283. Signalling at a Double-track Crossing.—In the case of a double-track crossing, the arrangement of signals and derails is precisely the same as for a single-track crossing, each set of signals shown in Fig. 15 covering one track. In other words, the line of single track is to take the place of each rail with its set of signals in that figure. There will be but four derails, one for each track only on the approach to the crossing. The working of the signals with the derails is precisely the same as has already been explained for the single-track crossing.

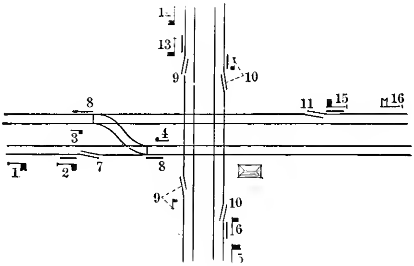


FIG. 15.

284. Signalling for Double-track Junction and Cross-over.—Fig. 16 represents a skeleton diagram of signals required for a junction of two double-track roads and a cross-over. This arrangement covers the use of switches. The location of signals and signal cabin as shown is self-explanatory, after what has already been stated in connection with single- and double-track crossings. It will be observed that the home signals for both the west-bound main and branch tracks are identical in location, and are shown by the solid double flag, the distant signal being shown by its notched end at a considerable distance back

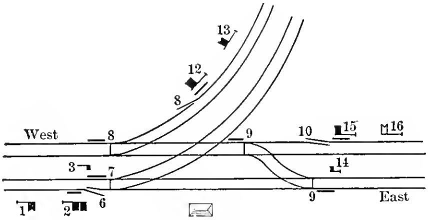


FIG. 16.

of the double home signal. It will, furthermore, be observed that at each home signal there is a derailing-switch interlocked, in the lock-and-block system presently to be explained, with the home signals operated simultaneously with them. If, therefore, an engineman attempts to run his train past a home signal set at danger, the result will be the derailment of his train, thus brought to rest before it can make any collision with another. It is obvious in this case that if the switches from the main to the branch tracks or at the extremities of the cross-over are worked independently, they must be operated directly in connection with the signals. For complete protection they should be interlocked with the signals so that it would be impossible to clear any signal without simultaneously setting the switches consistently with those signals. The diagram exhibits clearly the indications which must be made in order to effect any desired train movement at such a junction of tracks.

285. General Observations.—Similar arrangements of signals, derails, or switches must be made wherever switches, cross-overs, and junctions are found, the detailed variations of those signals and switches being made to meet the individual requirements of each local case. The combinations of switches and switch-signals frequently become very complicated in yards where the tracks are numerous and the combinations exceedingly varied, in order to meet the conditions created by the movement of trains into and out of the yard.

The preceding explanations are intended only to give a clear idea of the main features of signalling, in order to secure the highest degree of safety and facility in the movement of trains over a modern railroad. While they exhibit the external or apparent combinations of signals for that purpose, they do not touch in detail and scarcely in general upon the mechanical appliances found in the signal cabin and along the tracks required to accomplish the necessary signal movements. The considerations in detail of those appliances would cover extended examinations of purely mechanical, electrical, pneumatic, and electro-pneumatic combinations too involved to be set forth in any but the most extended and careful study. They have at the present time been brought to a wonderful degree of mechanical perfection and afford a field of most interesting and profitable study, into which, however, it is not possible in these general statements of the subject to enter.

286. Interlocking-machines. — The earliest machine perfected for use in this department of railroad signalling was the Saxby and Farmer interlocking-machine, first brought out in England and subsequently introduced in this country between 1874 and 1876. This machine has been much improved since and has been widely used. Other interlocking-machines have also been devised and used in this country in connection with the most improved systems of signalling, until at the present time a high degree of mechanical excellence has been reached.

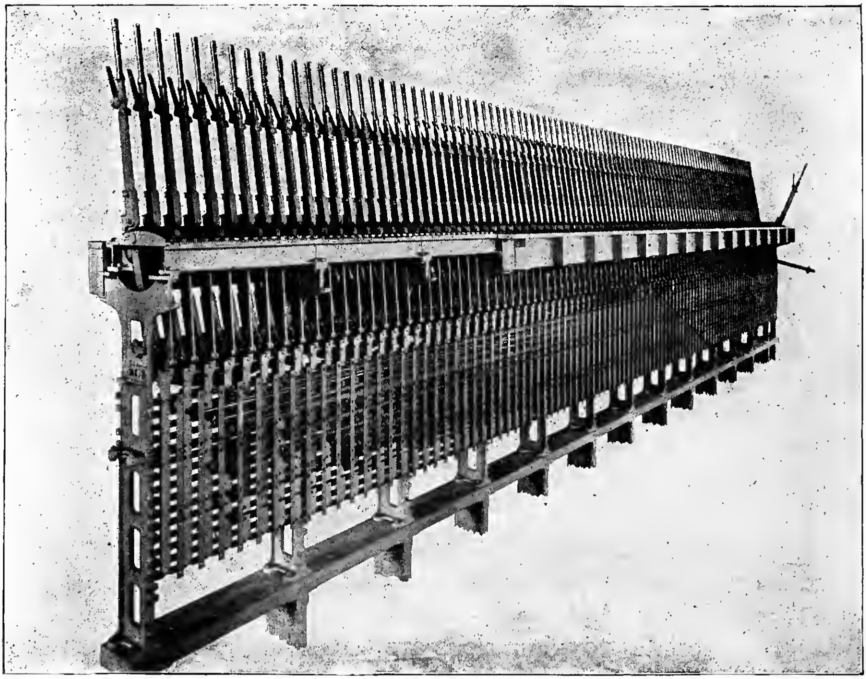


FIG. 17.

The interlocking-machine in what is called the lock-and-block system of signalling is designed to operate signals, or signals in connection with switches, derailing-points, or other dangerous track features, so as to make it impossible for a signalman to make a wrong combination, that is, a combination in which the signals will induce the engineman to run his train into danger. The signals and switches or other track details are so connected and interlocked with each other as to form certain desired combinations by the movement of designated levers in the signal cabin or tower. These combinations are predetermined in the design and connections of the appliances used, and they cannot be changed when once made except by design or by breakage of the parts; they cannot be deranged by any action of the signalman. He may delay trains by awkward or even wrong movement of levers, but he cannot actually clear his signals for the movement of a train without simultaneously giving that train a clear and safe track. As has been stated, he cannot organize an accident. Figs. 17 and 18 show banks or series of levers belonging to interlocking-machines. As is evident from these figures, the levers are numerous if the machine operates the switches and signals of a large yard, for the simple reason that a great many combinations must be made in order to meet the requirements of train movements in such a yard. The signalman, however, makes himself acquainted with the various combinations requisite for outgoing and incoming trains and the possible movements required for the shifting or hauling out of empty trains. He has before him diagrams showing in full the lever movements which must be made for the accomplishment of any or of all these movements, and he simply follows the directions of the diagrams and his instructions in the performance of his duty. He cannot derange the combinations, although he may be slow in reaching them. The locking-frame which compels him to make a clear track whenever his signals give a clear indication to the engineman lies below the lower end of the levers seen in the figures. The short arms of the levers carry tappets with notches in their edges into which fit pointed pieces of metal or dogs; the arrangement of these notches and dogs is such as to make the desired combinations and no others. It will be observed that a spring-latch handle projects from a point near the upper end of each lever where the latter is grasped in operating the machine. This spring-latch handle must be pressed

