charged without a graduation of the release being made, the parts will remain in the positions shown in Fig. 127 and the release will be complete and without graduations. The only change which takes place while such a release is being made is the movement of the service-reservoir charging valve from the position shown in Fig. 127 to that shown in Fig. 118, which should properly be regarded as illustrating the final stage in the re-charging of the equipment of which Fig. 127 illustrates the initial stage. That is to say, at first the pressure chamber alone is re-charged and this re-charge is accomplished from the emergency reservoir only, without any air being drawn for this purpose from the brake pipe. The air which is supplied through the brake valve to the brake pipe is, therefore, given every possible advantage and opportunity to accomplish what is intended when the brake-valve handle is moved to release position, namely, to release the brakes by causing an increase of pressure sufficient to accomplish this, throughout the entire length of the brake pipe. After the release has been thoroughly established in this manner, the re-charging of the reservoirs to their original pressure takes place as explained in connection with Fig. 118.

(d) **Release Lap Position.** If, however, the brake-pipe pressure is not fully restored, a graduation of release being made, that is, if the brake pipe is partially re-charged and the brake-valve handle then returned to lap position, the continued flow of air from the emergency reservoir to pressure chamber and chamber *E* will tend to increase the pressure in the pressure chamber and chamber *E* above that of chamber *B* which is now stationary, causing the release piston and graduating valve to move over until the shoulder on the end of the release piston stem comes in contact with the release slide valve, Fig. 128. This closes the exhaust from the application chamber to the atmosphere and prevents further flow of air from the emergency reservoir to the pressure chamber and chamber *E*.

The flow of air from the service brake cylinder to the atmosphere (continuing as explained in connection with Fig. 127), will at once reduce the pressure in chamber *M* below that now retained in chamber *C* by the small amount which is sufficient to cause the application piston to move over to the position shown in Fig. 128, in which the exhaust valve is closed, thus preventing further release of air from the service brake cylinder. The other connections remain as already explained

(e) **Release and Charging Pressure Chamber and Emergency and Service Reservoirs.** The gradual release of brake-cylinder pressure may be continued as explained above, Fig. 128, until the pressures in the emergency reservoir and pressure chamber have become equal. On account of the relatively large volume of the emergency reservoir compared with that of the pressure chamber, this equalization will not take place until the pressure chamber has been re-charged to within about 5 pounds of the brake-pipe pressure carried.

Beyond this point, whatever small amount of pressure may remain in the service brake cylinder is released entirely and the emergency and service reservoirs, as well as the pressure chamber, are re-charged from the brake pipe as described in connection with Fig. 128.

(f) **Direct Release and Charging Position.** Up to this point, the direct- and graduated-release cap has been assumed to be in the position for graduated release. Fig. 129 corresponds to Fig. 127, except that the direct- and graduated-release cap is adjusted for direct release. It will be noted that there is now no connection from the emergency reservoir to the pressure chamber or chamber *E*. Consequently the pressure chamber is being re-charged only by air

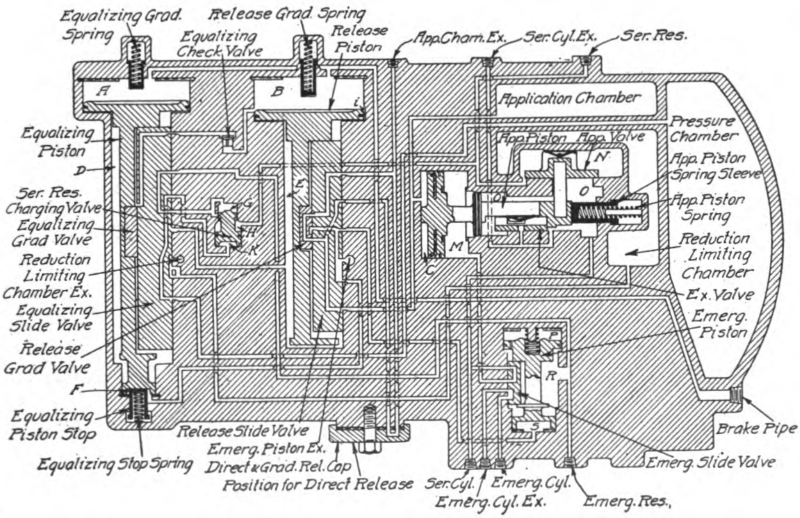


Fig. 129. Direct Release, Charging Pressure Chamber Only, for Westinghouse "3-W" Control Valve

from the brake pipe going through feed groove *i* to chamber *E*, and thence by way of the equalizing slide valve to the pressure chamber. The pressure in chamber *E* cannot, therefore, increase above that in chamber *B*, and the release piston, graduating valve, and slide valve remain in the position shown in Fig. 129.

With the direct- and graduated-release cap adjusted for direct release, it will be noted from Fig. 129 that the application chamber and chamber *C* are open through the release slide valve to a port connecting through the direct- and graduated-release cap to the application-chamber exhaust and atmosphere. This affords an outlet from the application chamber to the atmosphere which cannot be closed as long as the release slide valve remains in the position shown, even though the release piston and graduating valve should, from any cause, be moved back so that the release graduating valve would partially or entirely restrict the application-chamber release port, which is also shown to be open through the release graduating valve in Fig. 129. Moreover, it will be noted that there are two outlets from the application chamber to the atmosphere when the valve is adjusted for direct release as compared with one when graduated release is cut in.

Emergency Position

(a) **Quick-Action Valve Venting.** When the brake-pipe pressure is reduced faster than at the predetermined rate for service

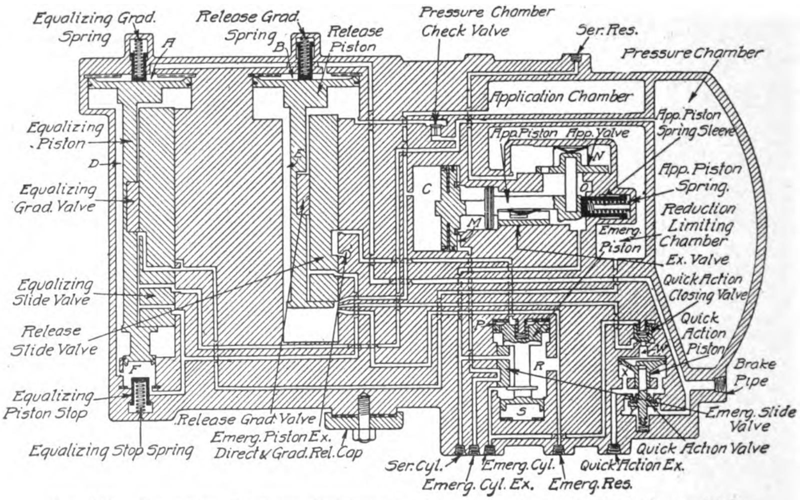


Fig. 130. Emergency Position, Quick-Action Valve Venting, for Westinghouse "3-E Control Valve

applications, or if the brake-pipe reduction should be continued below the point at which the pressure and reduction-limiting chambers equalize (as explained under "Over-Reduction Position"), the differential pressure acting on the release and equalizing pistons becomes sufficient to move them to their extreme or emergency positions, Fig. 130.

In this position, air from the emergency reservoir flows directly to chamber E and from chamber E to the under side of the quick-action closing valve. Chamber *T*, above the quick-action closing valve, is connected to the emergency brake-cylinder port in which there is no pressure, even though a full-service application of the brakes may have just preceded the emergency application.

The higher pressure on the under side of the quick-action closing valve, therefore, raises this valve and air flows to chamber *W* above the quick-action piston, forcing the latter down and opening the quick-action valve against brake-pipe pressure in chamber *Y*. As soon as the quick-action valve is unseated in this manner, air from the brake pipe flows past the quick-action valve to the quick-action exhaust and atmosphere, causing a local venting of brake-pipe air and transmitting the quick application serially throughout the train.

Air from the emergency reservoir flowing to chamber *E* also flows directly to the application chamber and chamber *C*, which forces the application piston and its valve over into their extreme positions, opening the service reservoir through the application slide valve and chamber *O* to the service brake cylinder, thus permitting the pressures in the service reservoir and service brake cylinder to equalize.

At the same time chamber *P*, above the large emergency piston, is connected through the release slide valve to the emergency-piston exhaust and atmosphere, permitting the emergency-reservoir pressure in chamber *R* to force the emergency piston and its slide valve upward to their emergency positions.

In this position of the emergency parts, the emergency reservoir is connected past the end of the emergency slide valve to the emergency brake cylinder, thus permitting the pressures in the emergency reservoir and brake cylinder to equalize. Chamber *R* is also connected through the emergency slide valve to the service cylinder port, which permits equalization of the service and emergency reservoirs and brake cylinders.

It will be noted that in this position the emergency slide valve opens a port which connects chamber *M*, behind the application piston, through the emergency slide valve to emergency cylinder exhaust. This, in connection with the admission of air from the emergency reservoir to the application chamber and chamber *C*, as already explained, still further insures a quick and positive movement of the application piston and its valves to emergency position.

In this position the pressure chamber is connected through the equalizing slide valve to chamber *D*. The pressure chamber is also connected past the pressure-chamber check valve to chamber *E*, and chamber *D* is connected past the end of the equalizing graduating valve through the equalizing slide valve to the reduction-limiting chamber.

(b) **Quick-Action Valve Closed.** The emergency brake-cylinder pressure and the pressure in chamber *T* above the quick-action closing valve continue to rise and the pressure in the emergency reservoir and in chamber *W* below the quick-action closing valve falls, as explained above, until these pressures become substantially

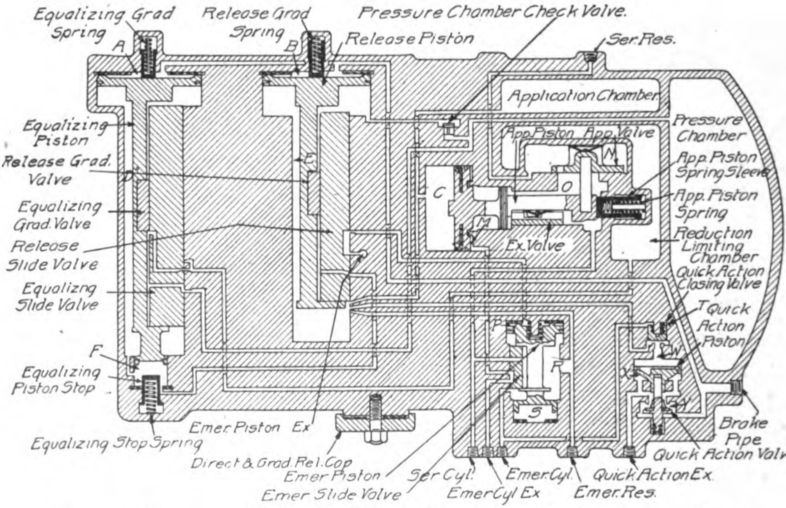


Fig. 131. Emergency Position, Quick-Action Valve Closed, for Westinghouse "3-E" Control Valve

equal. This equalization of the pressures on the opposite sides of the quick-action closing valve permits its spring to return the valve to its seat, cutting off further flow of air to chamber *W*. Chamber *W* is connected through the leakage hole in the quick-action piston to chamber *X* so that as soon as the quick-action closing valve is seated, the pressure in chamber *W* expands through this leakage hole to chamber *X* and the atmosphere through the quick-action exhaust opening. The balancing of the pressures in chambers *X* and *W* thus permits the quick-action valve spring to return the quick-action valve to its seat, closing the outlet from the brake pipe to the atmosphere, Fig. 131. This insures against an escape of air from the brake pipe to the atmosphere when a release is made following the operation of the quick-action parts.

Except for the closing of the quick-action valve and return of the quick-action parts to normal position, the positions of the other parts of the valve and connections between the various reservoirs and cylinders, etc., remain as already explained in connection with Fig. 130.

When releasing after an emergency application, as soon as the brake-pipe pressure in chambers *A* and *B* is increased above that which remains in chambers *D* and *E*, the parts will move to their release positions, exhausting the air from the brake cylinders and re-charging the reservoirs and pressure chamber as explained under "Release and Re-Charging", Figs. 125, 126, 127.

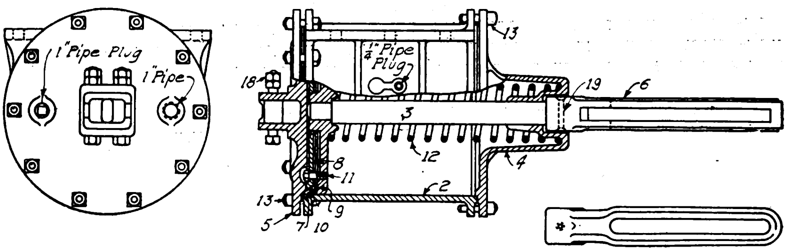


Fig. 132. Diagrammatic Section of Brake Cylinder

Fig. 132 illustrates the type of brake cylinder employed, two of which are used on each car. As previously explained, one brake cylinder is used during service application and both in emergency applications.

INSTRUCTIONS FOR OPERATING "PC" PASSENGER BRAKE EQUIPMENT

The following suggestions are given by the builders for the general handling of the "PC" Passenger Brake Equipment.

The brake should be handled by the engineers in the same manner as with cars equipped with quick-action triples, the only difference being that an emergency application will be obtained should a service reduction of the brake-pipe pressure be continued below 60 pounds when carrying 110 pounds pressure or below 35 pounds with 70 pounds brake-pipe pressure.

When it is found necessary to cut out the brake, close the cut-out cock in the crossover pipe and bleed both the service and emergency reservoirs.

Should it become necessary to bleed the brake when the engine is detached, or air connection is not made, first bleed the brake pipe and then bleed both the service and the emergency reservoirs.

The two sets of cylinder levers are connected to the same truck pull rods as stated above. Therefore, when a service application of the brake is made, the push-rod end of the emergency-cylinder lever will move the same distance as the push-rod end of the service-cylinder lever, but the crosshead being slotted, the piston of the emergency cylinder will not move. Consequently, the fact that the emergency-cylinder crosshead is in release position does not indicate that the air brakes are released. To determine this, look at the ends of either the service- or emergency-cylinder levers.

Whenever it is necessary to change the adjustment of the automatic slack-adjuster, it is imperative that the crossheads of the two adjusters be left at the same distance from their respective brake-cylinder heads, in order that the piston travel of the two cylinders in emergency application will be the same.

The various exhaust openings referred to in the following are plainly marked on the outline drawings.

The quick-action exhaust is the one-inch opening in the bottom of the control-valve reservoir. Should there be a continual blow at this opening, make an emergency application and then release; if the blow continues, remove the quick-action portion and substitute a new or repaired portion or repair the quick-action valve seat, which will be found defective. The quick-action portion is at the left hand when facing the equalizing portion.

There are three control-valve exhaust openings—two on the equalizing portion and one on the side of the control-valve reservoir, all tapped for ⅜-inch pipe.

Should there be a blow at the application-chamber exhaust (⅜-inch exhaust opening on side of the control-valve reservoir) with the brakes applied or released, it indicates a defective equalizing portion, and a new one, or one that has been repaired, should be substituted.

Should there be a blow at the reduction-limiting chamber exhaust (⅜-inch exhaust on left side of equalizing portion) in release or service position, it indicates a defective application portion, and a new one, or one that has been repaired, should be substituted. This portion is located back of the equalizing portion inside the reservoir. If the blow occurs only after 30 pounds brake-pipe reduction, it indicates a defective emergency-reservoir check valve (the middle check valve in the equalizing portion) and a new one, or one that has been repaired should be substituted. If the blow does not cease, it indicates a defective equalizing portion, and a new one, or one that has been repaired, should be substituted.

Should there be a blow at the emergency-piston exhaust (⅜-inch exhaust on the right-hand side of the equalizing portion), make a 15-pound brake-pipe reduction and lap the brake valve. If the blow ceases, it indicates that the emergency piston is defective, and a new portion or one that has been repaired, should be substituted. If the blow does not cease, it indicates that the equalizing portion is defective, and a new one, or one that has been repaired, should be substituted.

A hard blow at the service brake-cylinder exhaust (tapped for ¾-inch pipe and located at the left side of the control-valve reservoir) with the brakes applied indicates that the application portion is defective, and a new one, or one that has been repaired, should be substituted. This portion is located back of the equalizing portion inside the reservoir. If this blow occurs when the brakes are released, it indicates either a defective application or emergency portion, and a new one or a repaired portion, as found to be required on investigation, should be substituted.

A hard blow at the emergency-cylinder exhaust (tapped for ½-inch pipe and located on the bottom of the control-valve reservoir) with the brakes either applied or released indicates a defective emergency portion, and a new one, or one that has been repaired, should be substituted.

If the trouble described in the five paragraphs immediately preceding is not overcome by the remedies therein suggested, remove the application portion and examine its gasket, as a defect in same may be the cause of the difficulty.

When removing the application, emergency, and quick-action portions, their respective gaskets should remain on the reservoir. On removing the equalizing portion, its gasket should remain on the application portion, except when the application portion is shipped to and from points where triple valves are cared for.

When applying the different portions, the gaskets should be carefully examined to see that no ports are restricted, and that the gasket is not defective between ports. See also that all nuts are drawn up evenly to prevent uneven seating of the parts.

On the front and at the center of the equalizing portion is located the direct- and graduated-release cap (held by a single stud) on which is the pointer. The position of this pointer indicates whether the valve is adjusted for direct release or graduated release. This cap should be adjusted for either direct or graduated release according to the instructions issued by the railroad.

Recent Improvements in Brake Equipment. In addition to the different brake equipments described, mention might be made of two other equipments which have just recently been tried out. One of these is the Westinghouse Electro-Pneumatic Brake Equipment with the Type "U" standard universal valve, for use in passenger service. The other is the Empty and Load Freight Brake Equipment. The results of tests conducted on each of these equipments has been satisfactory in every way, but the apparatus has not at the present time been very widely used.

WESTINGHOUSE TRAIN AIR-SIGNAL SYSTEM

Essentials of Air-Signal System. A train signal system is very essential in maintaining fast schedules with passenger trains, its object being to furnish a means of communication between the trainmen and enginemen. The most common form used is the pneumatic, and is made up of the following principal parts:

(1) A ¾-inch signal pipe, which extends throughout the length of the train, being connected between cars by flexible hose and suitable couplings.

(2) A reducing valve, which is located on the engine, and which

feeds air from the main reservoir into the signal pipe at 40 pounds pressure.

(3) A signal valve and whistle, located in the cab and connected to the signal pipe.

(4) A car discharge valve, located on each car and connected to the signal pipe.

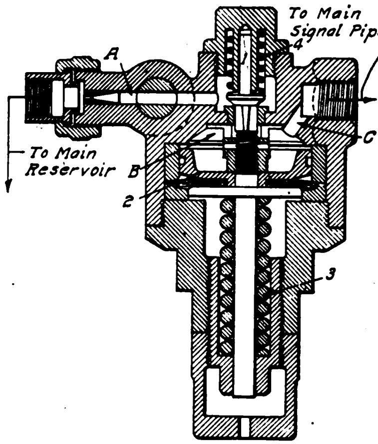


Fig. 133. Section through Reducing Valve in Westinghouse Air-Signal System

The action of the signal system is automatic. If an accident happens to the train which breaks the signal pipe, the pressure in the signal pipe is reduced and the whistle in the cab blows a blast. The trainmen may also signal the enginemen by opening the car discharge valve, which reduces the pressure in the signal

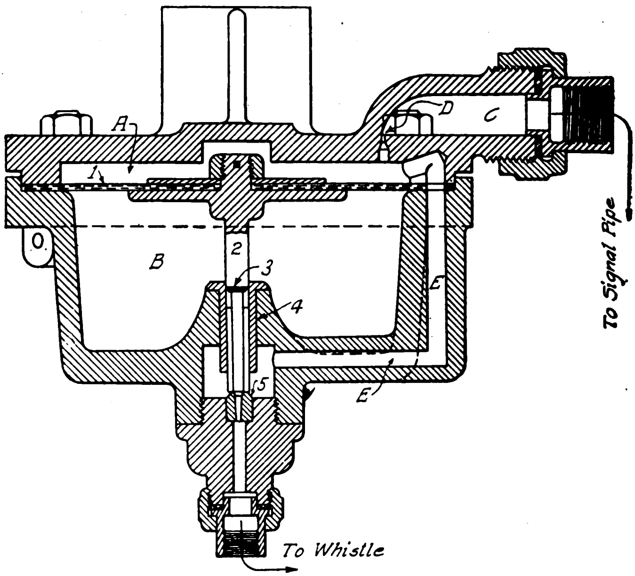


Fig. 134. Section through Signal Valve in Westinghouse Air-Signal System

pipe, thus operating the signal valve in the cab and blowing the whistle as before. The operation of the various parts is as follows:

Reducing Valve. The reducing valve, a section through which is shown in Fig. 133, is located in a suitable place on the locomotive. Its purpose is to receive air from the main reservoir and feed it into the signal pipe, maintaining a pressure of 40 pounds. When no air is in the system, the parts occupy the position shown, but when air is admitted from the main reservoir, it flows through the passage *A* and the supply valve *1*, into the chamber *B* and out through the port *C* into the main signal pipe. When the air in the main signal pipe attains a pressure of 40 pounds, the pressure in the chamber *B*, acting on the piston *2*, forces it downward and compresses the spring *3*. This permits the spring *4* to close the supply valve *1*. No more air can then enter the signal pipe until its pressure becomes reduced so that the spring *3* will force the piston *2* upward and lift the supply valve *1*. Type "C-6" reducing valve, Fig. 36, is also used.

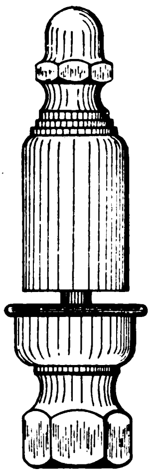


Fig. 135. Signal Whistle in Westinghouse Air-Signal System

Signal Valve. The signal valve, Fig. 134, controls the supply of air to the whistle, a reduction of air pressure in the signal pipe admitting air to the whistle through the signal valve. The two compartments *A* and *B* are divided by the diaphragm *1* to which is attached the stem *2*. This stem is milled triangular in section from the lower end to the peripheral groove *3* but above the groove *3* it fits the bushing *4* snugly. The lower end of the stem *2* acts as a valve on the seat *5*. Air enters the signal valve from the signal pipe, through the passage *C*, passing through the small port *D* into the chamber *A*, and through the passage *E*, around the triangular portion of the stem *2*, into the chamber *B*. This charges the chambers *A* and *B* to the signal-pipe pressure. A sudden reduction in signal-pipe pressure reduces the pressure in the chamber *A*; and the diaphragm *1*, acted on by the pressure in the chamber *B*, rises, lifting the stem *2* and momentarily permitting air to pass from the signal pipe to the whistle, Fig. 135. The resulting blast of the whistle is a signal to the enginemen. This same reduction of pressure in the signal pipe causes the reducing valve to re-charge the system. The pressures in the chambers *A* and *B* equalize quickly, and the lower end of the stem *2* returns to its seat.

Car Discharge Valve. The car discharge valve, Fig. 136, is usually located outside the car above the door or under the roof of the vestibule, in such a position that the signal cord passing through the car can easily be fastened to the small lever of the valve. The valve is connected to a branch pipe which extends from the signal pipe. The signal cord is connected to the eye in lever *1*. Each pull in the signal cord causes the lever *1* to open the check valve *2*, permitting air to escape from the signal pipe. This causes a reduction in the signal pipe, which, in turn, causes the whistle to blow as previously described. The spring *3* closes the valve *2* when the signal cord is not held.

For the successful operation of the signal system, the signal pipe must be perfectly tight. Care must be exercised in using the car discharge valve so that sufficient time is permitted to elapse between successive discharges.

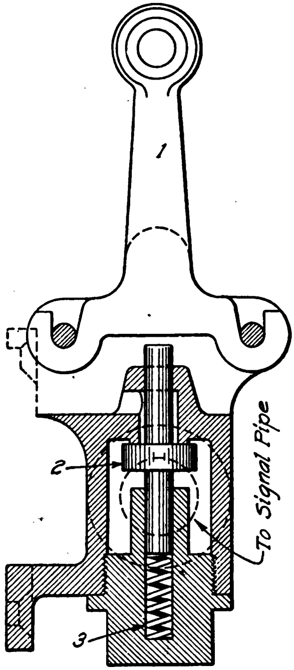


Fig. 136. Section through Car Discharge Valve in Westinghouse Air-Signal System

BRIEF INSTRUCTIONS FOR THE USE AND CARE OF AIR-BRAKE EQUIPMENT

The following instructions apply more directly to the old types of passenger and freight brake equipments, applying only in a general way to the later improved types.

Train Inspection. When a train is made up at a terminal, the air hose should all be coupled and the angle cocks all opened except the one at the rear end of the last car. The brake pipe should then be charged to about 40 pounds, in order that the inspector may examine for leaks. When the brake pipe has been fully charged, the engineer should apply the brake by making a light reduction in the brake pipe, which should then be followed by a full-service application. He should note the time required in making these reductions, in order to be assured that all pistons are moved past the leakage groove when the train is out upon the road. The engineer, after making the full reduction, should leave his brake valve in lap position until the inspector has examined the brake under every car. It should be the duty of the engineer to see that the brake equipment on the locomotive is in proper working order.

Running Test. In passenger service, when a locomotive has been changed or a train made up, the engineer should make a running test within a mile of the station, as follows: A brake-pipe reduction of about 5 pounds should be made. If the brakes are felt to be applying and the time of the discharge is proportional to the number of cars in the train, the engineer will conclude that the brake is in proper working order. It is well, also, to make this test on approaching hazardous places.

Service Applications. In making a service application of the brakes, the first reduction should be about 5 pounds on a train of cars 30 or less, and about 7 pounds on a train exceeding 30 cars. This will insure the travel of all pistons beyond the leakage groove. Subsequent reductions of from two to three pounds can be made to increase the braking power, if desired. A reduction of 25 to 30 pounds will make a full-service application.

In stopping a passenger train, at least two applications should be used; the first should reduce the speed of the train to about 8 miles an hour, when the train is within two or three car lengths of the point at which the train is to be stopped. Moving the brake-valve handle to release position for only sufficient time to release all brakes, then returning it to lap position, will make it possible for a second light application to stop the train. Just before all stops of passenger trains, except exact-position stops at water stations and coal chutes, the brakes should be released to avoid shocks to passengers. This release should be made on the last revolution of the drivers. If it should be made too soon and the train keep on moving, the engineer's brake valve should be moved to service position until the train stops.

In making stops of freight trains, the best practice is to shut off the steam and allow the slack to run in before applying the brakes. The stop should be made with one application of the brakes. After the first reduction is made, if there are any leaks in the brake pipe, the braking force will be increased, and any subsequent reduction should be made less, in order to make up for these leaks. In stopping a long freight train at water stations and coal chutes, it is best to stop short of the place, cut off, and run up with the locomotive alone.

On a freight train, where the locomotive is not equipped with the straight air brake or the "ET" equipment, the brakes should not be released when the speed of the train is 10 miles per hour or less. If this is done, the brakes in the front of the train may release, and, as the slack runs out, the train may part. If the locomotive is equipped with straight air or "ET" equipment, the train brakes can be released after the locomotive brakes are set, without danger of parting the train.

Emergency Applications. The emergency application should never be used, except in case of an emergency. If the necessity arises, an emergency application may be made after a service reduction of about 15 pounds. In case an emergency is caused by the train parting, hose bursting, or the conductor's valve being opened, the engineer should place his valve on lap, in order to save the main-reservoir air.

Use of Sand. The use of sand increases the braking power of a train and should be made in emergency stops. If sand is used in service stops, it should be supplied some time before the brakes are applied in order to have sand under the entire train. If, for any reason, the wheels should skid, do not apply the sand as it will produce flat spots on the wheels.

Pressure Retaining Valve. In holding trains on grades, a part or all of the retaining valves are set to maintain air pressure in the brake cylinder. If only part are set, those in the front of the train should be used.

Backing Up Trains. In backing up long freight trains, the train should be stopped by the hand brakes on the leading end of the train, for the reason that if air were used, the brakes would apply on the cars near the engine and the leading cars might cause a break-in-two.

In backing up a passenger train, where the train is controlled by a man on the leading car by means of an angle cock, the engineer's valve should be in running position. This gives the man on the rear of the train full control of the brakes. As soon as the engineer feels the brake apply, he should place his valve on lap.

Double-Heading. When two or more locomotives are coupled in the same train, the brakes are operated by the leading locomotive. The cut-out cocks in the brake pipe just below the engineer's valve on all locomotives but the first should be closed. The pumps on all engines should be kept running.

Conductor's Brake Valve. A conductor's brake valve is located on each passenger car. The purpose of this valve is that the conductor may stop the train in case of emergency; if the engineer's brake valve should fail to operate, he may signal the conductor to apply the brakes by opening the valve.

Use of Angle Cocks. In setting a car out of a train, first release the brakes, then close the angle cock on both sides of the hose to be disconnected, and finally disconnect the hose by hand. Before leaving a car on the side track, the air brakes should first be released by opening the release valve on the auxiliary reservoir; and if the car is on a grade, the hand brake should be set.

The angle cock should not be opened on the head end of a train while the locomotive is detached. When connecting a locomotive to the train that is already charged with air, the angle cock at the rear of the tender should be opened first to allow the hose to become charged and thus prevent a slight reduction in the brake pipe, which might set the brakes. All angle cocks upon charged brake pipes should be opened slowly.

Cutting Out Brakes. If the brake equipment on any car is defective, it may be cut out by closing the cut-out cock in the branch pipe leading from the brake pipe to the triple valve. The release valve on the auxiliary reservoir should be opened to discharge the air. Never more than three cars with their brakes cut out should be placed together in a train on account of the emergency feature being unable to skip more than this number.

Air Pump. The air pump should be run slowly with the drain-cocks open until the steam cylinder becomes warm and sufficient air-pressure has been attained to cushion the air, after which time the throttle may be fully opened. The lubricator should be in operation as soon as possible after starting, and the swab on the piston rod should be kept well oiled. The air cylinder should receive oil each trip. Valve oil should be used, and it should be inserted through the oil cup provided for that purpose, and not through the air strainer.

Engineer's Brake Valve. With the handle in running position, the main-reservoir pressure should be maintained at 90 pounds or as high as needed, and the brake pipe at 70 or 110 pounds, depending on the system. This requires that the springs in the pump governor and feed valve must be carefully adjusted and that no leaks exist between ports in the rotary valve. The rotary valve should be cleaned and oiled when necessary; and if leaks exist, the valve should be scraped to a fit.

Triple Valve and Brake Cylinders. The triple valve and brake cylinders should receive an occasional cleaning and oiling in order that they may be relied upon to fulfill their function. In cleaning the cylinder, special attention should be given to removing any deposit in the leakage groove. The walls of the cylinder should be coated with suitable oil or grease, and all bolts in the cylinder head and follower should be kept tight.

In cleaning the triple valve, a common practice is to place the removable parts in kerosene until the other parts and the brake cylinder have been cleaned. The parts are then removed, cleaned, oiled, and replaced. Special care should be given to the slide valve and its seat, and to the graduating valve. All lint should be removed before replacing the parts. The piston packing ring should never be removed, except for renewing. A few drops of oil is all that is necessary for lubricating the entire triple valve. No oil should be permitted to get upon the gaskets or rubber-seated valve. The graduating-valve and check-valve springs should be examined and, if necessary, renewed.

AIR BRAKES AS APPLIED TO ELECTRIC CARS

GENERAL SURVEY OF SYSTEMS DEVELOPED

That electric street cars and interurban cars should be equipped with reliable and efficient braking apparatus is a well-established fact, which is emphasized by the frequency of accidents on roads where poorly constructed braking appliances are used. The modern electric car is several times heavier than cars used a decade ago and speeds have increased remarkably, yet we frequently find cars fitted with braking apparatus but little better than that used in the days of the horse car. Of recent years, the most progressive roads have given much attention to the construction of their equipment in order to insure the safety of their passengers and, as a result, braking appliances have been greatly improved.

Hand Brakes. The hand brake was the first form of brake used on electric cars and is still used in many of the smaller cities. It is also found today on many cars fitted with air brakes, to be used in case of necessity. The early forms of hand brakes consisted of a brake staff located at either end of the car, having a chain connected to the lower end of the staff. As the handle turned, the chain was wound up on the staff, and the resulting motion actuated the rods and levers which brought the brake shoes in contact with the wheels.

An improved form of brake staff is shown in Fig. 137. Here the winding drum takes the form of a spiral cam. In operation, the slack in the chain is quickly taken up and a very great braking pressure can be obtained.

Early Forms of Air Brake. The first form of air brake installed on electric cars was known as the *straight air-brake system.* It is largely used today, as is also the *automatic air-brake system.* The straight air-brake system is usually found on trains of not more than one or two cars in length. Since electric roads do not, at this time, interchange cars to any great extent, there is no very great necessity of interchangeable air-brake apparatus. As a result, there are a number of different types and makes of air-brake apparatus found in use on electric cars. All operate upon practically the same general principles.