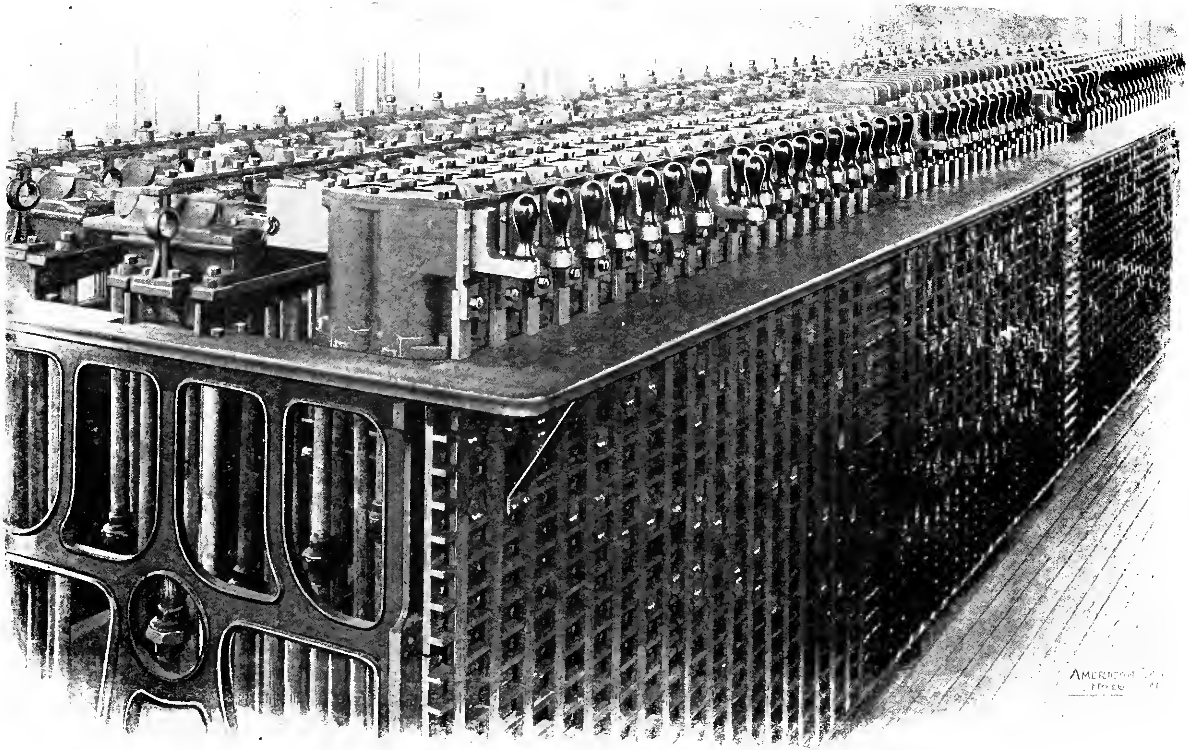


FIG. 18.

close to the lever before the latter can be moved. The pressing of the spring-latch handle against the lever effects a suitable train of unlocking before which the lever cannot be moved and after which it is thrown over to the full limit and locked there. The desired combination for the movement of the train through any number of switches may require a similar movement of a number of levers, but the entire movement of that set, as required, must be completely effected before the signals are cleared, and when they are so cleared the right combination forming a clear track for the train, and that one only, is secured. These meagre and superficial statements indicate in a general way, however imperfectly, the ends attained in a modern interlocking-machine. They secure for railroad traffic as nearly as possible an absolutely safe track. They eliminate, as far as it is possible to do so, the inefficiency of human nature, the erratic, indifferent, or wilfully negligent features of human agency, and substitute therefor the certainty of efficient mechanical appliances. In some and perhaps many States grade crossings are required by statute to adopt measures that are equivalent to the most advanced lock-and-block system of signalling. So vast has become railroad traffic upon the great trunk lines of the country that it would be impossible to operate them at all without the perfected modern systems of railroad signalling. They constitute the means by which all train movements are controlled, and without such systems great modern railroads could not be operated.

The swiftly moving "limited" express passenger trains, equipped with practically every luxury of modern life, speed their way so swiftly and smoothly over many hundreds of miles without the incident of an interruption, and in such a regular and matter-of-fact way, that the suggestion of an intricate system of signalling governing its movements is never thought of. Yet such a train moves not a yard over its track without the saving authority of its block signals. If the engineman were to neglect even for a mile the indication of the semaphore, he would place in fatal peril the safety of his train and of every life in it.

287. Methods of Applying Power in Systems of Signalling.—The mechanical appliances used in accomplishing these ends are among the most efficient in character and delicate yet certain in motive power which engineering science has yet produced. The electric circuit formed by the rails of the track plays a most important part, particularly in securing the safety of the rear of the train in making it absolutely certain whether even rear cars that may have broken away have either passed out of the block or are still in it. The electric circuit in one application or another was among the earliest means used in railroad signalling. Electric power is also used in connection with compressed air for the working of signals. Among the latest and perhaps the most advanced types of lock-and-block signalling is that which is actuated by low-pressure compressed air, the maximum pressure being 15 pounds only per square inch. The compressed air is supplied by a simple compressor, and it is communicated from the signal cabin to the most remote signal or switch by pipes and suitable cylinders fitted with pistons controlled by valves, thus effecting the final signal or switch movements. It has been successfully applied at the yard of the Grand Central Station in New York City and at many other similar points. In this connection it is interesting to observe that while the original Saxby and Farmer interlocking-machine was installed from England in this country, as has already been observed, about 1875, American engineers have within a year reciprocated the favor by furnishing and putting in place most successfully in one of the great railroad yards of London the first low-pressure pneumatic lock-and-block system * found in Great Britain.

288. Train-staff Signalling.—The lock-and-block system gives the highest degree of security attainable at the present time for double-track railroad traffic, but the simpler character of the single-track railroad business can be advantageously controlled by a somewhat simpler and less expensive system, which is a modification of the old train-staff method. It is one of the "machine" methods of signalling. The type which has been used widely in England, Australia and India, and to some extent in this country is called the Webb and Thompson train-staff machine, shown in Fig. 19. It will be observed that the machine contains ten staffs (18 to 20 inches long and 1 to $1\frac{1}{4}$ inches in diameter), but as many as fifteen are sometimes used. These staffs can be

* By Standard Railroad Signal Company of Troy, N. Y.

removed from the machine at one end of a section of the road at which a train is to enter, only by permission from the operator at the farther end of the section. If the station at the entrance to that section is called *A*, and the station at the farther end *X*, the following description of the operation of the instrument is given by Mr. Charles Hansel in a very concise and excellent manner:

"When a train is ready to move from *A* to *X* the operator at *A* presses down the lever which is seen at the bottom of the right-hand dial, sounding one bell at *X*, which is for the purpose of calling the attention of the operator at *X* to the fact that *A* desires to send a train forward. The operator at *X* acknowledges the call by pressing the lever on his instrument, sounding a bell in the tower at *A*. The operator at *A* then asks permission from *X* to withdraw staff by pressing down the lever before mentioned three times, giving three rings on the bell at *X*, and immediately turns his right-hand pointer to the left, leaving it in the horizontal position pointing to the words 'For staff,' indicating that he desires operator at *X* to release his instrument so that he can take a staff or train order from it. If there is no train or any portion of a train between *A* and *X*, the holding down of the lever at *X* closes the circuit in the lock magnets at *A*, which enables the operator at *A* to withdraw a staff. As soon as this staff is removed from *A*, *A* turns the left-hand pointer to the words 'Staff out,' and in removing this staff from the instrument *A* the galvanometer needle which is seen in the centre of the instrument between the two dials vibrates, indicating to the operator

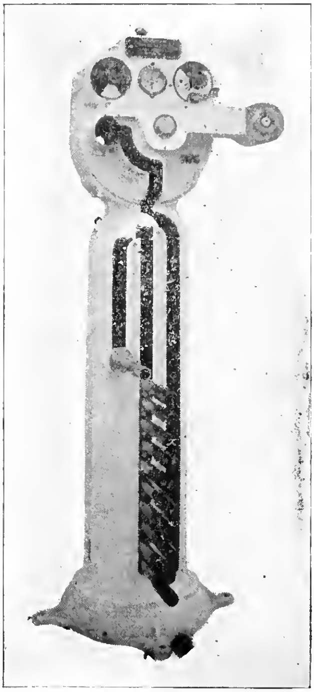


FIG. 19.—Webb and Thompson Train-staff Machine.

at *X* that *A* has withdrawn his staff. *X* then releases the lever which he has held down in order that *A* might withdraw a staff and turns his left-hand indicator to 'Staff out,' and with this position of the instrument a staff cannot be withdrawn from either one.

"The first method of delivering this staff to the engineer as a train order was to place it in a staff-crane, which crane was located on the platform outside of the block station. With the staff in this position it has been found in actual practice that the engineman can pick it up while his train is running at a speed of 30 miles per hour. A second staff cannot be removed from *A* nor a staff removed from *X* until this staff which was taken by the engineman in going from *A* to *X* is placed in the staff instrument at *X*; consequently the delivering of a staff from *A* to the engineman gives him absolute control of the section between *A* and *X*.