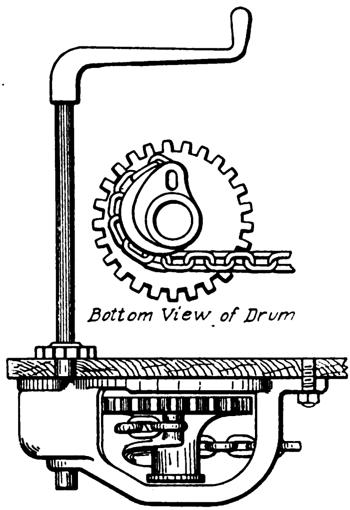


Fig. 137. Hand Brake for Electric Cars

Characteristics of Modern Systems. The Westinghouse Company, in order to meet the requirements of the different classes of electric car service, has developed the following different brake equipments: (a) The "SM-1" Brake Equipment; (b) the "SM-3" Brake Equipment; (c) the "SME" Brake Equipment; (d) the "AMS" Brake Equipment; (e) the "AMM" Brake Equipment; (f) the "AMR" Brake Equipment; and (g) the "EL" Locomotive Brake Equipment.

"SM-1" and "SM-3" Brake Equipments. Both the "SM-1" and "SM-3" brake equipments are straight air equipments, designed only for use on cars operated as single units. The two systems cover the air brake in its simplest form and are not considered satisfactory or safe for use on trains of more than one car in length.

"SME" Brake Equipment. This is a straight air-brake equipment having an automatic emergency feature by means of which the simplicity of the straight air brake is retained for service operation, but it also has the additional protection afforded by the automatic

application of the brake in case of a break-in-two or the bursting of a hose. It is designed for use on trains of not more than two cars in length.

"AMS" Brake Equipment. The "AMS" equipment is designed for use on cars running either singly or in not more than two-car trains, in city or slow-speed service. It combines the safety features of an automatic brake with the ease and flexibility of manipulation of the straight air system. A simple form of plain triple valve is used, having a quick re-charging feature.

"AMM" Brake Equipment. The "AMM" equipment is constructed for use on cars operated in trains of not more than three cars in length. It is especially well adapted for both city and high-speed interurban service. It is designed to provide for quick and flexible operation of the brakes on a single car unit by the straight air-brake system with the added feature of an immediate change to automatic brake operation whenever two or three cars make up the train.

"AMR" Brake Equipment. The "AMR" equipment is designed for use on trains of not more than five cars in length. It is designed for either city or high-speed interurban service and is strictly an automatic brake system. This equipment possesses such advantages as quick service, emergency, graduated release, and quick re-charging features.

"EL" Locomotive Brake Equipment. The development of the modern high-power electric locomotive for handling both freight and passenger traffic at terminals and for service on electrified steam railroads created a demand for a thoroughly reliable and efficient brake which would embody the desirable features of the Westinghouse No. 6 "ET" equipment. Accordingly the No. 14 "EL" locomotive brake equipment was developed, which is an adaptation of the No. 6 "ET" equipment to the conditions of electric service. The important and general features of this equipment may be obtained by reference to the description of the "ET" equipment, pages 110 to 132, Part II.

As the space allotted to this subject is limited, only one electric car system will be described—the Westinghouse "SME" brake equipment. This system is chosen because it represents in a general way many systems now in common use.

DETAILS OF "SME" BRAKE EQUIPMENT

Features of "SME" System. As previously mentioned, this equipment is essentially a straight air-brake equipment having an automatic emergency feature. The simplicity of the straight air brake is available for ordinary service operation, while the additional safety features of the automatic application of the brake is provided in case of a break-in-two, bursting of a hose, etc. The system is designed for use on trains of not more than two cars in length. The chief features of the equipment when using the Type "D" emergency valve, as set forth in the manufacturer's pamphlets are as follows:

(a) Straight air operation for service stops.
(b) Brake cylinder release operates locally, i.e., through the emergency valve on each car.
(c) Prompt service application and release operations due to design of the emergency valve.
(d) Automatic maintenance of brake cylinder leakage.
(e) Uniform brake cylinder pressure, independent of variations in piston travel or leakage.
(f) Practically uniform compressor labor insured without the necessity of a governor synchronizing system.
(g) Automatic application of the brakes in case of ruptured piping, burst hose, or parting of the train.
(h) Retarded release after an emergency application, as a penalty to discourage the unnecessary use of this feature.
(i) One size of emergency valve for any size of brake cylinder.
(j) Possibility of conductor setting the brakes in emergency by means of conductor's valve.

Principal Working Parts. The system is composed of the following principal parts, which are located on the motor car:

(a) A motor-driven air compressor which furnishes the compressed air for use in the brake system.
(b) An electric compressor governor which automatically controls the operation of the compressor between predetermined minimum and maximum pressures.
(c) A fuse box, fuse, and two snap switches in the line from the trolley to the governor and air compressor, protecting the latter from any excessive flow of current and enabling the current supply to the compressor to be entirely cut off when desired.
(d) Two main reservoirs to which the compressed air is delivered from the air compressor, where it is cooled and stored for use in the brake system. Where the climatic conditions render it necessary, a radiating pipe should be installed between the compressor and the first reservoir and between the two reservoirs to assist in the cooling process.

(e) A check valve installed between the main reservoirs and the emergency valve, to prevent a back flow of air into the main reservoirs when two motor cars are operated together. This being the case, each compressor is required to supply the air used for braking purposes on its own car.

(f) A safety valve connected to the first main reservoir, which protects against excessive main-reservoir pressure should the compressor governor, for any reason, become inoperative.

(g) Two brake valves, one at each end of the car, through which (1) air is allowed to charge the emergency pipe and to exhaust from the straight air application and release pipe when releasing the brakes; (2) air enters the straight air application and release pipe when applying the brakes; (3) the flow of air to or from the brake system may be prevented, as when the brakes are being held applied; and (4) the air in the emergency pipe is allowed to escape to the atmosphere in emergency applications.

(h) An exhaust muffler placed under the platform to deaden the brake valve exhaust.

(i) Just below the brake valve a pipe leads from the emergency pipe to the black hand connection of the duplex air gage, which hand shows main-reservoir pressure, as the emergency pipe is always charged to main-reservoir pressure, except when an emergency application of the brakes is made, as explained later.

The red hand of the duplex air gage is connected either to the brake cylinder direct or to the piping so as to show brake cylinder pressure.

(j) An emergency valve, connected to the brake cylinder head (or pipe bracket if used) which (1) controls the flow of air from the reservoirs to the brake cylinder when applying the brakes; (2) controls the flow of air from the brake cylinder to the atmosphere when releasing the brakes; and (3) automatically maintains brake cylinder pressure against leakage, keeping it constant when holding the brakes applied.

(k) A brake cylinder, with a piston and rod so connected through the brake levers and rods to the brake shoes that, when the piston is forced outward by air pressure, this force is transmitted through said rods and levers to the brake shoes and applies them to the wheels.

(l) A conductor's valve (furnished when ordered) located inside each car, enabling the conductor to apply the brakes if necessary.

(m) Various cut-out cocks, air strainers, hose couplings, dummy couplings, etc., the location and uses of which will be readily understood from the explanations which follow.

(n) While not a part of the air-brake apparatus proper, the car is usually equipped with two air alarm whistles, one at each end of the car, to be used as a warning of approach, with the necessary whistle valves and cut-out cocks.

Two lines of pipe—the emergency pipe and the straight air application and release pipe—extend the entire length of the car and train, when two or more cars are coupled together, being provided with suitable hose and couplings at the ends of the cars. The cut-out cocks in these pipes, located just back of the hose connections, should always be enclosed at each end of a single car or train and always open between cars which are being operated together as a train.

Equipment on Non-Motor Trailers. The equipment of a non-motor trailer car consists of a brake cylinder, auxiliary reservoir, emergency valve, straight air application and release pipe, and emergency pipe, all of which, except the auxiliary reservoir, have been described above.

In addition, an auxiliary reservoir is used on a non-motor trailer car to furnish an independent supply of air for applying the brakes on that car when an application is made. The auxiliary reservoir pipe is connected to the emergency valve in the same manner as is the main reservoir supply pipe on a motor car. The auxiliary reservoir is charged from the emergency pipe by way of the emergency valve.

OPERATION RULES FOR "SME" BRAKE EQUIPMENT

The following rules furnished by the Westinghouse Company for operating the "SME" brake equipment are intended to cover in a condensed form the important instructions to be observed in handling this equipment in service.

Charging. Before starting the air compressor, see that the following cocks are closed: the drain cocks in the reservoirs; the cut-out cocks (if used) under the non-operative brake valves, also under the whistles not to be operated; and the cut-out cocks in the emergency and straight air pipes at the head and rear end of the car, or of the trains when two cars are coupled together.

See that the following cocks are open: the cut-out cock, if any is used, in the emergency pipe under the brake valve to be operated; governor cut-out cock; the cut-out cock under the whistles to be operated; and all the emergency pipe and straight air pipe cut-out cocks between cars.

See that all hand brakes are fully released. The fuse in the compressor circuit must be in place and must be "live".

Place the handle of the brake valve to be operated—all other brake valves being in *lap* position—in *release* position and start the compressor by closing the switches in the compressor circuit on each motor car.

Do not attempt to move the car until the gage shows full main-reservoir pressure.

Running. Keep the brake valve handle in *release* position when not being used. In event of sudden danger, move the brake-valve handle quickly to *emergency* position, at the extreme right, and leave it there until the car has stopped and the danger is past.

If the brakes apply while running over the road, due to bursting of hose, etc., move the brake-valve handle to *emergency* position at once, to prevent loss of main-reservoir pressure, and leave it there until the car or train stops and the danger is past. The cause of the application should be located and remedied before proceeding.

Service Application. To apply brakes for an ordinary stop, move the brake-valve handle to either *one-car service* position or *two-car service* position depending upon the conditions existing and results desired. When the desired brake-cylinder pressure has been obtained, as shown by the red hand of the air gage, the brake-valve handle should be placed in *lap* position, where it should remain until it is desired either to release the brakes or to make a heavier application.

How heavy an application should be made, and whether a full application should be made at once or the brakes graduated on, depends upon the circumstances in each particular case—such as the speed and weight of the train, condition of the rails, grade, kind of stop desired, and regard for the comfort of the passengers.

Because the retarding effect of a given brake-cylinder pressure is greater at low speeds, this fact will result in an abrupt stop, with perhaps danger to lading, discomfort to passengers, or slid flat wheels. With high speeds, however, a heavy initial application should be made in order to obtain the most effective retardation possible when the momentum of the car is greatest. If the brakes are applied lightly at first and the braking pressure increased as the speed of the car diminishes, it not only makes a longer stop, but the high brake-cylinder pressure at the end of the stop will be likely to produce a rough stop, slid wheels, and to result in loss of time.

The best possible stop will be made when the brakes are applied as hard, at the very start, as the speed, the conditions of the rails, and the comfort of the passengers will permit, and then graduated off as the speed of the car is reduced, so that at the end of the stop little or no pressure remains in the brake cylinder.

To properly weigh all these varying factors in every stop becomes, after a little practice, an act of unconscious judgment. Careful attention to cause and effect at the very start and a real desire to improve are the most necessary qualifications in order to become expert in handling this or any other form of brake equipment.

Holding Brakes Applied. The brake-valve handle should be left in *lap* position until it is desired either to release the brakes or to apply them with greater force. If the car is to be left standing with the brakes applied for any length of time, the air brakes should be released and the hand brakes set.

Release. The brakes are released, as with any straight air brake, by placing the brake-valve handle in *release* position and leaving it there, if it is desired to fully release the brakes; or, if it is desired to graduate or partially release the brakes, by moving the handle to *release* position for a moment, then back to *lap* position, repeating this operation until the car is brought to rest, only enough pressure being retained in the brake cylinder at the end of the stop to prevent the wheels from rolling.

Emergency. Should it become imperative to stop in the shortest possible time and distance, to save life or avoid accident, move the handle quickly from whatever position it may be in to *emergency* position, which is at the extreme right, and allow it to remain there until the car stops and the danger is past.

When releasing after an emergency application, it will be observed that the release takes place slowly. This is intentional, the equipment being so designed that when such a release is made, a fixed period of time must elapse from the movement of the handle to *release* position until the brake releases. This is not only to secure an additional protection but to discourage the unnecessary use of the *emergency* position of the brake-valve handle.

Changing Ends. When changing from one end of the train or car to the other, place the brake-valve handle in *lap* position; close the cut-out cock (if used) in the emergency pipe under the brake valve; then remove the handle, after placing it on the brake valve at the other end, move it to *release* position and open the cut-out cock (if used) in the emergency pipe under this brake valve.

GRAPHICAL REPRESENTATIONS OF PROPER BRAKING METHODS

Much time can be saved by a proper use of the brake in making service stops, in adapting the brake cylinder pressure to the speed at which the car or train is moving. For example, for high speeds

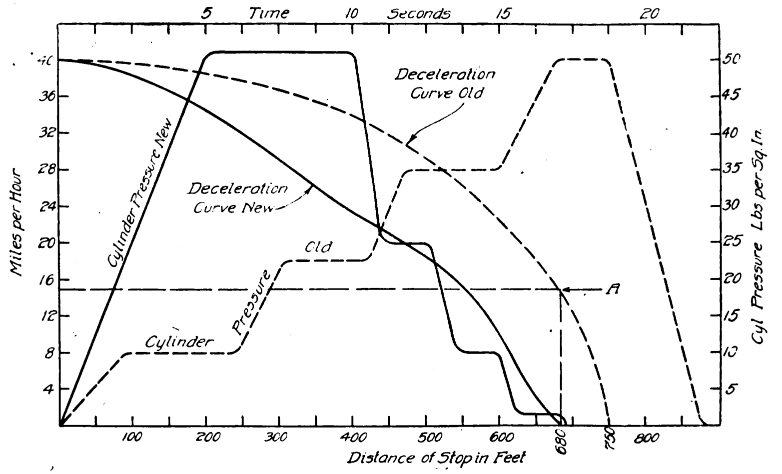


Fig. 138. Diagram Showing Distance of Stop for Electric Car in Feet

make a full application and graduate the pressure off as the speed reduces. To handle the train smoothly, make a heavy application and soon enough so that if held on, the train would stop short of the mark. Then as the stopping point is approached, graduate the pressure off of the brake cylinder so that little remains when the stop is completed. If on the level track, complete the release; if on a grade, hold until the signal to start is given, then release.

Proper and Improper Manipulation. A clear idea of proper and improper methods of brake manipulation is shown graphically in Fig. 138. The dotted lines show the usual method of operation and the results obtained with the old-style brake apparatus. Assume

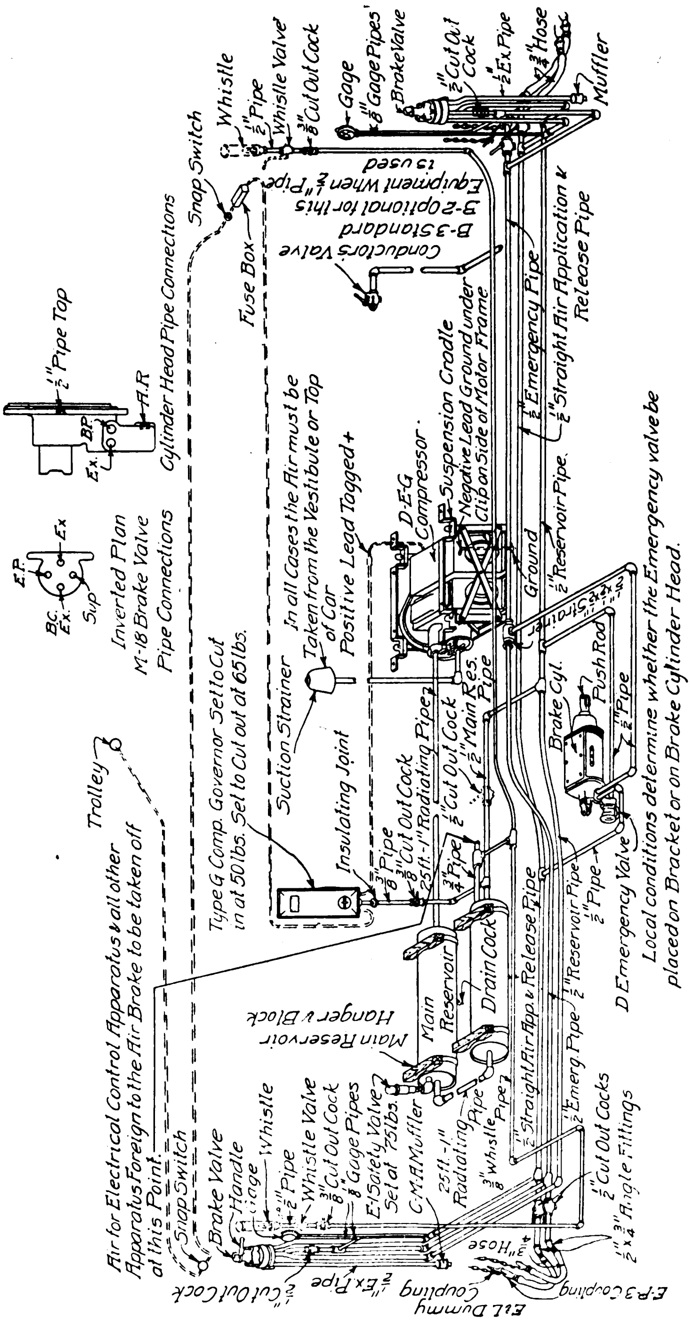


Fig. 139. Piping Diagram for Westinghouse "SME" Brake Equipment (with Type "D" Emergency Valve), for Motor Car

the speed to be 40 m. p. h. when the application is begun. The brake is applied in a series of steps or graduations so that in about 16 to 17 seconds, maximum cylinder pressure has been reached; but meanwhile the train has been brought nearly to a standstill with the highest brake-cylinder pressure being developed at the time the speed is lowest and, consequently, with great tendency on the part of the wheels to slide, making it necessary to get rid of this high-cylinder pressure at once or come to a stop with an unpleasant jerk. A stop by this method is made in say 750 feet.

The full lines illustrate the proper method and show what is possible in the way of smoothness of stop, accuracy of stop, saving of time, and freedom from tendency to wheel sliding. The maxi-

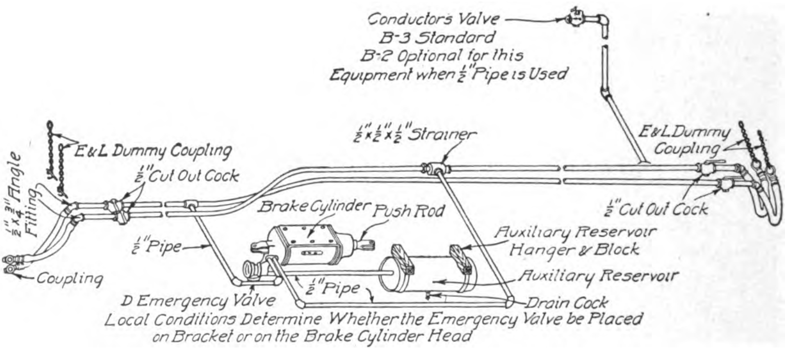


Fig. 140. Piping Diagram for Westinghouse "SME" Brake Equipment (with Type "D" Emergency Valve) for Trailer Car

mum cylinder pressure is obtained at once when the speed of the train is highest and the holding power of the brakes least effective. At the end of about ten seconds, when the speed has been reduced to say 20 m.p.h. and the brakes are "taking hold" more powerfully, a part of the cylinder pressure is released—enough (25 pounds) being retained in the cylinder to maintain as high a rate of deceleration as possible without danger of sliding of wheels. This operation is repeated as may be necessary to keep the retarding force (brake-cylinder pressure) in its proper relation to the decreasing speed of the train. A stop by this method is made in say 680 feet—70 feet shorter than by the improper method—and plainly with much greater smoothness, less tendency to wheel sliding, in shorter time, and with the brake-cylinder pressure nearly or completely exhausted and the system practically fully re-charged.

The point A in the diagram shows that during the stop by the first method the train was running at a speed of over 15 m.p.h. when passing the point at which it would have come to a stop, if the second and correct method of brake operation had been followed. Assuming a weight of 160,000 pounds for the train, it therefore possessed at the point A about 1,200,000 foot-pounds or 600 foot-tons of energy, which would have been harmlessly dissipated had the brakes been manipulated properly. Such a comparison as this shows clearly that the question of which method of operation to pursue is not of theoretical but of vital and practical importance.

DESCRIPTION OF EQUIPMENT

Figs. 139 and 140, illustrate diagrammatically the "SME' brake equipment, including piping and relative location and names of all parts.

Type "D-EG" Motor-Driven Air Compressor. Type "D-EG" air compressor is manufactured for use with 110-, 220-, and 600-volt direct-current operation, also two- and three-phase alternating current at 110, 220, 440, and 550 volts, and for 25, 40, or 60 cycles. It can also be furnished to operate on single-phase 100-volt current, and 15 or 25 cycles.

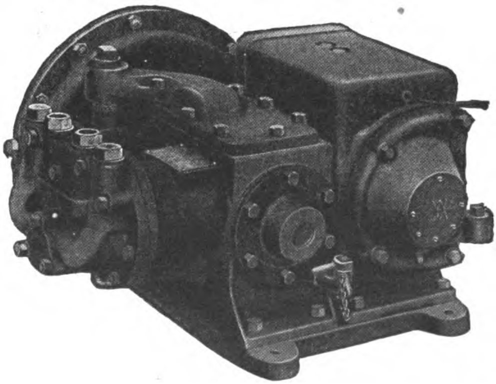


Fig. 141. Type "D-EG" Motor-Driven Air Compressor
Courtesy of Westinghouse Air Brake Company, Wilmerding, Pennsylvania

Fig. 141 illustrates the general appearance of the air compressor and Fig. 142, shows the method of cradle suspension under the car when in service. Figs. 143 and 144 illustrate its form of construction, Fig. 143 being a horizontal section and side elevation, and Fig. 144 an end elevation with a vertical section of the cylinder.

Type of Compressor. The compressor is of the duplex type, having pistons moving in opposite directions. Its action in compressing air is as follows: Air is drawn through suction screen *4* (which is now usually replaced by a cylinder cover with a piped suction to any convenient place for securing pure air) in the cylinder cover *25* to chamber *J* through chamber *H* (which is filled with curled hair), thence by raising either one of the two steel inlet valves *1*, through ports *C* or C^1 into cylinders *A* or *B* (depending upon which piston is moving away from the cylinder cover). On the return stroke the air is forced through either port *K* or K^1, past one of the discharge valves *2*, then into chamber *E*, from which it goes into discharge pipe *D*. Both the inlet and discharge valves are made of pressed steel tubing and are, therefore, light and easily removable. The inlet valves are accessible by removing caps *3*, the discharge valves by removing caps *26*. Inasmuch as all the valves close by gravity, there are no springs to break, corrode, or lose their temper.

Pistons. The pistons *5* are accurately fitted with rings *6*. For the best results, it is essential that the packing ring be installed with the square segment of the ring nearest the wrist pin. When this is done, the angle portion is next the pressure end of the piston, which is necessary in order that the ring joints may lap in such a way as to prevent leakage.

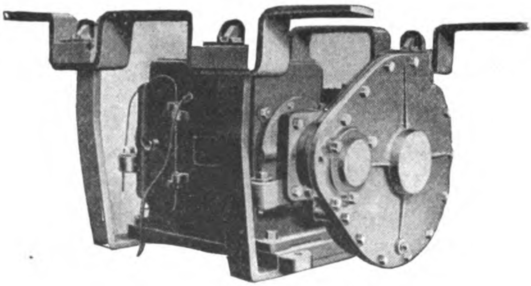


Fig. 142. Westinghouse Type "D-EG" Motor-Driven Air Compressor Suspended in Cradle under Car

To insure correct replacement of pistons and rings, a letter is stamped at the top of the outside flange of each cylinder, on the outside face of each piston, and on the inside face of the joint of each packing ring segment. In addition to this letter, each packing ring segment is also stamped.

Connecting Rod Construction. The wrist pins *7* are of steel, hardened, ground, and secured in place by a set screw *30*; a bronze bushing *8* in the connecting rod *9* works on them. The crank end of the connecting rod is lined, and has a strap *10* hinged at its lower end and secured by an eyebolt *11* at the upper end. On this bolt between the two parts are thin steel washers *12*, which may be removed as the bearing wears, and the strap then tightened down on the remaining ones and locked with the jam nut.

The center line of the cylinder is a little above the center line of

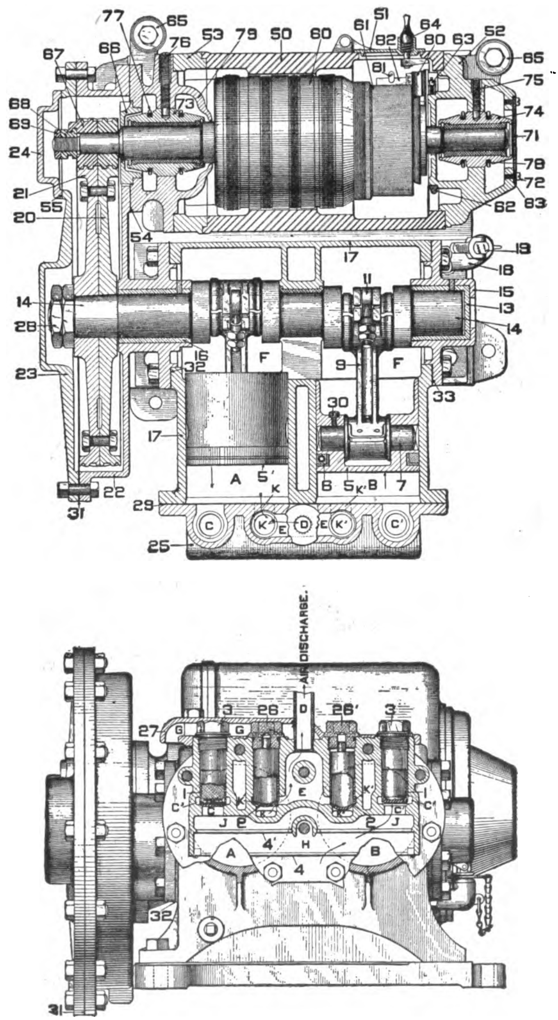


Fig. 143. Sectional Views of Westinghouse Type "D-EG" Motor-Driven Air Compressor

the crankshaft, so that the angularity of the connecting rod may be reduced during the period of compression, thereby reducing the vertical component of the thrust and consequently the wear on the cylinders. The shaft must, however, always run with the compression part of the stroke on the upper half revolution, i.e., clockwise when viewed from the gear end. The crankshaft *14* is made of heavy forged steel and, besides having ample end bearings *13* and *16* of bronze, is provided with a large babbitt-lined center bearing which is a part of the crankcase cylinder casting *17*.

Lubrication. The parts mentioned above are all lubricated from a bath of oil, poured into the dust-proof crankcase through a special fitting *18*, which acts as a gage of the oil level; the fitting is

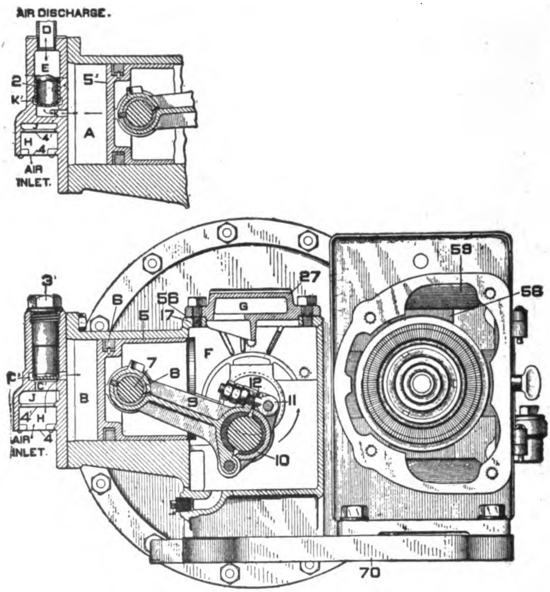


Fig. 144. Part Section of Westinghouse Type "D-EG" Motor-Driven Air Compressor

closed by a suitable screw plug *19* which is secured to it by means of a chain. On the overhanging end of the crankshaft is the gear wheel *20*, made of semi-steel mixture in two halves and bolted together to form the well-known "herringbone" type of gear. It is forced onto the shaft over a square key and secured by the nuts *28*.

Motor. The motor is of the series type with a cast-steel magnet frame *50*, having a prolongation on the commutator end, provided with an opening to permit of ready access to the brushes and commutator. This opening has a door *51* hinged to the frame and tight-fitting so as to exclude rain and dust. In the ends of the frame are centered housings *52*, *53*, and *79*, which carry the armature bearing at the ends of the motor; *52* and *79* are provided with an oil well with filling hole so located that it is impossible to flood the interior of the motor with oil. Cast-iron bearing shells *73* and *74*, of ample proportions, with babbitt inserts, are centered in the housings and secured by means of set screws *75* and *76*. Each bearing has two oil rings *77* and *78*, which insure the proper lubrication of the shaft as long as any oil remains in the wells. An overflow passage, below the opening into the motor at the pinion end, leads to the bottom of the gearcase in the earlier forms of the compressor and to the crankcase in the latter forms, effectively preventing any of the gear lubricating oil, which might work through the pinion bearing into its oil well, from flooding the motor.

Two of the four field poles are a part of the frame *50*, the other two, *58*, being made up of laminations of soft sheet steel riveted together and bolted to the frame, thereby also securing in place the field coils *59*. The armature *60* is built up of electric soft sheet-steel punchings. The commutator *61* is of liberal length, with deep segments insulated with the best grade of mica.

Fig. 145. Westinghouse Type "J" Electric Compressor Governor

Type "J" Electric Compressor Governor. The location of the compressor governor is shown in Fig. 139. That shown is a type used in connection with the smaller class of compressors and differs from the type under discussion. Its purpose is to start and stop the compressor, in order to maintain a predetermined pressure, by alternately making and breaking the circuit leading to the motor. The general appearance of the governor is shown in Figs. 145 and 146, while Fig. 147 is a vertical diagrammatic section.

As may be seen, the governor is made up of two distinct portions, one being a switch and the other a pneumatic regulator. Current from the trolley to the compressor is made or broken by the switch spider *43*, attached to the switch piston and rod *16* and making connection between finger contacts *5* when the governor is in "cut in" position. The governor operates equally well with either direct or alternating current. It is thoroughly insulated and is covered by an iron casing held in place by the thumb nuts *13*. The admission of air to and exhaust air from the cylinder *W* is controlled by the regulating portion of the governor and takes place through port *g* which, when the governor is in the "cut-in" position, is connected by cavity *h* in the slide valve *76* with the exhaust port *f* leading to the atmosphere.

Referring to Fig. 147, main-reservoir air enters the governor at the pipe connection marked "To Main Reservoir", and flows through the passage *a* to the space *B* between the double pistons *25*. From *B* it flows through ports *e* and *j* to space *K* on the face of the diaphragm *60*, on the opposite side of which is a spindle *61* held against the diaphragm by the regulating spring *62*. The stem of spindle *61* projects through the regulating nut *63* to the end of the "cutting-out" regulating valve *28*, which is held firmly against the end of the spindle or its seat, as the case may be, by the regulating valve spring *27*. So long as the main-reservoir pressure is less than that for which regulating spring *62* is adjusted, the latter holds the spindle *61* over so that the "cutting-out" regulating valve *28* remains seated. If the main-reservoir pressure is increased so that its pressure on diaphragm *60* is able to overcome the pressure on the regulating spring *62* on its opposite side, the spindle *61* will be forced back toward regulating valve *28*, which it lifts slightly and permits the air in chamber *C* to flow through port *l* and space *M* past the regulating valve to the atmosphere.