"This train-order staff also controls all switches leading from the main line between *A* and *X*, for with the style of switch-stand which we have designed for the purpose the trainman cannot open the switch until he has secured the staff from the engineman and inserted it in the switch-stand, and as soon as he throws the switch-lever and opens the switch he fastens the train-staff in the switch-stand, and it cannot be removed until the switchman has closed and locked the switch for the main line. When this is done he may remove the train-staff and return it to the engineman. It will thus be seen that this train order, in the shape of a staff, gives the engineman absolute control over the section, and also insures that all switches from the main line are set properly before he can deliver the train-staff to the instrument at *X*.

"In order that the operator at *X* may be assured that the entire train has passed his station, we may divide the staff in two and deliver one half to the engineman and the other half to the trainman on the caboose or rear end of the train, and it will be necessary for the operator at *X* to have the two halves so that he may complete the staff in order to insert it into the staff instrument at *X*, as it is impossible to insert a portion of the staff; it must be entirely complete before it can be returned to the staff instrument."

Instead of using the entire staff as a whole or in two parts, Mr. Hansel suggests that one or more rings on the body of the staff be removed from the latter and given to the engineman or other trainman to be placed upon a corresponding staff at the extreme end of the section. This would answer the purpose, for no staff can be inserted in a machine unless all the rings are in their proper positions. These rings can be taken up by a train moving at any speed from a suitable crane at any point alongside the track.

For a rapid movement of trains on a single-track railroad under this staff system an engineman must know before he approaches the end of the section whether the staff is ready for delivery to him. In order to accomplish that purpose the usual distant and home signals may readily be employed. The distant signal would show him what to expect, so that he would approach the entrance to the section either at full speed or with his train under control according to the indication. Similarly, electric circuits may be employed in connection with the staff or rings in the control of signals which it may be desired to employ.

The electric train-staff may also be used in a permissive block system, the section of the track between stations *A* and *X* constituting the block. In Fig. 19, showing the machine, a horizontal arm is seen to extend across its face and to the right. This is the permissive attachment which must be operated by the special staff shown on the left half of the machine about midway of its height. If it is desired to run two or three trains or two or three sections of the same train from *A* before admitting a train at *X* in the opposite direction, the operator at *A* so advises the operator at *X*. The latter then permits *A* to remove the special staff with which the extreme right-hand end of the permissive attachment is unlocked and a tablet taken out. This tablet is equivalent to a train order and is given to the train immediately starting from *A*. A second tablet is given in a similar manner to the second section or train, and a third to the third section. The last section of train or train itself starting from *A* takes all the remaining tablets and the special staff for insertion in the machine at *X*. In this manner head-to-head collisions are prevented when a number of trains are passing through the block in the same direction before the entrance of a train in the opposite direction. This system has been found to work satisfactorily where it has been used in this country, although its use has been quite limited. Evidently, in itself, it is not sufficient to prevent rear-end collisions in a block between trains moving in the same direction. In order to avoid such collisions where a train falls behind its schedule time or for any reason is stopped in a block, prompt use must be made of rear flagmen or other means to stop or to control the movement of the first following train.

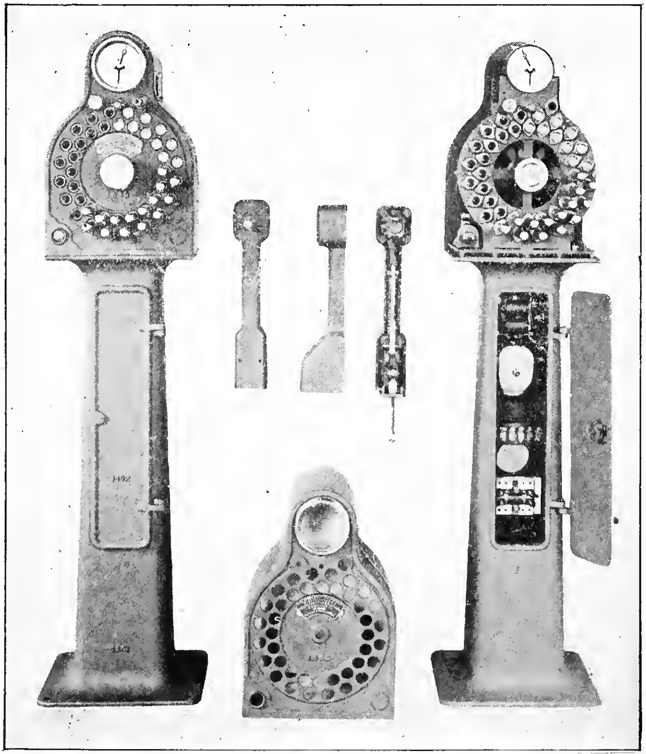


FIG. 20.

The most improved form of high-speed train-staff machine is shown in Fig. 20, as made and installed by the Union Switch and Signal Company and used by a number of the largest railroad systems of the United States. In these machines the staffs are but a few ounces in weight.

CHAPTER XXIII.

289. Evolution of the Locomotive. — The evolution of the steam locomotive may be called the most spectacular portion of the development of railroad engineering. The enormous engines used at the present time for hauling both heavy freight and fast passenger trains possess little in common, in respect of their principal features, with the crude machines, awkward in appearance and of little hauling capacity, which were used in the early part of the nineteenth century in the beginning of railroad operation. The primitive and ill-proportioned machine, ungainly in the highest degree, designed and built by Trevithick as far back as 1803, was a true progenitor of the modern locomotive, although the family resemblance is not at first very evident. Several such locomotive machines were designed and operated between 1800 and 1829 when Stevenson's Rocket was brought out. The water was carried in a boiler on a wagon immediately behind the engine, and the steam-cylinder in those early machines was placed almost anywhere but where it now seems to belong. The Rocket has some general features of resemblance to the machines built seventy years later, but when placed side by side it might easily be supposed that seven hundred years rather than seventy had elapsed between the two productions of the shop.

After the famous locomotive trial in which Robert Stevenson distanced his competitors, the design of the locomotive advanced rapidly, and it was but a few years later when the modern locomotive began to be accurately foreshadowed in the machines then constructed. This was true both in England and the United States.

The first steam locomotive in this country is believed to be the machine built by John Stevens at Hoboken, N. J., in 1825 and operated in 1825–27. This locomotive has practically the

jected to many vicissitudes in principles, general arrangement, and size in order to meet the varying requirements of different roads as well as the fancies or more rational ideas of the designers, its advance was rapid. As early as 1846 we find practically the modern consolidation type, followed in 1851 by the ordinary eight-wheel engine of which thousands have been constructed within the past fifty years. The first Mogul built by the Baldwin Locomotive Works was almost if not quite as early in the field. Both these types of machines carry the principal portion of their weight upon the driving-wheels and were calculated to yield a high tractive capacity, especially as the weights of the engines increased. The weight of the little "John Bull" was but 22,425 pounds, while that of the great modern machine may be as much as 267,800 pounds, with 53,500 pounds on a single driving-axle.

290. Increase of Locomotive Weight and Rate of Combustion of Fuel.—The development of railroad business in the United States has been so rapid as to create rigorous exactions of every feature of a locomotive calculated to increase its tractive force. Any enhancement of train-load without increasing the costs of the train force or other costs of movement will obviously lead to economy in transportation. In order that the locomotive may yield the correspondingly augmented tractive force the weight resting upon the drivers must be increased, which means a greater machine and at the same time higher working pressures of steam. This demands greater boiler capacity and strength and a proportionately increased rate of combustion, so as to move the locomotive and train by the stored-up energy of the fuel transformed in the engine through steam pressure The higher that pressure the greater the amount of energy stored up in a unit of weight of the steam and the greater will be the capacity of a given amount of water to perform the work of hauling a train. The greater the weight of train moved and the greater its speed the more energy must be supplied by the steam, and, again, that can only be done with a correspondingly greater consumption of fuel. In the early days of the small and crude machines to which allusion has already been made the simplest fuel was sufficiently effective. As the duties performed by the locomotive became more intense a higher grade of fuel, i.e., one in which a greater amount of heat energy is stored per unit of weight, was required. Both anthracite and bituminous coal have admirably filled these requirements. The movement of a great modern locomotive and its train at an average rate of 30 to 60 miles per hour requires the combustion of fuel at a high rate and the rapid evaporation of steam at pressures of 180 to 225 or more pounds per square inch. The consumption of coal by such a locomotive may reach 100 pounds per minute, and two barrels of water may be evaporated in the same time. This latter rate would require over a gallon of water per second to be ejected through the stack as exhaust steam. Some of the most marked improvements in locomotive practice have been made practically within the past six or seven years in order to meet these exacting requirements.