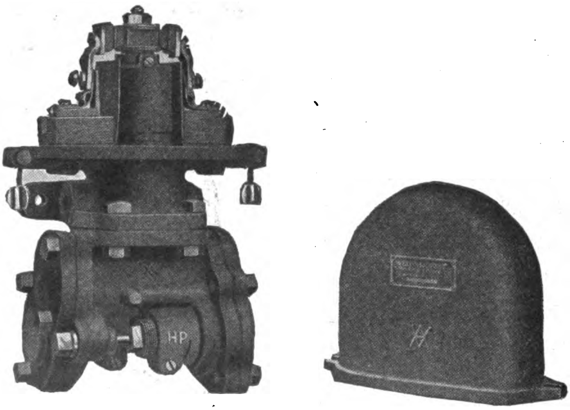


Fig. 146. Westinghouse Type "J" Electric Compressor Governor in Cut-in Position—Cover Removed

As the pressures on the smaller end of the double piston are balanced at this time and the pressure in chamber *B* on the right-hand side of the larger end of the double piston is now much higher than that in chamber *C*, the pistons and attached slide valve are moved to the left to "cut-out" position, as shown in detail at the right, Fig. 147. It will be seen that the first movement of the slide

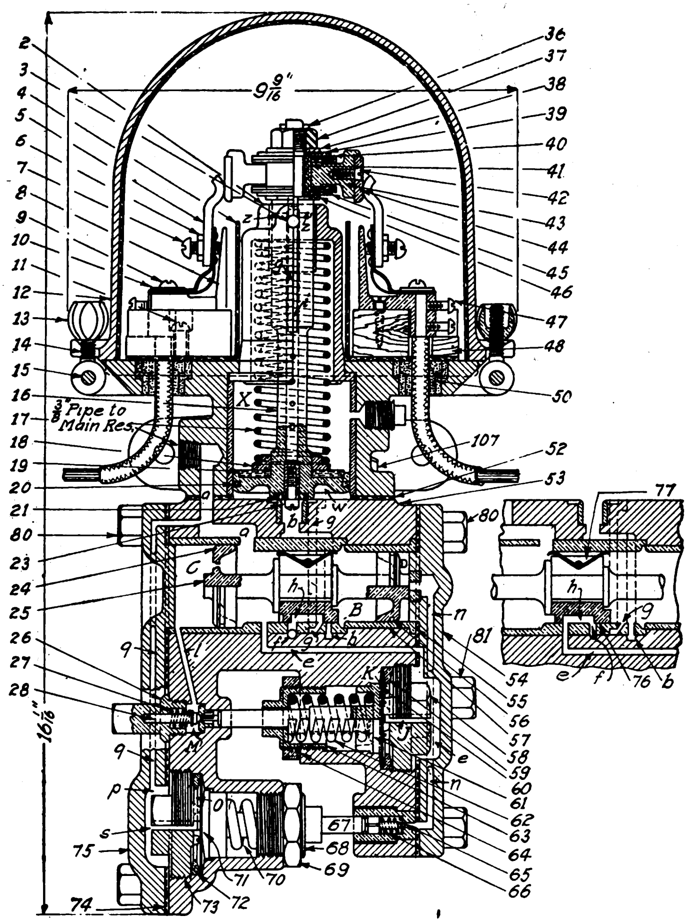


Fig. 147. Diagrammatic Sectional View of Westinghouse Type "J" Electric Compressor in Cut-in Position

valve *76* opens port *b* to chamber *B*, permitting air at main-reservoir pressure to flow through port *b* to the piston "seal" *21*. The area of port *b*, however, is so small that the main-reservoir pressure acting therein is not able to overcome the pressure of spring *17*, which holds the switch piston to its seat. But a further travel of the slide valve opens port *g*, which allows air at main-reservoir pressure to flow to the air cylinder *W*, thus breaking the "seal" of the piston and the main-reservoir pressure then acts on the entire area of the piston, causing it to move outward very rapidly and break the circuit. By having port *b* open before port *g*, a free flow of high-pressure air to the space *W* below the switch piston is insured and a "quick-break" obtained, which eliminates any tendency to cut out slowly. During this movement the air above the switch piston is compressed, and forced through ports *y* and *z* in the hollow rod to the atmosphere. The ports *z* are so placed that they pass the ends of the contact fingers just when the circuit is broken and the quick piston movement causes the air in *X* to be expelled with such force as to make an effective and complete pneumatic blow-out.

In this position of the slide valve *76* it will also be seen that cavity *h* connects port *e* to the exhaust port *f* and atmosphere, thus relieving diaphragm *60* of pressure and permitting the regulating valve *28* to seat. Air from chamber *C* can then no longer escape to the atmosphere and it rapidly becomes equal in pressure to that in chamber *B* (due to flow of air through the small leakage port shown in the large double piston). Both ends of the double piston are then balanced and the parts remain in "cut-out" position until the governor is "cut-in" as follows: A branch from port *a* permits air at main-reservoir pressure to flow through port *q* to *p* and the space *O* on the face of diaphragm *71*, on the opposite side of which is a spindle *67* held against the diaphragm by the "cutting-in" regulating spring *70*. The stem of the spindle projects through the regulating nut *68* and the "cutting-in" regulating valve *65* is held against the end of the stem by the regulating valve spring *66*. So long, therefore, as the main-reservoir pressure on the face of the diaphragm *71* is greater than the pressure of the regulating spring *70* on its opposite side, the regulating valve *65* will be held to its seat by the stem of spindle *67* and the port *n* is then closed.

After the governor has been "cut-out" as explained above and the main-reservoir pressure falls to such a point that the air pressure on diaphragm *71* is no longer able to overcome the pressure of the regulating spring *70* on its opposite side, the latter moves the spindle over so as to permit the regulating valve spring *66* to raise the regulating valve *65* slightly from its seat. This permits the air in chamber *D*, back of the smaller end of the double piston, to escape through port *n* and past the regulating valve *65* to the atmosphere. The larger end of the double piston is balanced at this time and the pressure in chamber *B*, therefore, forces the smaller piston back to the position shown in Fig. 147, carrying with it the large piston and slide valve, exhausting the air from the air cylinder *W* through ports *g* and *h* and exhaust port *f* to the atmosphere, and allowing the piston spring *17* to force the piston *16* and the circuit closer *43* back to "cut-in" position. It will be seen from the illustration that when the double piston moves to "cut-in" position, as explained, a projection boss on the outside face of the small piston closes the connection between chamber *D* and port *n*, so that the pressure in *D* has no escape when the governor is cut in. Chamber *D* is very small and as the small piston and its packing ring, when fitted as tight as is practicable, are still not absolutely air-tight, the slight leakage past the small piston soon equalizes the pressures in *D* and *B*, and, as the pressures in *C* and *B* are also equal, both double pistons are again balanced and the parts remain in "cut-in" position until the governor is "cut-out" as already explained.

The governor is adjusted for a cutting-in pressure of 50 pounds and a cutting-out pressure of 65 pounds.

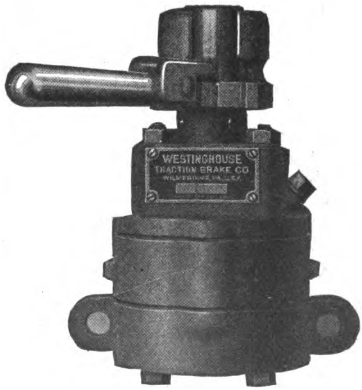


Fig. 148. Westinghouse "M-18" Brake Valve

Type "M-18" Brake Valve. The "M-18" brake valve, Fig. 148, is of the rotary type and it is fitted with a removable handle. A top view of the valve, Fig. 149, shows the different position of the handle, while a vertical section illustrates the arrangement of the ports, etc. The positions of the handle, named from left to right are, *release, lap, one-car service, two-car service,* and *emergency position.* The pipe connections are as follows:

(a) Straight air application and release pipe, leading to the emergency valve.
(b) Emergency pipe, which also leads to the emergency valve.
(c) Brake valve exhaust pipe, leading to the exhaust muffler under the platform.
(d) Reservoir pipe, leading to the emergency valve and to which the reservoir is connected through the check valve.

Duplex Air Gage. The duplex air gage, Fig. 150, is installed in the direct line of vision of the motorman, when operating the brake valve. The pipe connection for the brake-pipe gage hand is taken off from the brake pipe just below the cut-out cock. The

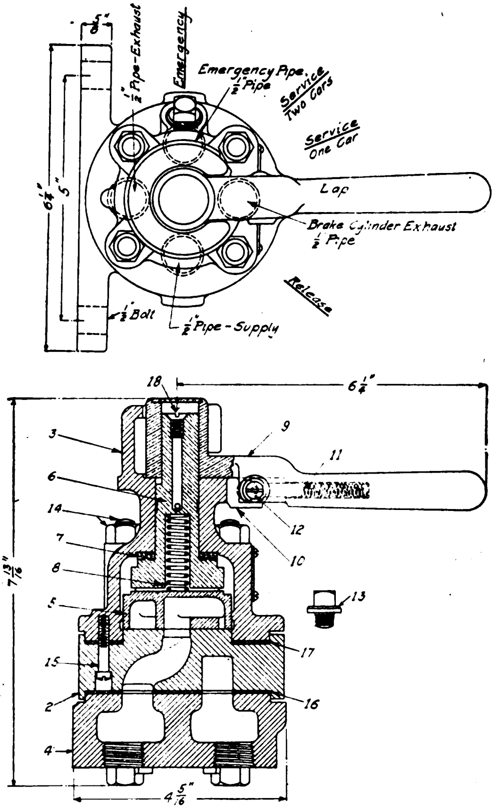


Fig. 149. Westinghouse "M-18" Brake Valve in Plan and Actual Section

connection for the main-reservoir gage hand is taken out from the emergency pipe.

Type "D" Emergency Valve. The Type "D" emergency valve is illustrated in Figs. 151 and 152. It contains an equalizing piston *11*, a slide valve *13* (which serves as a means of exhaust only), an emergency piston *24* and slide valve *25*. Communication between the reservoir and brake cylinder is controlled by the poppet valve *17*. The valve may be attached to the cylinder head or to a bracket under the car floor or on a stand inside of the car. The emergency reservoir and straight air and release pipes are connected directly to the cylinder head.

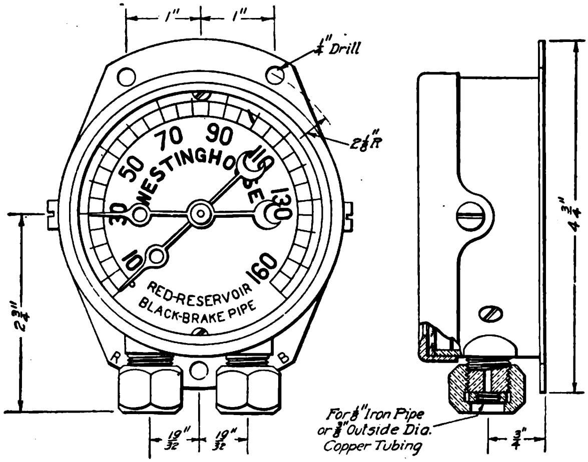


Fig. 150. Westinghouse Duplex Air Gage

Brake Cylinder. The brake cylinder employed is illustrated in Fig. 153. The piston *3* is connected to the brake rigging in such a manner that it moves only when the power brake is used. When the hand brake (if provided) is used, no movement of the piston occurs. The piston rod is made hollow to receive the push rod *14*, which is attached to the levers of the foundation brake gear. The release spring *9* forces the piston to *release* position when the air pressure is exhausted from the brake cylinder. The packing leather *7* is held against the cylinder wall by the expander *8* which insures an air-tight piston.

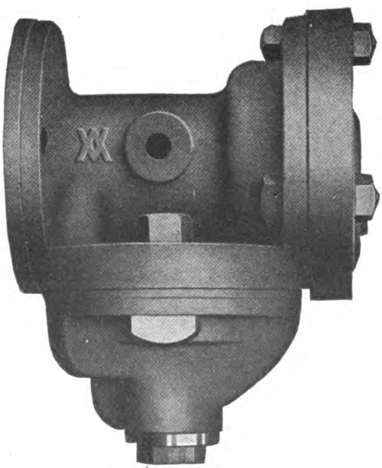


Fig. 151. Westinghouse Type "D" Emergency Valve

Conductor's Valve. This valve is located in a convenient position in the car and is preferably fitted with a cord attached to its handle and running the entire length of the car. It is to be used only in cases of necessity or emergency. It is connected to

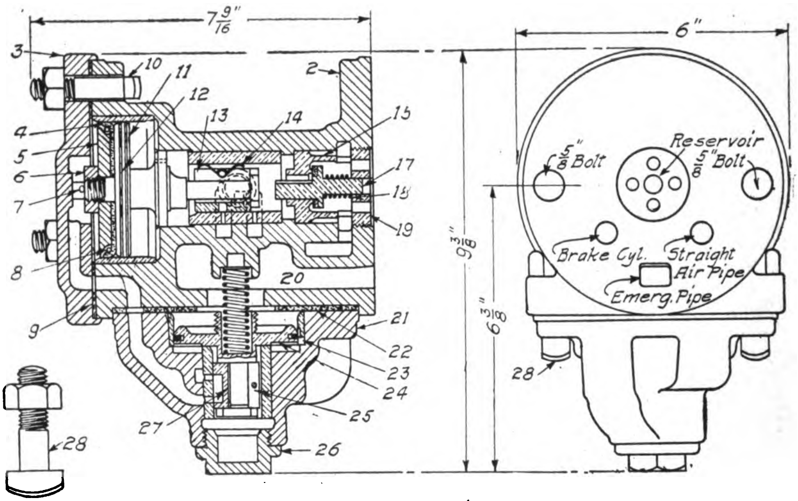


Fig. 152. Actual Section and End View of Westinghouse Type "D" Emergency Valve

the emergency pipe by a branch pipe and permits air to flow directly from the emergency pipe to the atmosphere, setting the brakes in

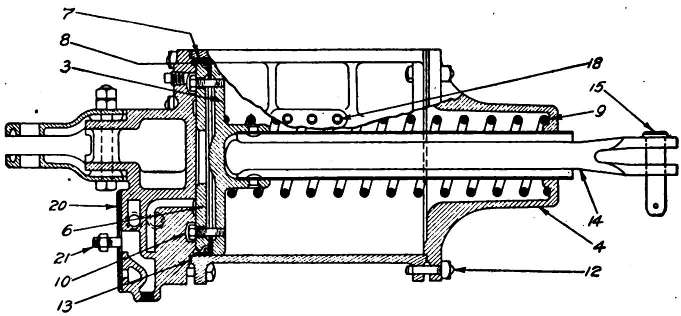


Fig. 153. Diagram of Brake Cylinder

emergency. The style of the valve is of the non-self-closing type and must be closed by hand after being used.

METHOD OF OPERATING "SME" BRAKE EQUIPMENT

In giving an explanation of the operation of the "SME" equipment, reference will be made to the diagrammatic views shown in

Figs. 154 to 158. In this discussion it is assumed that the non-operative brake valve on the rear of the car is in *lap* position.

Charging. With the reservoirs charged and the brake-valve handle in release position, air flows from the main reservoirs through the check valve to the brake valve and into the emergency pipe. A feed groove *i* around the emergency piston *24* permits an equalization of pressure in the emergency pipe with main reservoir pressure, which is assisted by a small port through the rotary valve *5* of the brake valve in all positions except emergency.

Service Application. To apply the brakes, move the brake-valve handle to either one-car service position or two-car service

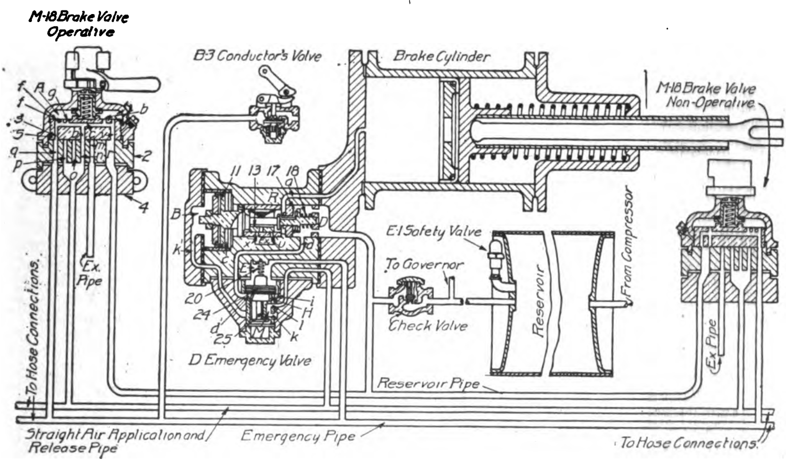


Fig. 154. Diagram of One-Car Service, "SME" Equipment with Type "D" Emergency Valve (*Westinghouse*)

position, depending upon the length of train, speed, condition of rail, kind of stop desired, etc. In one-car service position a relatively small opening (see port *b*, Fig. 154) is made from the reservoir pipe to the straight air application and release pipe and this position is, therefore, used with a single car or when running at slow speeds, and so on. In two-car service position the opening from the reservoir pipe to the straight air pipe is larger (see port *b*, Fig. 155), and this position is, therefore, used with trains of greater length, when running at higher speeds, or, in general, when a heavier application of the brakes is desired.

In response to this movement of the brake-valve handle, air is admitted from the reservoir pipe to the straight air application and release pipe and emergency valve through port *r*, cavity *c*, and ports *b*, *n*, and *o* of the brake valve, thence through port *l*, cavity *M* of emergency slide valve *25*, ports *k* and *k'* to chamber *B* and the face of equalizing piston *11*, forcing it inward. The first movement of the emergency valve piston takes up the lost motion between the collar on the stem and the exhaust valve *13*, and after closing the exhaust ports *x* and *u*, cutting off the brake cylinder from the atmosphere unseats check valve *17*. Communication is thus established between chambers *D* and *R* and the brake cylinder so that air is admitted direct from the main reservoirs to the brake cylinder. When the pressure in the brake cylinder

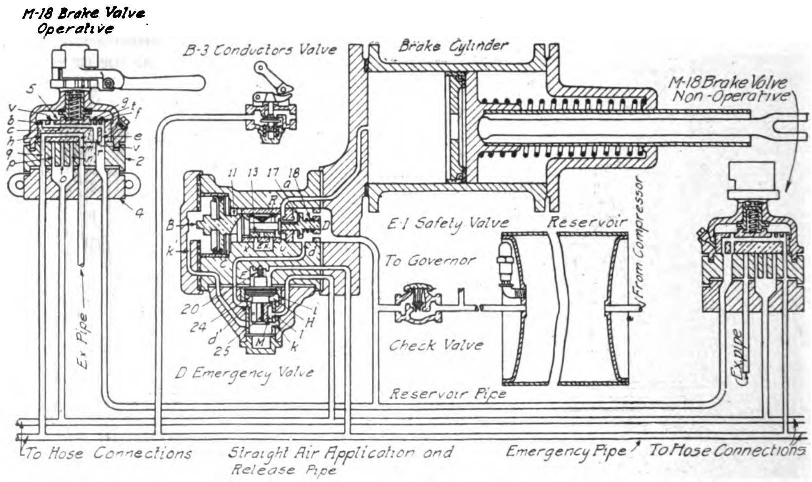


Fig. 155. Diagram of Two-Car Service, "SME" Equipment with Type "D" Emergency Valve (*Westinghouse*)

almost equals that in chamber *B*, spring *18* will drive the equalizing piston outward until the check valve *17* seats. A further rise of pressure in chamber *B* will move the equalizing piston inward, unseating the check valve and causing an equal rise in brake-cylinder pressure.

Holding Brakes Applied. When the desired brake-cylinder pressure has been obtained, the brake-valve handle should be placed in *lap* position. This causes the parts of the emergency valve to assume lap position, Fig. 156, and holds the brakes applied. In this position communication is cut off between the reservoir pipe and the straight air application and release pipe so that no further supply of air is admitted to chamber *B* of the emergency valve, and check valve *17* is seated so that no air is admitted to

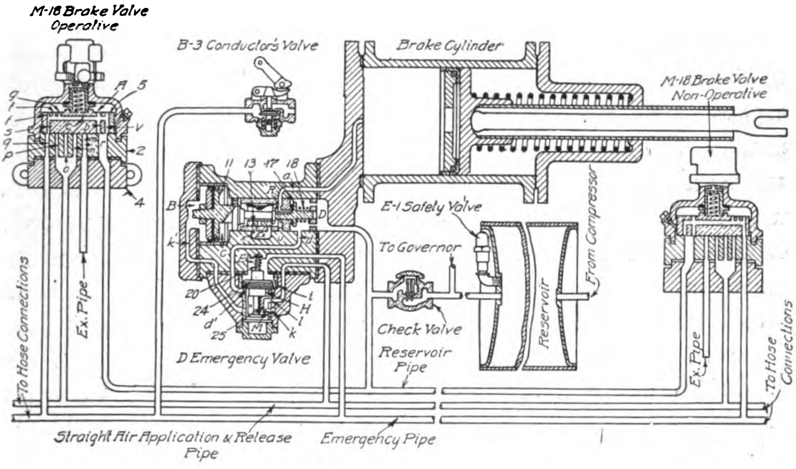


Fig. 156. Diagram of Service Lap Position, "SME" Equipment with Type "D" Emergency Valve (*Westinghouse*)

the brake cylinder. However, should leakage occur in the brake cylinder, it will be automatically maintained, for a decrease of

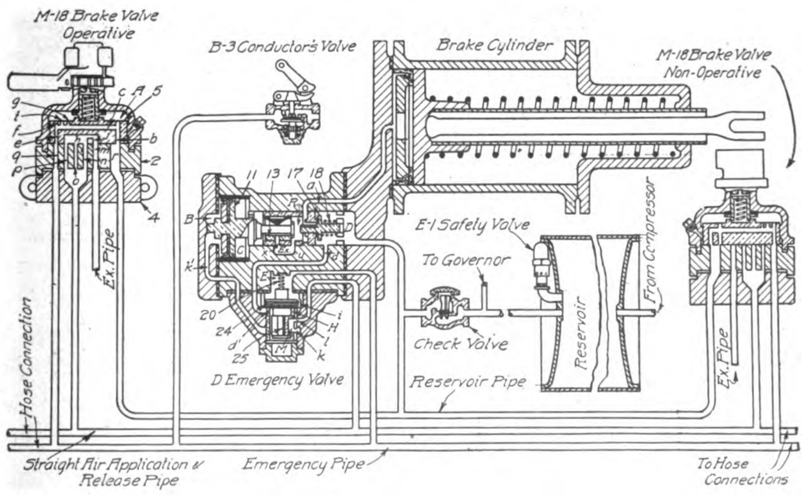


Fig. 157. Diagram of Release Position, "SME" Equipment with Type "D" Emergency Valve (*Westinghouse*)

pressure in chamber *R*, which is always open to the brake cylinder, below that in chamber *B* on the opposite side of the piston will cause piston *11* to move inward again, unseating check valve *17* and admitting more air to the brake cylinder to replace that lost by leakage.

Releasing. In releasing the brakes after an application, Fig. 157, the air in chamber *B* of the emergency valve is exhausted through ports *k'* and *k*, cavity *M* of slide valve *25*, and port *I* to the straight air pipe, thence through ports *n*, *o*, and *p* in the rotary valve seat *2*, cavity *h* and port *j* in the rotary valve, and port *m* to the atmosphere through the exhaust pipe. The greater pressure in chamber *R* then forces the equalizing piston to *release* position, uncovering the exhaust ports *x* and *u* and allowing the air from the brake cylinder to escape to the atmosphere.

Emergency Application. The *emergency* position of the brake valve should be used only when it is necessary to stop the car within

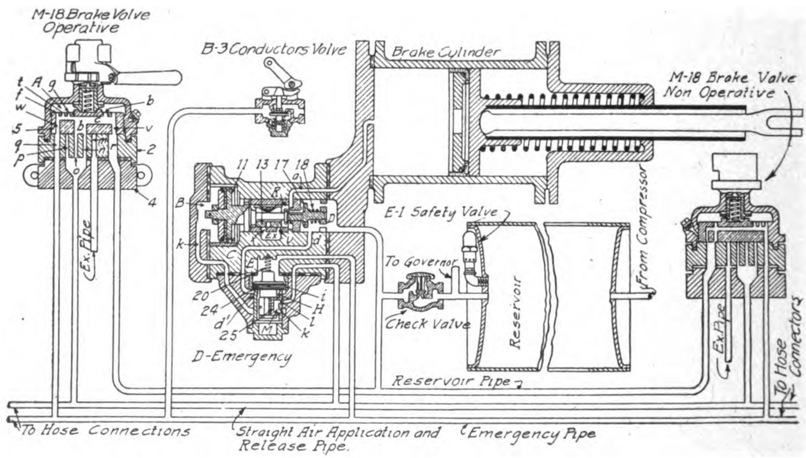


Fig. 158. Diagram of Emergency Position, "SME" Equipment with Type "D" Emergency Valve (*Westinghouse*)

the shortest possible distance to save life or avoid accident. In this position, Fig. 158, the straight air application and release-pipe connection is blanked in the brake valve, while the emergency-pipe air is exhausted to the atmosphere through port *q* in the rotary valve seat, ports *h* and *j* in the rotary valve, and port *m* in the seat, thus reducing the pressure on the upper side of the emergency piston *24*, which is forced to the upper end of its stroke by the main-reservoir pressure on the under side, carrying with it slide valve *25*. This cuts off the straight-air pipe connection and admits air from the main reservoirs through ports *d* and *d′*, *k* and *k′*, to chamber *B*, forcing piston *11* to its extreme inner position. This action opens the check valve *17* wide and permits the air from the main reservoir to flow rapidly into the brake cylinder until the pressures equalize. In the same way also, should a hose burst or uncouple, or pipe break, the resulting rapid drop in emergency pipe pressure will insure an emergency application of the brakes as described.

Upon restoring the pressure in the emergency pipe by placing the brake-valve handle in *release* position, the equalized pressure on either side of the emergency piston *24* permits spring *20* to return the piston to its normal position, thus releasing the pressure back of the equalizing piston through the straight air pipe and brake valve to the atmosphere, at the same time allowing brake-cylinder air to escape through the exhaust ports *x* and *u* in the emergency valve.

Axle-Driven Compressor Equipment. Axle-driven compressors are now practically extinct. When used, a slight change in the piping is necessary from that above described. Since the compressor is mounted on the truck and has some movement relative to the car frame which carries the reservoir, flexible hose connections are necessary to make connections to the reservoir and also to the compressor regulator. A small reservoir is also used which receives air from the compressor. This small reservoir is connected to the main reservoir by a pipe containing a regulating valve. The air attains a pressure of about 35 pounds in the small reservoir before any air passes into the main reservoir. This 35-pound pressure in the small reservoir is attained while the car runs about 100 yards and is available for applying the brakes. This always insures air for operating the brakes, if the car previously runs a short distance. With this exception, the piping would be the same, and no further description is thought necessary.

Storage Air-Brake Equipment. If a car is fitted with a storage air-brake equipment, no compressor is installed on the car. The compressed air which is used for braking is carried on the car in large reservoirs. The general scheme of a storage equipment is shown in Fig. 159, which illustrates an obsolete type of the straight air-brake system as applied to a single car. Two large reservoirs connected by a one-inch pipe carry air at high pressure. These reservoirs

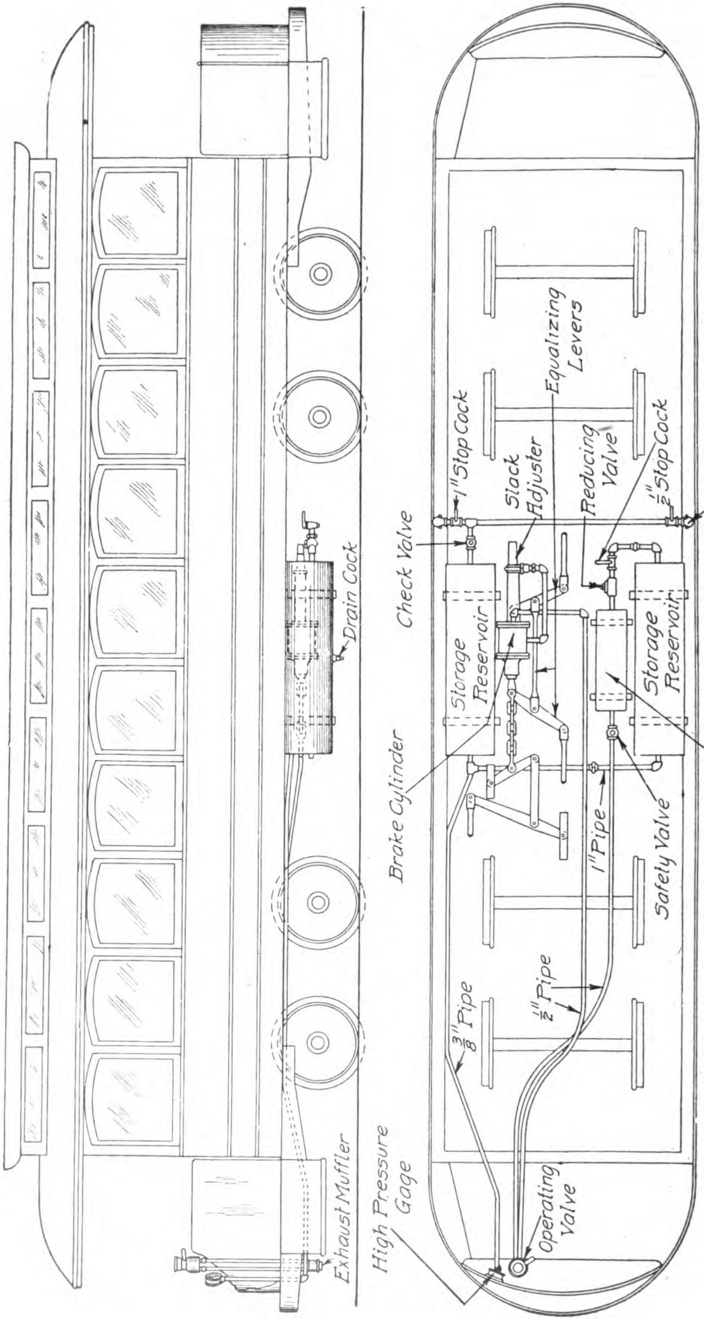


Fig. 159. General Layout of Storage Air-Brake Equipment on a Street Car

deliver air through a reducing valve to a service reservoir. The pressure in the service reservoir corresponds to that in the reservoir previously described. Other than these parts just mentioned, the straight air-brake system and the storage air-brake system are the same.

Train Air Signal. As the size of electric cars and the length of trains increase, a reliable signal system becomes more and more a necessity. The systems now used are quite similar to those employed on steam roads, one of which has already been explained.

Stopping a Car. The brake equipment of all electric cars is calculated with reference to the unloaded weight of the car, that is, the parts are so designed that there will be no danger of slipping the wheels when the car is unloaded. In stopping a car, the forces which act to retard its motion are: (a) the resistance of the atmosphere; (b) the frictional resistance of the journals and track; and (c) the resistance of the brake shoes on the wheels.

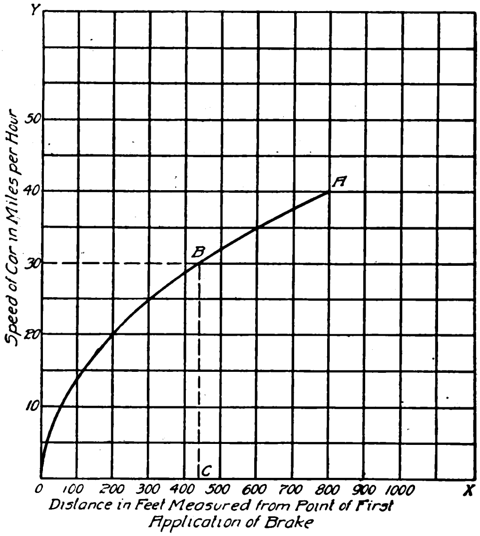


Fig. 160. Diagram Showing Relation between Speed of Car and Distance in Which Stop Can Be Made after Application of Brake

When the brake is applied, the car pitches forward on the front truck, and the weight of the rear truck is thereby decreased. If proper allowances have not been made in proportioning the brake levers, the rear wheels will probably slip on the track. If the wheels should slip, the distance required in which to bring the car to rest would probably be greater than that required had the wheels not slipped. In bringing a car to rest, the energy of translation of the entire car and the energy of rotation of all the wheels and motors must be absorbed by friction. To do this efficiently and safely in the shortest possible time is the purpose of the modern brake system.

The average person who rides on street and interurban cars knows nothing as to the distance in which these cars can be stopped. "In what distance can a modern double-truck electric car be stopped?" is a question which is frequently asked. In answer to this question, Fig. 160 has been prepared. A great many experiments have been made in stopping cars, with varying results. The chief factors which affect the results of such tests are the condition of the rails and the character of the material composing the brake shoes. Fig. 160 shows graphically the relation between the distance required to stop a car and the speed (in miles per hour) at the instant the brake was applied. It represents the average result of a large number of experiments with a double-truck car fitted with a brake equipment as described in the preceding pages. With perfect conditions, the curve *A B O* would fall above that shown, while with very poor conditions, it would fall lower. The value of the diagram is made apparent by the following application:

Example. Find the distance in which a double-truck electric car may be stopped, if the power is shut off and the brake applied while running at a speed of 30 miles per hour.

Solution. Starting on the vertical line *O Y* at 30 miles per hour, follow the horizontal line to the right until the curve *A B O* is reached at the point *B*. From point *B*, follow the vertical line downward until the horizontal line *OX* is reached at the point *C*. This point *C* indicates the difference in feet in which the car may be stopped, which in this instance is 440 feet. In the same way, the stopping distances may be determined for cars running at any speed.

AIR-BRAKE TROUBLES AND REMEDIES

STEAM-CAR AIR BRAKES

High Reliability of Air-Brake Mechanism. The importance of the air brake in both freight and passenger equipment cannot be overestimated. Were it not for the high standard of perfection of the present braking systems, the relatively fast schedules of our modern passenger trains as well as those of freight service would not be possible. A failure of some part of the air-brake equipment to function properly is often given as the cause of accidents which occur on the road. True as this may be, there are of course many accidents on the road with which the condition of the braking apparatus has nothing to do. The development of the modern braking apparatus has reached such a high stage that, notwithstanding the adverse conditions under which the equipment often operates, it can safely be said that it is almost always in operating condition. To prevent the occasional failure of the brake system to properly perform its duty, it is desirable to point out where the troubles are most likely to appear.

Disorders of Air Compressors. The compressor is an important part of the air-brake system and must be kept in perfect working condition. Without its use the brake system is worthless. For this reason it is important that it be given proper attention in the matter of lubrication, repairs, etc. The Westinghouse Company gives the following directions for remedying disorders of the compressor:

Compressor Refuses to Start. Cause: Insufficient oil, from scant or no feed; water in cylinder; worn main-piston rings; or rust having accumulated during time compressor has lain idle. Remedy: Shut off steam, take off cap nut, put in a tablespoonful of valve oil (not too much), let the oil soak down for one or two minutes, and then turn on steam quickly. In many cases when the compressor will not start when steam is first turned on, if steam is then turned off and allowed to remain off for one or two minutes and then turned on quickly, it will start without the use of any oil except that from the lubricator.