While the operations of locomotives will obviously depend largely upon quality of fuel, speed, and other conditions, the investigations of Prof. W. F. M. Goss and others appear to indicate that 12 to 14 pounds of water per hour may be evaporated by a good locomotive boiler per square foot of heating surface, and that 25 to 30 pounds of steam will be required per indicated horse-power per hour.

291. Principal Parts of a Modern Locomotive.—The principal features of a modern locomotive are the boiler with the smoke-stack placed on the front end and the fire-box or furnace at the rear, the tubes, about 2 inches in diameter, through which the hot gases of combustion pass from the furnace to the smoke-stack, the steam-cylinders with their fittings of valves and valve movements, and the driving-wheels. These features must all be designed more or less in reference to each other, and whatever improvements have been made are indicated almost entirely by the relative or absolute dimensions of those main features. The boiler must be of sufficient size so that the water contained in it may afford a free steam production, requiring in turn a corresponding furnace capacity with the resulting heating surface. The latter is that aggregate surface of the interior chambers of the boiler through which the heat produced by combustion finds its way to the water evaporated in steam; it is composed almost entirely of the surfaces of the steel plates of the fire-box and of the numerous tubes running through the boiler and parallel to its centre, exposed to the hot gases of combustion and in contact with the water on the opposite sides of those plates. Evidently an increase in size of the fire-box with the correspondingly increased combustion will furnish a proportionally larger amount of steam at the desired high pressure, but an increase in the size of the fire-box is limited both in length and in width. It is found that it is essentially impracticable for a fireman to serve a fire-box more than about 10 feet in length. The maximum width of the locomotive limits the width of the fire-box.

292. The Wootten Fire-box and Boiler.—As the demand arose for an enlarged furnace the width of the latter was restricted by the width between the driving-wheel tires, less than 4 feet 6 inches. That difficulty was overcome by what is known as the Wootten fire-box, which was brought out by John E. Wootten of the Philadelphia and Reading Railroad about 1877, and has since been developed and greatly improved by others. The Wootten boiler with its sloping top and great width extending out over the rear driving-wheels presented a rather curious appearance and was a distinct departure in locomotive-boiler design. Fig. 21 shows an elevation and two sections of the original Wootten

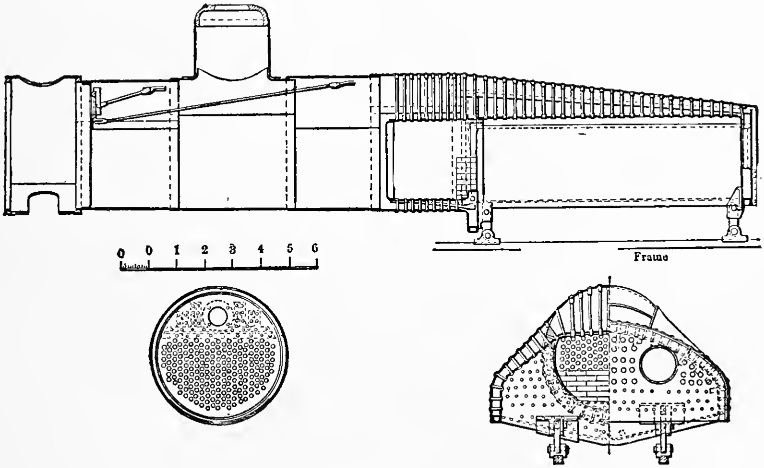
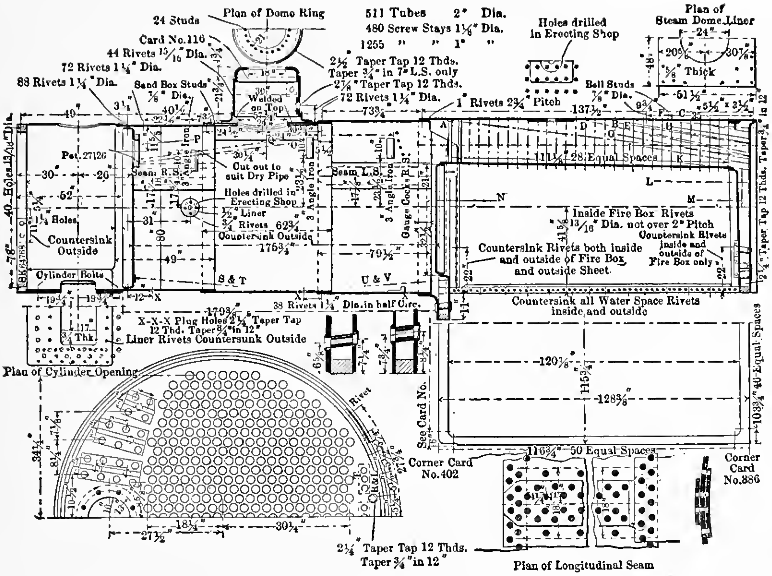


Fig. 21.

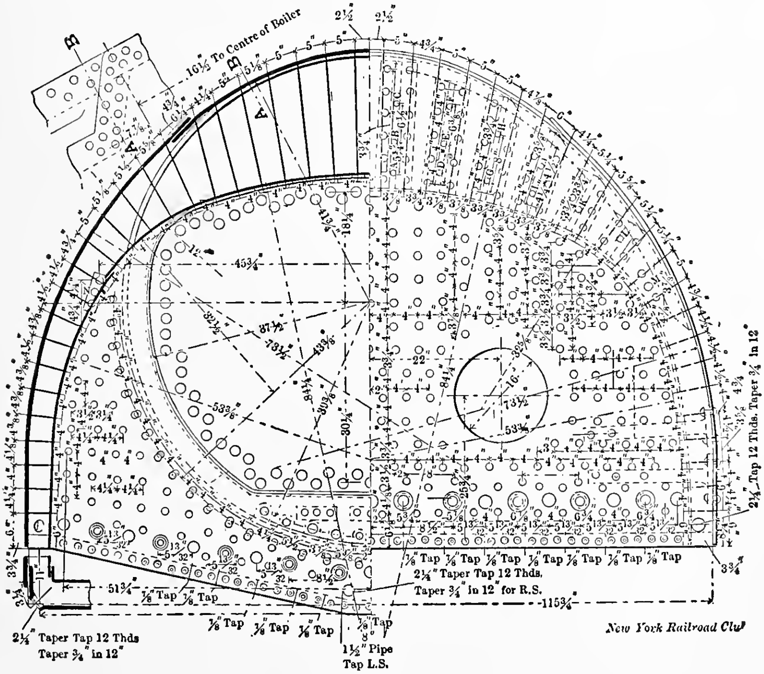
type of boiler. It will be noticed that in front of the fire-box there is a combustion-chamber of considerable length, 2½ to 3 feet long. This boiler was first designed to burn the poorer grades of fuel, such as coal-slack, in which the combustion-chamber to complete the combustion of the fuel was thought essential. By Wootten's device, i.e., extending the boiler out over the driving-wheels, a much greater width of fire-box was secured, but the height of the locomotive was considerably increased. It cannot be definitely stated just how high the centre of the locomotive boiler may be placed above the track without prejudice to safety in running at high speeds, but it has not generally been thought best to lift that centre more than about 9½ feet above the tops of rails, and this matter has been held clearly in view in the development of the wide fire-box type of locomotive boilers.

Like every other new form of machine, the Wootten boiler developed some weak features, although there was no disappointment in its steaming capacity. It will be noticed in the figure that the plates forming that part of the boiler over the fire-box show abrupt changes in curvature which induced ruptures of the stay-bolts and resulted in other weaknesses. This boiler passed through various stages of development, till at the present time Figs. 22 and 23 show its most advanced form, which is satisfactory in almost or quite every detail. The sudden changes in direction of the plates in the first Wootten example have been displaced by more gradual and easy shapes. Indeed there are few features other than those which characterize simple and easy boiler construction. The enormous grate area is evident from the horizontal dimensions of the fire-box, which are about 120 inches in length by about 106 inches in breadth. The boiler has over 4000 square feet of heating surface and carries about 200 pounds per square inch pressure of steam. The combustion-chamber in front of the fire-box has been reduced to a length of about 6 inches, just enough for the protection of the expanded ends of the tubes. The barrel of the boiler in front of the fire-box has a diameter of 80 inches and a length of about 15 feet. The grate area is not far from 100 square feet. The improvements which have culminated in the production of this boiler are due largely to Mr. Samuel Higgins of the Lehigh Valley Road.



New York Railroad Club

FIG. 22.



New York Railroad Club

FIG. 23.

293. Locomotives with Wootten Boilers.—Fig. 24 exhibits a consolidation freight locomotive of the Lehigh Valley Railroad, having the boiler shown in Figs. 22 and 23. This machine is one of the most efficient and powerful locomotives produced at the present time. The locomotive shown in Fig. 25 has a record. It is one used on the fast Reading express service between Philadelphia and Atlantic City during the season of the latter resort. It has run one of the fastest schedule trains in the world and has attracted attention in this country and abroad. Its type is called the Atlantic and, as the view shows, it is fitted with the Wootten improved type of boiler. It will be noticed that the wide fire-box does not reach out over the rear drivers, but over the small trailing-wheels immediately behind them. This is a feature of wide locomotive fire-box practice at the present time to which recourse is frequently had. There is no special significance attached to the presence of the small trailing-wheels except as a support for the rear end of the boiler, their diameters being small enough to allow the extension of the fire-box over them without unduly elevating the centre of the boiler.

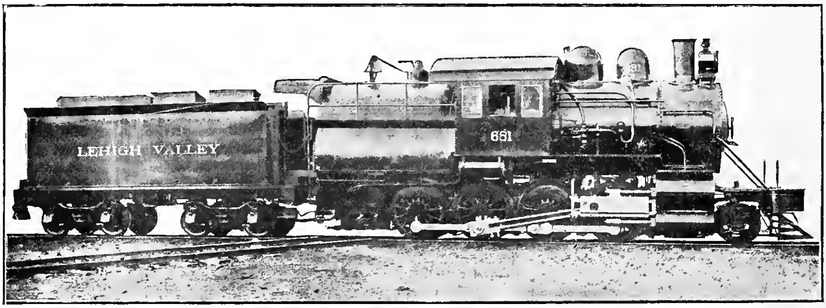


FIG. 24.

The cylinders of these and many other locomotives are known as the Vauclain compound. In other words, it is a compound locomotive, there being two cylinders, one immediately over the other, on each side. The diameter of the upper cylinder is much less than that of the lower. The steam is first admitted into the small upper cylinder and after doing its work there passes into the lower or larger cylinder, where it does its work a second time with greater expansion. By means of this compound or double-cylinder use of the steam a higher rate of expansion is secured and a more uniform pull is exerted upon the train, the first generally contributing to a more economical employment of the steam, which in turn means a less amount of fuel burned for a given amount of tractive work performed.

In the early part of November, 1901, an engine of this type hauling a train composed of five cars and weighing 235 tons made a run of 55.5 miles between Philadelphia and Atlantic City at the rate of 71.6 miles per hour, the fastest single mile being made at a rate of a little less than 86 miles per hour.

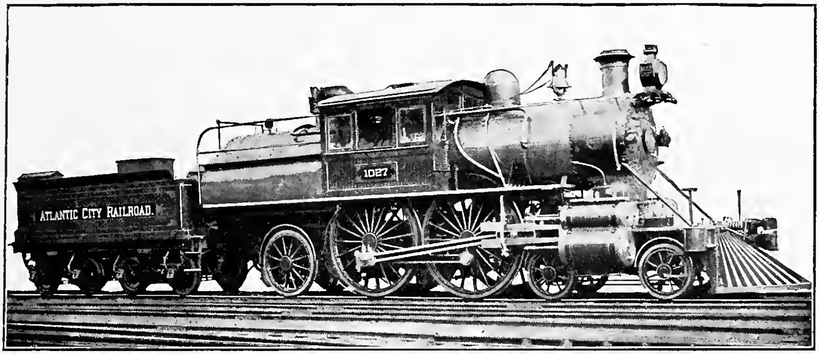


FIG. 25.

The power being developed by these engines runs as high as 1400 H.P. at high speeds and 2000 H.P. at the lower speeds of freight trains.

The chief economic advantage of these wide fire-box machines lies in the fact that very indifferent grades of fuel may be consumed. Indeed there are cases where fuel so poor as to be unmarketable has been used most satisfactorily. With a narrow and small fire-box a desired high rate of combustion sometimes demands a draft strong enough to raise the fuel over the grate-bars. This difficulty is avoided in the large fire-box, where sufficient combustion for rapid steaming is produced with less intensity of blast.

294. Recent Improvements in Locomotive Design.—Concurrently with the development of the Wootten type of boiler, other wide fire-box types have been brought to a high state of excellence. In reality general locomotive progress within the past few years has been summed up by Mr. F. J. Cole as follows:

(*a*) The general introduction of the wide fire-box for burning bituminous coal.

(*b*) The use of flues of largely increased length.

(*c*) The improvements in the design of piston-valves and their introduction into general use.

(*d*) The recent progress made in the use of tandem compound cylinders.

The piston-valve, to which reference is made, is a valve in the shape of two pistons connected by an enlarged stem or pipe he entire length of the double piston, the arrangement depending upon the length of steam-cylinder or stroke; it may be 31 or 32 inches. This piston-valve is placed between the steam-cylinder and the boiler, and is so moved by eccentrics attached to the driving-wheel axles through the medium of rocking levers and valve-stems as to admit steam to the cylinder at the beginning of the stroke and allow it to escape after the stroke is completed. Fig. 26 shows a section through the centre of one of these piston-valves. It will be noticed that the live steam is admitted around

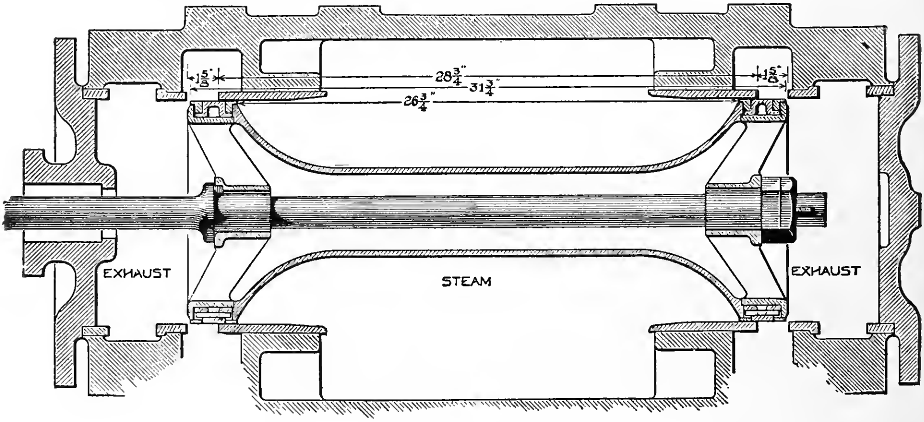


FIG. 26.

a central portion of the valve, and that the steam escapes through the exhaust-passages at each end of the piston-valve. This type of valve is advantageous with high steam pressures for the reason that its "blast," i.e., the steam pressure, does not press it against its bearings as is the case with the old type of slide-valve, the wear of which with modern high steam pressures would be excessive, although under more recent slide-valve design this objection does not hold.