Compressor Groans. Cause: (1) Air cylinder needs oil. Remedy: (1) Put some valve oil in air cylinder and saturate piston swab with valve oil, then replace it on the rod. Cause: (2) Steam cylinder needs oil. Remedy: (2) Increase lubricator feed. Leakage past the air-piston packing rings or past a discharge valve causes heating, destroys lubrication, and results in groaning. Piston-rod packing dry and binding is another cause of groaning.

Uneven Strokes of Compressor. Cause: (1) Probably leakage past air-piston packing rings and sticky air valves: (2) unequal lift of air valves; (3) clogged discharge valve passages; or (4) leaky air valves. Remedy: Locate cause, if possible, and correct it by cleaning out clogged or dirty passages, adjusting lift of valves, or replacing leaky valves or rings.

Slow in Compressing Air. Cause: (1) Leakage past the air-piston packing rings, due to poor fit or wear in cylinder or rings; (2) valves and passages dirty; or (3) air-suction strainer clogged. Remedy: (1) and (2): To determine which is causing the trouble, obtain about 90 pounds air pressure, reduce the speed to from 40 to 60 single strokes per minute, then listen at the "air inlet" and note if air is drawn in during only a portion of each stroke and if any blows back. If the latter, an inlet valve is leaking. If the suction does not continue until each stroke is nearly completed, then there is leakage past the air-piston packing rings or back from the main reservoir past the air-discharge valves. The leaking of one of these valves will cause an uneven stroke. Remedy: (3) Clean strainer thoroughly.

Compressor Erratic in Action. Cause: Worn condition of valve motion. Remedy: Renew it.

Compressor Heats. Cause: (1) Air passages are clogged; (2) leakage past air-piston packing rings; or (3) the discharge valves have insufficient lift. Remedy: (1) Clean air passages; (2) renew air-piston rings; (3) regulate lift of discharge valves to $\frac{3}{32}$ inch on the $8\frac{1}{2}$-inch and to $\frac{5}{32}$ inch on the $10\frac{1}{2}$-inch compressor. A compressor in perfect condition will become excessively hot and is liable to be damaged if run very fast and continuously for a long time.

Compressor Pounds. Cause: (1) Air piston is loose; (2) compressor either not well secured to boiler or causes some adjacent pipe to vibrate; (3) the reversing valve plate *18* is loose; or (4) the reversing rod or plate may be worn so that the motion of compressor is not reversed at the proper time. Remedy: Repair and renew worn parts and tighten loose connections.

Disorders of Air Compressor Governors. The failure of any one of the three different types of compressor governors, previously described, to function properly is usually due to one of two causes: either the governor fails to stop the compressor when the desired pressure has been reached; or, when the compressor is stopped, the governor fails to start it upon a slight reduction of pressure.

In correcting troubles which have been reported in connection with the use of such governors, the Westinghouse Company has issued the following instructions:

If the cutting-out pressure gradually increases without any change having been made in the adjustment of the governor, it is probable that dirt has accumulated on the pin valve or its seat, thus slightly raising the valve and increasing the compression of the regulating spring.

If the governor fails to stop the compressor when the desired pressure has been reached, examine the drip-pipe connection to see that it has not frozen or become closed. Also, if the small hole in the spring box becomes closed and there is a slight leakage of air past the diaphragm, pressure may accumulate above the latter sufficiently to prevent the pin from raising and stopping the compressor.

If, after being stopped by the governor, the compressor fails to start upon a slight reduction in air pressure, examine the pin valve for leakage at the relief port *c*, when the air pressure is a few pounds less than that for which the governor is regulated. Also, if the relief port itself should become stopped up, the compressor would fail to start when the air pressure fell.

Keep all parts of the mechanism clean, particularly the strainers *29*, Fig. 16, in the air connections. Keep the joints at the stem unions absolutely tight to prevent any escape of oil or steam. Oil will escape with even no sign of steam leakage, and the compressor is thereby deprived of part of its lubrication.

Maintenance of Air Compressor. *Heating Air Cylinders.* One of the most important problems of maintenance of the air compressor is the heating of the air cylinder or cylinders incident to the compression of the air. The continual operation of a compressor at high speeds or against excessive pressures results in relatively high temperatures. The effect of these high temperatures is to burn the lubricating oil used in the air cylinders and ultimately destroy its lubricating qualities and cause groaning and cutting of the air cylinders. In addition to these more noticeable features, it also fills the discharge passages with deposits from the burnt oil, produces undesirable condensation of moisture throughout the brake system, and reduces to a very large extent the over-all efficiency of the compressor. Care should be exercised that the speed of the compressor does not exceed 140 single strokes per minute, and this speed should be maintained for but short periods of time as, if continued for any very great length of time, it will cause excessive heating. If the class of service requires such a speed in order to maintain the desired pressure, it is an indication that the compressor should be replaced by a larger one or that an additional compressor should be installed.

From the foregoing it is seen that it is desirable first, that the compressor should be of ample capacity; second, that it should be well lubricated and otherwise maintained in good working condition; and third, that all leakage from any source whatsoever should be minimized in every practical way.

Leaks in Stuffing Box. One of the most serious leaks often occurs in the air-cylinder stuffing box. Such a leak not only greatly decreases the amount of air delivered but, on account of the faster speed required, increases the heating effect. It may also, through the loss of the air cushion, cause the pump to pound. In tightening the packing gland to reduce air leakage, use care not to bind the rod, since to do so will damage not only the packing but the rod as well. Exercise care not to cross the gland nut threads and use a well-oiled swab on the rod.

In cases where two compressors are installed on the locomotive, the separate throttles should be kept wide open and the speed regulated by the main compressor throttle, the idea being to divide the work equally between each compressor.

Broken Air Valves. When necessary to replace a broken air valve on the road or under conditions where proper fitting cannot be made, the temporary valve should be replaced at the very first opportunity by one properly fitted, joint ground, and with lift adjusted to $\frac{3}{32}$ inch. The Westinghouse Company furnishes a small air valve lift gage to be used in determining the proper lift of all air valves.

Leaky Air Valves and Piston. Leaky air valves and a leaky air piston may cause the compressor to run hot and inefficiently. The condition of the valves and piston may be determined by the following simple tests:

To test for leaky inlet valves, operate the compressor slowly against full main-reservoir pressure and listen carefully at the air inlet. If the valves blow it will be easily distinguishable.

To test for leaky discharge valves, operate the compressor until full main-reservoir pressure is attained, then close the throttle and stop the compressor. Now open the oil cup, if this type of oiler is used, and hold your finger over it. If the top discharge valve is leaking the air will be noticed to blow out continuously. If an automatic or sight-feed oiling system is used instead of the oil cup, the oil pipe union near the air cylinder can be opened and the test made as with the oil cup. To test for the bottom discharge valve, remove the bottom plug and examine for leaks the same as before. The bottom plug should be removed before testing the top discharge valve, as a leaky bottom valve and leaky piston would et air blow from the oil cup in the same way as a leak from the top discharge valve.

To test for a leaky air piston, operate the compressor at a speed of, say, 40 strokes per minute, and open the oil cup or oil pipe, as the case may be, and note whether or not a gush of air is discharged on the down stroke. Such an indication means a bad leak in the air-piston packing ring.

When such tests reveal leaks in the air valves and air piston, they should be reported at once and repairs made at the first opportunity.

In making repairs to the steam cylinder of a compressor, never remove or replace the upper cylinder head with the reversing valve rod in place. Such a practice usually results in bending the rod, and a bent rod will probably sooner or later cause a compressor failure.

Sounds as Indications of Faults. A compressor cannot compress more air than it draws into the cylinder, and not even this much if the air inlet passages are obstructed and if there is any leakage to the atmosphere about the air cylinder. For these reasons the engineer should give attention occasionally to the character of the sound issuing from the air inlet when the compressor is working slowly under control of the governor. If a hissing noise or poor or weak suction is detected on either or both strokes, it should be reported and suitable repairs made.

A click, pound, thud, or noise of unusual character, noticed when the compressor is operating under normal conditions, may indicate a loose piston, deranged valve gear, or some other serious fault and should be reported at the first opportunity.

Obstructions in Strainer. A steam leak in the immediate vicinity of the air inlet should be repaired at once as this increases the danger of moisture passing over into the brake system and causing trouble. It is of great importance that the suction strainer be kept clean and free from dirt. A slightly clogged strainer greatly reduces the capacity of the compressor, especially at the higher speeds. A seriously or completely obstructed strainer, such as is caused by the accumulation of frost, will increase the speed of the compressor and prevent the compressor from raising or maintaining the desired main-reservoir pressure.

Cleaning Air Cylinder. The Westinghouse Air Brake Company gives the following directions concerning cleaning and washing the air cylinder of their compressors:

"It is an aid to good operation to thoroughly clean the air cylinder and its passages at least three or four times a year by circulating through them a hot solution of lye or potash in the proportion of 2 pounds of potash to 1 gallon of water. This should always be followed by sufficient clean hot water to thoroughly rinse out the cylinder and passages, after which a liberal supply of valve oil should be given the cylinder. Suitable tanks and connections for performing the operation can easily be arranged in portable form. Never put kerosene oil in the air cylinder to clean it."

Care of Triple Valve. *Installing Triple Valve.* The triple valve, being the most important of all the various parts that go to make up the modern freight-car brake equipment, should be located with care in order to have it free from obstructions which would render inspection or removal difficult. It should be conveniently located above the general level of the piping which, in turn, should be carefully planned to avoid pockets in which moisture might collect. If the question of piping layout is not given proper attention, trouble will be experienced in cold weather from water freezing at different points and possibly in the triple valve.

The tee in the brake pipe at the point where the branch pipe is taken off should point upward rather than horizontally or downward, because this arrangement will prevent moisture which may be deposited in the brake pipe from passing over into the branch pipe and from thence to the triple valve. The centrifugal dirt collector has proved to be very efficient in removing dirt and moisture from the piping of the air-brake system, but since excessive deposit of moisture in the piping system is sometimes occasioned by locomotives having insufficient reservoir capacity or cooling pipe to insure precipitation of the water before passing to the brake system, it is advisable to take the added precaution of taking off the branch pipe from the top of the brake pipe.

What has been said concerning the piping arrangement and installation of the triple valve on freight cars also applies to passenger cars.

Removal of Scale. All the piping should be thoroughly hammered and blown out in order to loosen and remove all scale and foreign matter before the triple valve is connected. This precaution is especially important in new installations, and after the piping is complete, it should be tested under pressure with soapsuds and made tight.

Repair of Triple Valve. The removable parts of the triple valve should never be removed while the valve is attached to a car. If the valve is not functioning properly it should be removed and repaired on a bench by a competent workman. Any attempt to open triple valves while still attached to cars is sure to result in a great many failures because of injuries by careless handling and because of dirt getting inside the pipes or parts.

Weighted Retaining Valve. The weighted retaining valve, which is practically a part of the triple valve, must be installed in a vertical position, accessible for repairing and for use when the train is in motion. It should be cleaned but not oiled every time the triple valve receives attention.

Lubrication of Triple Valve. Under ordinary conditions of service the triple valve should be cleaned and lubricated at least once a year. The proper interval can best be determined by careful inspection. A valve subjected to severe conditions of service and exposure to extreme weather conditions, dirt, etc., will need more frequent cleaning and oiling than one which has been more or less protected and not subjected to hard usage. After the valve has been removed from the car and opened, all the parts should be made free of all oil, gum, or grease by the use of gasoline or benzine.

The face of the graduating valve, both the upper and lower surfaces of the slide valve, the slide-valve seat and the upper portion of the bushing, where the slide-valve spring bears, should be lubricated with a high grade of very fine dry pure graphite. The graphite should be well rubbed in so that as much as possible will adhere to the surface and fill the pores of the brass and leave a very light thin coating of graphite.

The graphite can best be applied by using a stick about 8 inches long having a small piece of chamois glued to one end. Dip the skin-covered end in dry graphite and rub on the surfaces in question. After rubbing, a light blow of the stick on the side of the slide-valve seat will leave the desired coating of loose graphite. When the work is completed, the slide valve and its seat must be entirely free from oil or grease. Care should be taken in handling the parts after lubrication that the hands do not come in contact with the lubricated parts and remove the thin coating of graphite.

The piston ring and the bushing in which it works should be very sparingly lubricated by first pushing the piston to release position and applying a drop or two of light oil to the circumference of the piston bushing, or cylinder, spreading it over the surface as uniformly as possible and then moving the piston back and forth several times to insure proper distribution of this oil on the wall, or inner surface, of the cylinder. There should be no free oil left on the parts. Care should be exercised not to permit any oil to get on the gaskets or rubber-seat valves. No lubricant should be used on the quick-action parts of the triple valve.

The general scheme which should be followed in the lubrication of all types of triple valves, distributing valves, etc., is the same as that just presented.

Lubrication of Brake Cylinder. In cleaning the brake cylinder and piston care should be exercised to remove all lint, free the leakage groove of any deposit, and thoroughly clean the expander ring, packing leather, and piston. In lubricating the cylinder special attention should be given to the thorough lubrication of the top of the cylinder, as well as the bottom, and the inside of the packing leather where the expander ring rests. A good lubricant specially prepared for the purpose should be used. Special examination should be made to see that the follower nuts are tight, as they frequently become loosened.

Lubrication of Brake Valve. It is essential for satisfactory performance that the brake valve or valves receive occasional cleaning and lubricating. A good grade of graphite grease has been found to give the best results for use on the brake valve and rotary valves whenever it can be conveniently applied, as when assembling after overhauling and repairs. Graphite grease is not convenient for use as a lubricant, however, after the brake is assembled. In such cases a good grade of oil should be used, but very sparingly. The equalizing piston may be lubricated in much the same manner as the main piston of a triple valve, by pushing it to its normal position and applying a drop or two of oil to the inner surface of the piston bushing, spreading it as uniformly as possible, then moving the piston up and down several times to insure a proper distribution of the oil. There should be no free oil on the parts and no oil should be permitted to get on the gaskets.

Air Leaks in Type "K" Triple Valve. The Type "K" triple valve, like all other air valves, will sometimes develop air leaks which may make necessary the cutting out of the air-brake equipment of the car on which the defective triple valve is located. This is accomplished, as previously explained, by closing the cut-out cock in the brake-pipe branch pipe and bleeding the auxiliary reservoir. The most serious defects which might occur on the road are, viz, air leaks in the slide valve, check valve, valve-case gasket, triple-valve body gasket, emergency valve, main-piston packing ring, auxiliary-reservoir tube, and broken graduating spring.

If an air blow is noticed from the triple-valve exhaust, it indicates a leak either from the brake pipe or auxiliary reservoir. To determine from which source, cut out the brake by closing the brake-pipe branch-pipe cut-out cock. If the brake applies and the blow stops, it indicates a leak from the brake pipe. If the blow continues and the brake does not apply, it indicates a leak from the auxiliary reservoir.

An auxiliary-reservoir blow is caused by a leaky slide valve, triple-valve body gasket, or the auxiliary-reservoir tube. A leaky slide valve will usually cause a blow when the triple valve is in either *release* or *application* position, while a leaky body gasket or auxiliary-reservoir tube will cause a blow only when the triple valve is in *release* position.

A brake-pipe blow is caused either by a leaky emergency valve or the check valve case gasket.

A leaky main-piston packing ring may prevent the brake from applying on a light reduction on a long train, or if the brake applies may prevent a proper release.

A broken graduating spring may cause undesired quick action, depending upon the conditions of the triple valve and the rate of brake-pipe reduction. If the triple valve is dry and gummy or the brake pipe is reduced at too rapid a rate through leakage or otherwise, quick action is almost sure to result.

A broken retarding spring permits the triple-valve piston to move to *retarded release* position and results in a slow release of the brake.

The triple valve will not produce a buzzing sound if in good condition. Such a noise indicates that the emergency valve is leaking, in which case there will be a blow at the exhaust. This can sometimes be remedied by jarring the valve. When this does not stop the *buzz*, apply the brake in emergency, by parting the hose and opening the angle cock quickly, then release the brake by connecting up the hose, and repeat the operation if necessary. This process may dislodge the dirt or foreign matter and permit the valve to seat properly. In case it does not, then the brake should be cut out.

Broken Pipe Connections. Accidents sometimes happen to the brake piping system which may make inoperative a part or the whole of the entire brake system. These accidents are most likely to occur to the locomotive brake piping system. Perhaps the most complicated system is that of the No. 6 "ET" locomotive brake equipment, and for this reason a discussion of the effect of broken pipes in this system and emergency repairs will be given.