295. Compound Locomotives with Tandem Cylinders. — The tandem compound locomotive, as recently built, is a locomotive in which the high-pressure cylinder is placed immediately in

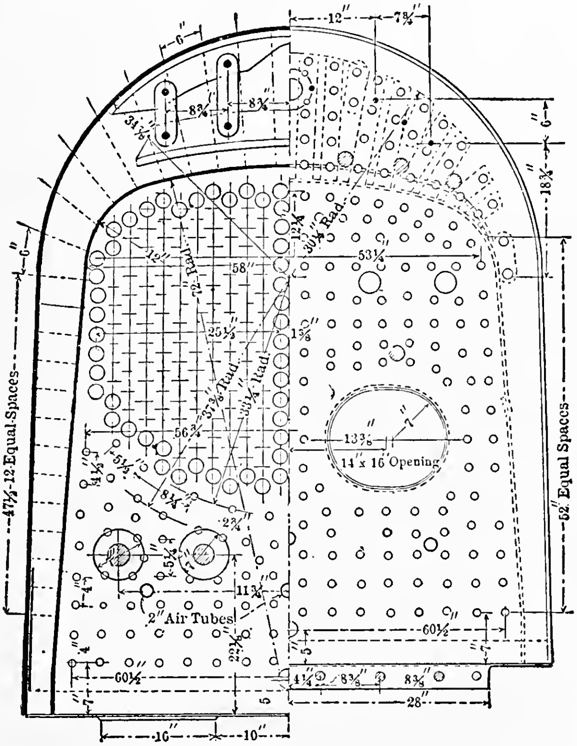


FIG. 27.

front of the low-pressure cylinder and in line with it. In the Vauclain type it is necessary to have a piston-rod for each of the two cylinders, one above the other, each taking hold of the same

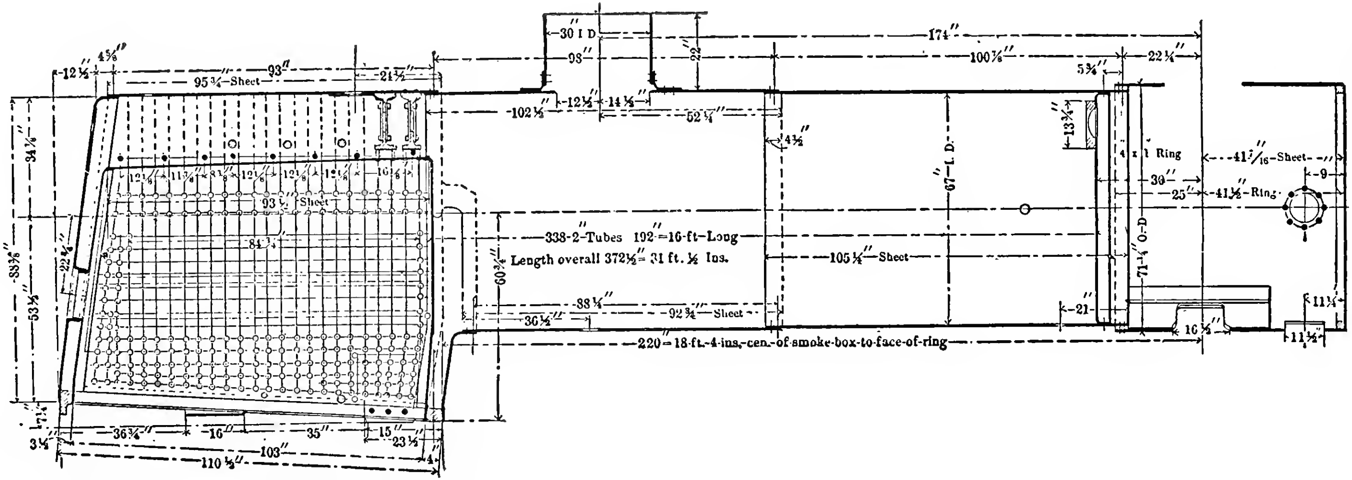

30 I D
174″
98″
100⅞″
22¼″
22
5¾″
12½
4⅝″
95¾–Sheet
93″
21½″
102½″
12½″
14⅛″
52¼″
4½″
13¾″
67″ I. D.
4 x 1 Ring
41¹⁄₁₆″–Sheet
30″
9
25″
41½″–Ring
71-¼″ O-D
34⅛
33⅜″
53½″
22¾″
12⅛
11⅞
8⅞
12⅛
12⅛
12⅛
16⅛
93½ Sheet
84¼″
338-2″-Tubes 192″=16-ft-Long
Length overall 372½″= 31 ft. ½ Ins.
105¼″–Sheet
60¾″
88¼″
92¾″–Sheet
36½″
21″
11¼
16½″
11½″
220″=18-ft.-4-ins.-cen.-of-smoke-box-to-face-of-ring
7¼
3⅛″
36¾″
16″
35″
15″
23½″
103″
110½″
4

FIG. 28.

cross-head. In the tandem arrangement with the two cylinders each in line, but one piston-rod is required. An example of a locomotive with this tandem arrangement of compound cylinders will be shown farther on.

Figs. 27 and 28 show two sections, one transverse and one longitudinal, of a type of large fire-box boiler built by the American Locomotive Works at Schenectady. The diameter of the barrel of the boiler in front of the fire-box is about 5 feet 8 inches, while the clear greatest width of the fire-box is 5 feet 4½ inches. The length of the latter is 8 feet 7 inches, making a total grate area in this particular instance of over 45 square feet. There are 338 2-inch tubes, each 16 feet in length. The total length over all of the boiler is 31 feet ½ inch. The result of such a design is an arrangement by which a large grate area is secured and a corresponding high rate of combustion without a too violent draft. In designing locomotive boilers for bituminous coal one square foot of grate area is sometimes provided for each 60 to 70 square feet of heating surface in the tubes.

296. Evaporative Efficiency of Different Rates of Combustion.—In the development of this particular class of locomotive boilers it is to be remembered that as a rule the highest rates of combustion frequently mean a decreased evaporation of water at boiler pressure per pound of fuel. Modern locomotives may burn over 200 pounds of coal per square foot of grate area per hour, and in doing so the evaporation may be less than 5 pounds

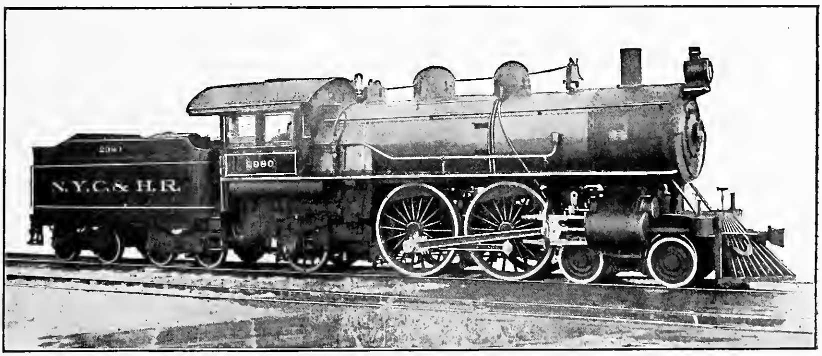


FIG. 29.

of water per pound of fuel. On the other hand, when the coal burned does not exceed 50 pounds per square foot of grate area per hour, as much as 8 pounds of water may be evaporated for each pound of coal. It is judicious, therefore, to have large grate area, other things being equal, in order that the highest attainable efficiency in evaporation may be reached.

296a. Tractive Force of a Locomotive.—The tractive force of a locomotive arises from the fact that one solid body cannot be moved over another, however smooth the surface of contact may be, without developing the force called resistance of friction. This resistance is measured by what is called the coefficient of friction, determined only by experiment. The resistance of friction and this coefficient will depend both upon the degree of smoothness of the surface of contact and on its character. If surfaces are lubricated, as in the moving parts of machinery, the force of friction is very much decreased, but in the absence of that lubricant it will have a much higher value. The coefficient of friction is a ratio which denotes the part of the weight of the body moved which must be applied as a force to that body in order to put it in motion against the resistance of friction. In the case of lubricated surfaces this ratio may be as small as a few hundredths. In the case of locomotive driving-wheels and the track on which they rest this value is usually taken at .2 to .25.

There are times when it is desirable to increase the resistance of friction between locomotive drivers and the rails. For this purpose a simple device, called the sand-box, is frequently placed on the top of a locomotive boiler with pipes running down from it so as to discharge the sand on the rails immediately in front of the drivers. The sand is crushed under the wheels and offers an increased resistance to their slipping.

The tractive force of a locomotive may also be computed from the pressure of steam against the pistons in the steam-cylinders. If the indicated horse-power in the cylinder be represented by H.P., and if all frictional or other resistance between the cylinder and the draw-bar be neglected, the following equality will hold:

$$\left.\begin{array}{c}\text{Draw-bar pull}\times\text{speed of train in miles}\\ \text{per hour}\times 5280\end{array}\right\} = \text{H.P.}\times 33{,}000\times 60.$$

If S = speed in miles per hour, and if T = draw-bar pull, then the preceding equality gives

$$T = \frac{375 \times \text{H.P.}}{S}.$$

This value of the "pull" must be diminished by the friction of the locomotive as a machine, by the rolling resistance of the trucks and tender, and by the atmospheric resistance of the locomotive as the head of the train. Prof. Goss proposes the following approximate values for these resistances in a paper read before the New England Railroad Club in December, 1901.

A number of tests have shown that a steam pressure of 3.8 pounds per square inch on the piston is required to overcome the machine friction of the locomotive. Hence if d is the diameter of the piston in inches, L the piston-stroke in feet, and D the diameter of driver in feet, while f is that part of the draw-bar pull required to overcome machine friction, the following equation will hold:

$$f.\pi D = 3.8\frac{\pi d^2}{4} \times 2L \times 2. \quad \therefore\ f = 3.8\frac{d^2L}{D}.$$

Again, if W be the rolling load in tons on tender and trucks (exluding that on drivers), and if r be that part of the draw-bar pull required to overcome the rolling resistance due to W, then experience indicates that approximately, in pounds,

$$r = \left(2 + \frac{S}{6}\right)W.$$

As before, S is the speed in miles per hour.

Finally, if h be that part of the draw-bar pull in pounds required to overcome the head resistance (atmospheric) of the locomotive, there may be written approximately

$$h = .11S^2.$$

The actual draw-bar pull in pounds available for moving the train will then be

$$t = T - f - r - h = \frac{375\ \text{H.P.}}{S} - 3.8\frac{d^2L}{D} - W\left(2 + \frac{S}{6}\right) - .11S^2.$$

The maximum value of t should be taken as one fourth the greatest weight on drivers.

If H is the total heating surface in square feet, and if 12 pounds of water be evaporated per square foot per hour, while 28 pounds of steam are required per horse-power per hour, then

$$\text{H.P.}=\frac{12H}{28} \quad \text{and} \quad \frac{375\,\text{H.P.}}{S}=\frac{161H}{S}.$$

Hence

$$t=\frac{161H}{S}-3.8\frac{d^2L}{D}-W\left(2+\frac{S}{6}\right)-.11S^2.$$

The actual draw-bar pull in pounds may then be computed by this formula.

Some recent tests of actual trains (both heavy and light) on the N. Y. C. & H. R. R. R. between Mott Haven Junction and the Grand Central Station, New York City, a distance of 5.3 miles, by Mr. Bion J. Arnold, by means of a dynamometer-car, gave the actual average draw-bar pull per ton of 2000 pounds as ranging from 12 to 25 pounds going in one direction and 12.1 to 24 pounds in the opposite direction. There were eight tests in each direction, and the greatest speed did not exceed 30 miles per hour.

As the diameter of the driver appears in the preceding formulæ, it may be well to state that an approximate rule for that diameter is to make it as many inches as the desired maximum speed in miles per hour, i.e., 70 inches for 70 miles, or 80 inches for 80 miles, per hour.

297. Central Atlantic Type of Locomotive.—Fig. 29 represents what is termed the Central Atlantic type (single cylinder) of engine, which is used for hauling most of the fast passenger trains on the New York Central and Hudson River Railroad. The characteristics of boiler and fire-box are such as are shown in Figs. 27 and 28.

The cylinders are 21 inches internal diameter, and the stroke is 26 inches. The total grate area is 50 square feet, and the total heating surface 3500 square feet. The total weight of the locomotive is 176,000 pounds, with 95,000 on the drivers. It will be observed that the total weight of locomotive per square foot of heating surface is scarcely more than 650 pounds, which is a low value. The boiler pressure carried may be 200 pounds per square inch or more. The tractive force of this locomotive may be taken at 24,700 pounds. There is supplied to these engines, among others, what is called a traction-increasing device. This traction-increaser is nothing more nor less than a compressed-air cylinder secured to the boiler, so that as its piston is pressed outward, i.e., downward, it carries with it a lever, the fulcrum of which is on the equalizing-lever of the locomotive frame, the other or short end of the lever being attached to the main bar of the frame itself. This operation redistributes the boiler-load on the frame, so as to increase that portion which is carried by the drivers. This has been found to be a convenient device in starting trains and on up grades. In the present instance the traction-increaser may be operated so as to increase the load on the drivers by about 12,000 pounds. It is not supposed to be used except when needed under the circumstances indicated.

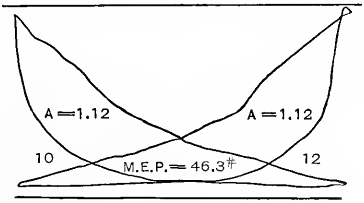


FIG. 30.

A number of indicator-cards taken from the steam-cylinders of these engines hauling the Empire State Express and other fast passenger trains on the Hudson River Division of the N. Y. C. & H. R. R. R., show that with a train weighing about 208 tons while running at a speed of 75 miles per hour 1323 H.P. was developed. Fig. 30 shows these indicator diagrams. With a train weighing 685 tons 1452 H.P. was indicated at a speed of 63 miles per hour.

298. Consolidation Engine, N. Y. C. & H. R. R. R. — One of the heaviest wide fire-box compound consolidation engines recently built for the New York Central freight service is shown in Fig. 31. It will be noticed that there is but one cylinder on each side of the locomotive, and that they are of different diameters. One of these cylinders, 23 inches inside diameter, is a high-pressure cylinder, and the other, 35 inches inside diameter, is a low-pressure cylinder, the stroke in each case being 34 inches. The total grate area is 50.3 square feet, the fire-box being 8 feet long by 6 feet 3 inches wide. The total heating surface is 3480 square feet. The diameter of the barrel of the boiler at the front end is 72 inches, and the diameter of the drivers 63 inches. The pressure of steam in the boiler is 210 pounds per square inch. The total weight of the locomotive is 194,000 pounds, of which 167,000 rests upon the drivers. These engines afford a maximum tractive force of 37,900 pounds. This engine is typical of those used for the New York Central freight service. They have hauled trains weighing nearly 2200 tons over the New York Central road.

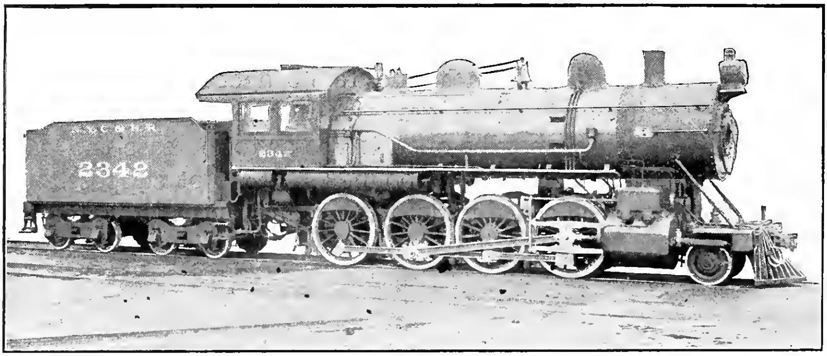


FIG. 31.

299. P., B. & L. E. Consolidation.—The consolidation locomotive shown in Fig. 32 is a remarkable one in that it was for a time the heaviest constructed, but its weight has since been exceeded by at least two of the Decapod type built for the Sante Fé company. It was built at the Pittsburg works of the American Locomotive Company for the Pittsburg, Bessemer and Lake Erie Railroad to haul heavy trains of iron ore. The total weight is 250,300 pounds, of which the remarkable proportion of 225,200 is carried by the drivers. The tender carries 7500 gallons of water, and the weight of it when loaded is 141,100 pounds, so that the total weight of engine and tender is 391,400 pounds. The average weight of engine and tender therefore approaches 7000 pounds per lineal foot. This is not a compound locomotive, but each cylinder has 24 inches inside diameter and 32 inches stroke, the diameter of the driving-wheels being 54 inches. The boiler carries a pressure of 220 pounds, and the tractive force of the locomotive is 63,000 pounds.

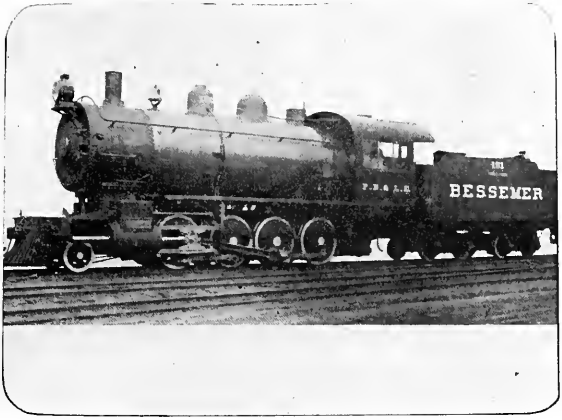


FIG. 32.