Broken Main-Reservoir Pipe. If a break that renders a temporary repair impossible should occur in the main-reservoir pipe between the reservoir and the branch to the distributing valve, the locomotive brakes cannot be applied by either brake valve except when a quick-action cap is used on the distributing valve, and then only in emergency. The pressure obtained in the brake cylinder in the latter case is due entirely to the air vented through the quick-action cap from the brake cylinder. If the break occurs between the brake valve and branch pipe leading to the distributing valve, both ends of the pipe should be plugged. The locomotive brakes can then be operated in the usual manner by means of the independent brake valve.

Broken Main-Reservoir Branch Pipe. In case of a break in the branch pipe from the main-reservoir pipe to the distributing valve between the main-reservoir pipe and the cut-out cock, the main-reservoir end of the break should be plugged and the cut-out cock closed. In this condition the locomotive brakes become inoperative, but the train brakes can be operated in the usual manner.

If the branch pipe leading to the feed valve and reduction valve should become broken, both broken ends should be plugged. Under this condition the independent brake valve and the signal system become inoperative. The *running* position (for releasing and recharging the train brakes) and the *holding* position of the automatic brake valve and the excess-pressure head of the compressor governor will be cut out also. There being no air pressure on top of the independent rotary valve to hold it to its seat, it will be impossible to secure an automatic application of the locomotive brakes. Under such circumstances the handle of the independent brake valve should be moved to the *slow-application* position before applying the brakes and permitted to remain there until it is desired to again release the locomotive brakes, when it should be returned to the *running* position. The train brakes must be released and recharged with the handle of the automatic brake valve in *release* position. The locomotive brakes can be released by moving the handle of the automatic brake valve to *running* position or by placing the handle of the independent brake valve in *release* position. Since the feed valve will be inoperative, the excess-pressure operating pipe should be closed by a blind gasket placed in the union at the governor. This cuts out the excess-pressure head of the governor so that the maximum-pressure head controls the compressor. In order to prevent too high a brake-pipe pressure with the handle of the automatic brake valve in *release* position, it will be necessary to throttle the compressor by hand.

If the break occurs between the reducing valve and the branch pipe leading to the feed valve, plug on both sides of the break. In this condition the independent brake valve and signal system are cut out, but the locomotive and train brakes can still be operated by the automatic brake valve, although in so doing the independent brake valve must be manipulated as explained above.

If the pipe should be broken beyond the feed valve or the reducing valve it will not be necessary to plug the ends of the pipe, as the same result can be secured by turning the adjusting nut until the regulating spring is sufficiently loose to cause the blow to cease. The break can be handled in another manner by regulating the adjusting nut, as just described, plugging the broken end of the pipe toward the independent brake valve and the exhaust port of this valve. The handle of the independent brake valve should then be kept in *running* position. With this arrangement the locomotive brakes as well as those of the train can be operated by the automatic brake valve.

Broken Brake Pipe. The brake-pipe branch to the distributing valve is probably more often broken than all others. In case of such an accident the end of the pipe leading from the brake pipe should be plugged and the pressure chamber drained. Under these conditions, the train brakes can be operated as usual, but the locomotive brakes cannot be operated except by the use of the independent brake valve and the *release* position of the valve handle must always be used in releasing them.

If the break is ahead of the branch pipe to the distributing valve, the end of the pipe toward the distributing valve may be plugged without affecting the operation of the brake.

When the break occurs between the branch pipe to the distributing valve and the branch pipe to the automatic brake valve, both ends of the pipe should be plugged. In this condition the locomotive brakes will be inoperative by the automatic brake valve but the train brakes can be operated as usual. The locomotive brakes will be operative by means of the independent brake valve.

If the brake pipe is broken ahead of the cut-out cock of the pilot section and it is necessary to couple to a train ahead of the locomotive instead of at the rear, a *combination hose* must be used to connect the brake hose to the signal hose at the rear of the tender, the angle and cut-out cocks opened, and the cut-out cock in the supply line to the signal system closed. At the pilot end, another *combination hose* must be used to connect the signal hose to the brake hose of the car and the angle and cut-out cocks opened. With this arrangement both the locomotive and train brakes can be operated as desired. A similar plan can be used if such a break occurs at the rear of the tender instead of at the front end of the locomotive.

If the brake pipe becomes broken under the tender the *combination hose* will permit the signal pipe to be used as a brake pipe in the manner described above.

Broken Brake Cylinder Pipe. A broken brake cylinder pipe will permit the escape of main-reservoir air to the atmosphere whenever the locomotive brakes are applied and may cause the release of one or more of the brakes depending on the point at which the break occurs. In such a case, if the break cannot be repaired, the cut-out cock leading to the broken pipe should be closed. If the break occurs near the distributing-valve reservoir, close the cut-out cock in the main-reservoir pipe leading to the distributing valve.

Broken Application Cylinder Pipe. If the application cylinder pipe is broken, plug the pipe on the distributing-valve side of the break. If the break occurs between the distributing valve and the tee to the independent and automatic brake valves, the locomotive brakes cannot be applied with the independent brake valve and the emergency maintaining feature is lost. In such a case, however, the locomotive brakes can be applied as usual by the automatic brake valve and released with the valve in the *running* position. If the break occurs between the tee and the automatic brake valve, the independent brake can be applied and released as usual, but the emergency maintaining feature is lost. If the break is located between the independent brake valve and the tee, the locomotive brakes cannot be applied by the independent brake valve, but the emergency maintaining feature is retained.

Broken Distributing-Valve Release Pipe. A failure of the distributing-valve release pipe merely renders inoperative the holding feature of the automatic brake valve. If the release pipe breaks between the two brake valves, the locomotive brakes can be held applied while the train brakes are being released and recharged by placing the handle of the independent brake valve in *lap* position; the locomotive brakes can then be released by returning the handle of the independent brake valve to *running* position. The broken release pipe may be plugged on the distributing-valve side and the locomotive brakes can then be released with the independent brake valve in *release* position. If the pipe is broken between the distributing valve and the independent brake valve, plug the broken pipe on the distributing valve side. Then the locomotive brakes can be held applied as indicated above, but to release them the handle of the independent brake valve must be placed in *release* position.

Broken Equalizing-Reservoir Pipe. If the equalizing-reservoir pipe becomes broken, it should be plugged at the brake-valve union. The brake-pipe service exhaust should also be plugged. Under these conditions, to apply the brakes, move the handle of the automatic brake valve very gradually towards *emergency* position until the desired service reduction is secured, when the handle should be gradually returned to *lap* position.

Broken Excess-Pressure Operating Pipe. Should the excess-pressure operating pipe become broken, place the handle of the automatic brake valve in *lap* position and plug the broken pipe on the brake-valve side. Under these conditions the compressor will be controlled by the maximum-pressure head of the governor.

Broken Excess-Pressure Pipe. With a broken excess-pressure pipe the compressor will not operate when the main-reservoir pressure is greater than about 20 pounds. Under these circumstances the broken pipe on the feed valve side should be plugged and a blind gasket placed in the excess-pressure operating pipe. With this arrangement the excess-pressure head of the governor is rendered inoperative and the compressor is under control of the maximum-pressure head of the governor.

Broken Pipe to Maximum-Pressure Head of Governor. In case the pipe to the maximum-pressure head of the governor is broken, it should be plugged on the main-reservoir side. With the handle of the automatic brake valve in *release, running,* or *holding* position the excess-pressure head of the governor will control the main-reservoir pressure. However, when the handle of the automatic brake valve is in *lap, service,* or *emergency* position, since the maximum-pressure head of the governor is rendered inoperative, the compressor must be controlled by hand in order to prevent an excessive main-reservoir pressure.

ELECTRIC-CAR AIR BRAKES

Instructions Applying to All Systems. As has already been stated in the text proper, a survey of the available literature on the subject of Air Brakes for Electric Cars, reveals the fact that a great many systems are being used. Many of these systems are quite similar in their method of operation. The Westinghouse "S M E" brake equipment represents one form of modern air-brake system for electric-car service which has given highly satisfactory results. Much of the matter presented on the preceding pages applies in a general way to this system.

The remaining pages refer more directly to the "SME" brake equipment but in some cases apply equally well to other systems.

Train Tests. As a safeguard against accidents caused by defective air-brake equipment, it is recommended that the following three tests be carried out before the train is sent out on the road. It is assumed that all valves, connections, etc., have received proper attention and that the system is charged with air and the governor has stopped the compressor.

Test No. 1 consists in first applying the brakes in service from the head car and returning the handle to *lap* position. The inspector or conductor should then pass, at once, along the side of the train and note whether the piston of each brake cylinder has moved out sufficiently to indicate that the brakes are set on all cars. Should any brake release after the service application, while the brake-valve handle is still in *lap* position, it probably would be due to the brake valve not being properly *lapped,* a leaky rotary valve, or a leaky brake cylinder piston packing leather. Any improper brake action developed during this test should be corrected before proceeding further.

Test No. 2 should immediately follow Test No. 1 and consists in releasing the brakes by placing the handle of the brake valve in *release* position. With the brake-valve handle held in this position the inspector should return along the side of the train and examine all push rods to ascertain whether or not they have all fully released and whether all brake shoes hang free of the wheels.

Test No. 3 consists in making an emergency application with the brake valve and also with the conductor's valve to determine if proper action is secured. It is usually considered safe to assume that the brakes will apply in emergency properly if Test No. 1 is satisfactory, but it is safest to also make Test No. 3 to make sure that no obscure causes exsist which would render inoperative this important feature of the brake.

Cutting Out Brakes. Small leaks or temporary inconveniences are not sufficient causes for cutting out brakes and thus reducing the braking power of the train. All brakes should remain cut-in unless it is absolutely impossible to operate them safely.

Coupling Cars. Much time can be saved if the cut-out cocks at the ends of the cars are opened slowly when coupling cars. If the valves are opened quickly an emergency application will be obtained which requires a certain length of time to release. By opening the cocks slowly this action will be prevented and less time will be lost.

Switching Cars. In setting a car out of a train, first close the emergency and straight-air application and release the pipe cut-out cocks ahead of and behind the couplings to be separated, then separate the couplings by hand and attach the hose to the dummy couplings. Never permit the hose couplings to be pulled apart, as this practice always results in defective hose couplings and eventually unsatisfactory brake operation.

Before setting the hand brake on the car which has been set out of the train, make sure that the air brake has first been released.

Rail Sanding. The use of sand should begin if practicable before the brakes are applied, for if the brakes are set and the wheels begin to slide the application of sand will probably not cause them to revolve again and flat spots on the wheels will result. In such cases it is the best practice to release the brakes slightly at the moment of applying the sand, after which a much higher brake-cylinder pressure can be used without causing skidding of the wheels. When sand is used the rails should be continuously sanded until the stop is made or the brakes released.

Unexpected Brake Applications. Occasionally the brakes may apply unexpectedly due to conditions over which the motorman has no control. Such applications may be caused by the train parting, a bursted hose, or some accident to the piping system. When such applications occur, the motorman should place the handle of the brake valve in *emergency* position, where it should remain until the train stops and an examination is made and the trouble located and, if possible, remedied.

In case an emergency pipe or straight-air application- and release-pipe hose bursts, it can be replaced by an extra hose, if one is carried, or by one taken from the front or rear end of the train. If it is impossible to replace the bursted hose in the emergency pipe or if the emergency pipe itself is ruptured, thus rendering the brakes in the rear thereof inoperative, close the emergency pipe and straight-air pipe cut-out cocks immediately ahead of and behind the point of rupture. Then, if the car concerned is a motor car, release the brakes thus cut out by placing the handle of one of the brake valves on that car in *release* position and cut out the compressor by means of the snap switch. However, should the rupture occur on a non-motor trailer, release the brakes thus cut out by opening and leaving open the auxiliary-reservoir drain cock and proceed with the train. The hand brakes on the disabled car should be tested and someone assigned to operate them should it become necessary.

If the straight-air pipe becomes broken, close the cut-out cocks in that pipe ahead of and behind the point of rupture. In such a case the brakes on the car in question will be operative only in emergency applications.

Effect of Air Leaks. It is easily seen that leaks will produce results not intended or desired by the motorman, both during a straight-air application of the brake and while holding the brakes applied with the handle of the brake valve in *lap* position. Leaks will not only interfere with the accuracy and smoothness of the stop but will also impose an additional heavy duty upon the compressor. For these reasons air leakage should be kept at a minimum and reported as soon as detected. It should be the duty of the motorman to notice as carefully as possible the action of the compressor governor and pressure gages, as much better results can be secured if they are in proper adjustment.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

LOCOMOTIVE BOILERS AND ENGINES

PART I

1. In what respect did the first locomotives differ from the modern locomotive?

2. Explain Whyte's system of classification.

3. What is a *compound locomotive?* Give its advantages.

4. What methods are in use for supporting the crown sheet?

5. What was the name of the first locomotive built in America? When was it constructed?

6. Give the names of some of the early locomotives built in America?

7. Describe the action of exhaust steam in creating draft in the front end.

8. Name the types of fire-boxes commonly used.

9. What created the demand for a wide fire-box?

10. Determine the principal dimensions of a tapered stack for a locomotive boiler 70 inches in diameter, the nozzle being 2 inches below the center of the smoke box.

11. Compute the thickness of the sheets of a straight-top locomotive boiler, 70 inches in diameter, carrying a boiler pressure of 200 pounds per square inch, the pitch of the stay bolts being 4 inches.

Ans. { Thickness of shell = .67 inches.
" " fire-box side and fire door sheets = .36 inches. }

12. What parts comprise the *front end* of a locomotive?

REVIEW QUESTIONS

ON THE SUBJECT OF

LOCOMOTIVE BOILERS AND ENGINES

PART II

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1. What effect does the changing of a valve from inside lap to inside clearance have on the events of the stroke?

2. What pressure in tons would be required to force a cast steel driving wheel center on an 8-in. axle? What allowance is commonly made for tire shrinkage?

3. State briefly how the dead center points are located.

4. What two types of valve gears are generally used in this country?

5. State the advantages and disadvantages of each.

6. What is the resistance, due to grade only, of a freight train weighing 2,000,000 pounds, moving up a grade of .9 of one per cent? Ans. 18,000 pounds.

7. What is the resistance, due to acceleration only, of a train weighing 200 tons that is accelerated from a speed of 50 to one of 60 miles an hour in a distance of one mile?

Ans. 264 pounds.

8. State the two different forms of locomotive frames in use and give the principal features of each.

9. What is the tractive power of a simple locomotive having cylinders 18 inches in diameter, a piston stroke of 24 inches, driving wheels 62 inches in diameter, and working under a boiler pressure of 200 lbs. per sq. in.? Ans. 21,321.

10. What is meant by the terms *lead, outside lap,* and *inside clearance?*

REVIEW QUESTIONS

ON THE SUBJECT OF

AIR BRAKES

PART I

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1. What are the three main objections to the straight air-brake system?
2. Name the important parts used in the Westinghouse system.
3. What are the two sources of drain on the brake pipe which will tend to prevent an increase in pressure?
4. Give the positions of the ordinary Westinghouse engineer's brake valve, and tell what occurs in each position.
5. Describe the Westinghouse single-stage air compressor.
6. Give causes and remedies for the following disorders of the compressor: Compressor refuses to start; slow in compressing air; compressor pounds; compressor heats; compressor erratic in action.
7. What is the principal difference between "SD" and "SF" types of compressor governors?
8. You are operating the compressor and after having been stopped by the governor the compressor fails to start upon a slight reduction of air pressure. What would be the possible cause for this?
9. In what position is the brake-valve handle placed in order to make the shortest possible stop?
10. Give the principles upon which the Westinghouse plain triple valve operates.
11. Explain how the quick-action triple valve overcomes the defects of the plain triple valve.
12. Sketch the Westinghouse plain triple valve, showing service position.
13. Sketch the Westinghouse quick-action triple valve, showing emergency position.
14. In the Type "K" triple valve, how is the rate of brake-pipe reduction for service application determined?

REVIEW QUESTIONS

ON THE SUBJECT OF

AIR BRAKES

PART II

1. State the principle involved in the operation of the high-speed brake equipment.

2. Name the parts comprising the "LN" passenger car brake equipment.

3. Give the advantages of the No. 6 "ET" equipment.

4. What should be the position of the automatic and independent brake-valve handle on the second engine when double heading?

5. What are the features which are peculiar to the "PC" equipment?

6. State in a general way the rules for operating the "PC" passenger brake equipment.

7. What are the essential parts of an air-signal system?

8. What is the purpose of the conductor's brake valve?

9. Give in a general way the rules for train inspection.

10. Describe the proper brake manipulation in freight service on heavy grades.

11. Give the office of the distributing valve on "ET" equipment.

12. Describe the process of charging empty equipment by means of the control valve.

13. Give the general relation of the different parts of the control valve in the graduated release position.

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