A noticeable feature of this design, and one which does not agree with modern views prompting the design of wide fire-boxes, is its great length of 11 feet and its small width of 3 feet $4\frac{1}{4}$ inches. There are in the boiler 406 $2\frac{1}{4}$-inch tubes, each 15 feet long, the total heating surface being 3805 square feet.

300. L. S. & M. S. Fast Passenger Engine.—The locomotive shown in Fig. 33 is also a remarkable one in some of its features, chief among which is the 19 feet length of tubes. It was built at the Brooks works of the American Locomotive Company for the Lake Shore and Michigan Southern Railroad. The total weight of engine is 174,500 pounds, of which 130,000 pounds rests upon the drivers. The rear truck carries 23,000 pounds and the front truck 21,500 pounds. This is not a compound engine. The cylinders have each an inside diameter of 20½ inches, and 28 inches stroke. As this locomotive is for fast passenger traffic, the driving-wheels are each 80 inches in diameter, and the driving-wheel base is 14 feet. The fire-box is 85 × 84 inches, giving a grate area of 48½ square feet and a total heating surface of 3343 square feet. There are 285 2¼-inch flues, each 19 feet long. The tender carries 6000 gallons of water. Cast and compressed steel were used in this design to the greatest possible extent, and the result is shown in that the weight divided by the square feet of heating surface is 52.18 pounds.

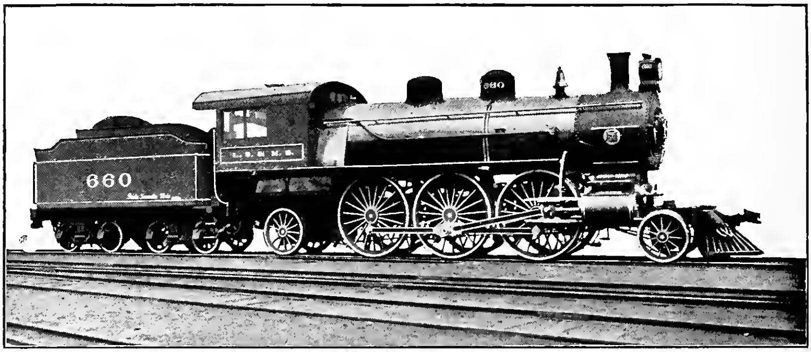


FIG. 33.

301. Northern Pacific Tandem Compound Locomotive.—The diagram shown in Fig. 34 exhibits the outlines and main features of a tandem compound locomotive to which allusion has already been made. It was built at Schenectady, New York, in 1900, for the Northern Pacific Railroad, and was intended for heavy service on the mining portions of that line.

The diameters of the high- and low-pressure cylinders are respectively each 15 and 28 inches, with a stroke of 34 inches, while the boiler pressure is 225 pounds per square inch. The total weight of the machine is 195,000 pounds and the weight on the drivers 170,000 pounds, the diameter of the drivers being 55 inches. As the figure shows, it belongs to the consolidation type. The fire-box is 10 feet long by 3.5 feet wide, giving a

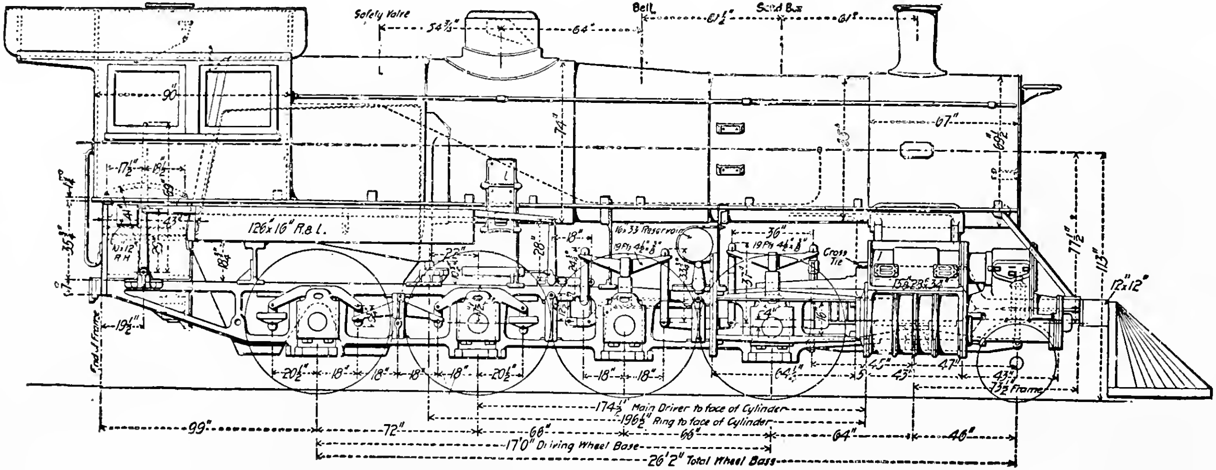

Safety Valve
34 7/8"
64"
Bell
81½"
Sand Box
81"
90"
74"
67"
83"
69½"
17½"
18½"
43"
126"x16" R.&L.
No 12 RH
35¾"
18¼"
25"
22"
28"
18"
16x33 Reservoir
19 Pts 4½ x ⅝"
36"
19 Pts 4½ x ⅝"
Cross Tie
15&23x34"
77½"
113"
12"x12"
19½"
End of Frame
20½"
18"
18"
18"
18"
20½"
18"
18"
64½"
45"
5
43"
47"
43"
73½" Frame
174½" Main Driver to face of Cylinder
196½" Ring to face of Cylinder
99"
72"
66"
66"
64"
46"
17'0" Driving Wheel Base
26'2" Total Wheel Base

FIG. 34.

grate area of 35 square feet, with which is found a total heating surface of 3080 square feet. There are 388 2-inch tubes, each 14 feet 2 inches long. These engines are among the earliest compound-tandem type and have been very successful. Other locomotives of practically the same general type have been fitted with a wide fire-box, 8 feet 4 inches long by 6 feet 3 inches wide, with the grate area thus increased to 52.3 square feet.

302. Union Pacific Vauclain Compound Locomotive. — The next example of modern locomotive is the Vauclain compound type used on the Union Pacific Railroad. It is a ten-wheel passenger engine and one of a large number in use. The weight on the drivers is 142,000 pounds, and the total weight of the locomotive is about 185,000 pounds. The high-pressure cylinder has an inside diameter of $15\frac{1}{2}$ inches, while the low-pressure cylinder has a diameter of 26 inches. The stroke is 28 inches and the diameter of the driving-wheels 79 inches. On the Union Pacific Railroad the diameter of the driving-wheel varies somewhat with the grades of the divisions on which the engines run.

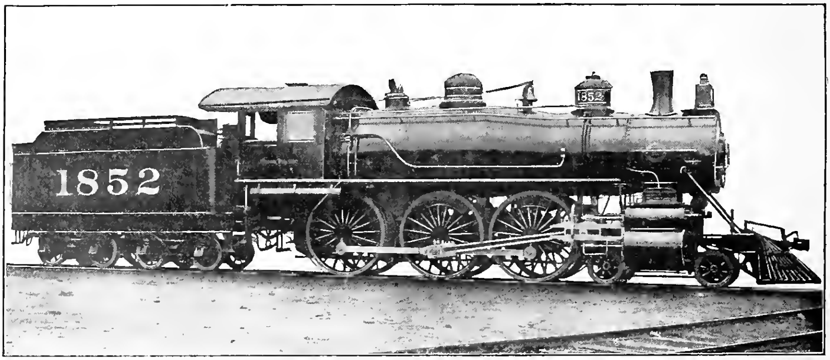


FIG. 35.

In some portions of the country, as in Southern California, oil has come into quite extended use for locomotive fuel.

303. Southern Pacific Mogul with Vanderbilt Boiler. — The locomotive shown in Fig. 36 belongs to the Mogul type, having three pairs of driving-wheels and one pair of pilots. It is fitted with the Vanderbilt boiler adapted to the use of oil fuel. The